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Utilization of Solar Energy in Irrigation Systems in Bangladesh

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Abstract

The demand for water pumping in urban water supply and irrigation in Bangladesh is significantly influenced by electricity deficits and high diesel costs. To address these challenges, the adoption of solar power for water pumping emerges as a viable alternative to traditional systems reliant on grid power and diesel. In recent years, there has been a growing emphasis on clean and renewable energies, aligning with the environmental and economic priorities of Bangladesh. The agricultural sector, serving as the backbone of the country's economy, witnesses an escalating demand for water as the population increases. The extraction and transfer of water for agricultural and drinking purposes translate to high-energy consumption. Leveraging the abundant and essentially free solar energy, particularly during the crop growth periods when irrigation is crucial, presents an optimal solution. This study underscores the underutilization of this vital resource in Bangladesh and advocates for the widespread implementation of solar energy conversion programs, specifically in photovoltaic pumping systems. By comparing these systems with conventional diesel pumps, this paper aims to inspire policymakers, statesmen, and industry professionals to integrate green energy into the water sector. The envisioned outcome is a strategic shift towards sustainable development, with a focus on harnessing solar power to pump water for villages and agriculture, thus contributing to economic and environmental sustainability.

Keywords

Solar Water Pump, PV Panel, Renewable Energy, Submersible Pump, Solar Energy

1. Introduction

It is a well-known fact that Bangladesh's economy is one of the world's leading economies. Bangladesh is an agricultural country, with agriculture taking up the majority of the land [1] [2]. Bangladesh, renowned for its robust economy and primarily agrarian landscape, faces the dual challenge of meeting escalating energy demands and mitigating environmental concerns. In this context, solar energy emerges as a pivotal and sustainable solution, offering a clean alternative to conventional fossil fuels. Photovoltaic (PV) generation, harnessing the abundant solar resource, stands as a promising avenue for addressing the country's energy needs [3]. As the demand for energy continues to escalate, coupled with the ongoing depletion of conventional fossil fuel reserves and growing concerns about environmental pollution, there is an imperative to explore alternative and renewable energy sources such as solar energy and wind energy [4]. Solar energy projects in numerous developing countries worldwide exhibit diversity in their applications, encompassing initiatives for rural power supply, communication services, water pumping, street lighting, as well as the cooling and heating of both residential and commercial spaces. These multifaceted projects contribute to environmental protection [5]. A highly impactful application of solar energy involves supplying drinking water to small communities, each comprising around a thousand members [6]. The World Bank approximates that approximately one billion individuals residing in isolated rural areas of developing countries lack access to safe drinking water [7].

The agricultural sector, a cornerstone of Bangladesh's economy, underwent significant transformations in the 1990s and 2000s, achieving food self-sufficiency through increased productivity driven by advancements such as high-yield paddy varieties and expanded groundwater irrigation. However, the reliance on imported diesel for irrigation posed fiscal challenges, marked by substantial subsidies reaching $1.6 billion by 2012-13. Beyond financial considerations, diesel-based irrigation contributed to 4.4% of Bangladesh's annual CO_2 emissions [8].

Aligned with global commitments to emissions reduction, Bangladesh aims for a 5% reduction (unconditional) and up to 15% (conditional with international support) by 2030. The Renewable Energy Policy set a 10% renewable energy target by 2020, with a specific focus on addressing emissions from the irrigation sector. In this context, the Nationally Determined Contributions (NDC) roadmap highlights solar pumps as a strategic solution. The Infrastructure Development Company Limited ambitiously plans to install 50,000 solar irrigation pumps by 2027, potentially averting 0.83 million tones of CO_2 emissions annually from diesel irrigation. This underscores the pivotal role solar pumps can play in aligning Bangladesh's agriculture with sustainable and low-carbon development trajectories [8].

Solar water pumps, distinguished by their high efficiency, particularly thrive in regions where extending the power grid proves impractical. Even in areas where a connection to the national grid is feasible, the preference for photovoltaic pumps persists due to various compelling reasons [9]. This preference is not merely driven by logistical considerations but is substantiated by the proven economic viability of photovoltaic pumps when compared to their diesel counterparts. A survey conducted among residents in the region attests to the high reliability and ample water supply provided by photovoltaic pumps. Further, research on photovoltaic pump systems in India offers additional validation of the economic justification and social advantages associated with these solar-powered systems [10].

In this paper, we aim to provide a comprehensive exploration of the underutilization of solar energy in Bangladesh's water pumping systems, particularly in the realm of photovoltaic pumping systems. By comparing these systems with traditional diesel pumps, our objective is to inspire policymakers, statesmen, and industry professionals to integrate green energy into the water sector. The envisioned outcome is a strategic shift towards sustainable development, emphasizing the harnessing of solar power for water pumping in both rural villages and agriculture. This not only contributes to economic sustainability but also aligns with global priorities of environmental conservation and combating climate change. Through this work, we aim to elucidate the potential transformative impact of solar energy on Bangladesh's agricultural landscape, offering a cleaner, more efficient, and economically viable path forward.

2. Solar Pumping Water System

Photovoltaic technology finds widespread application in various processes, particularly in water irrigation for agriculture. Additionally, it is utilized for refrigerating fruits and vegetables, fencing, providing lighting for cattle, and controlling insects. The techniques employed in photovoltaic systems are well-suited for activities requiring minimal power input. However, they prove inadequate for larger power-consuming areas, such as rice mills and high-powered agricultural processing [11]. In the present scenario, farmers face challenges in irrigating their plants to keep their crops healthy under the scorching sun. This difficulty arises due to a lack of awareness about the availability of power. The solar pumping system provides a solution to this problem. Typically, the solar pumping system comprises key components: electric solar panels, pump controller, submersible pump, converter, storage tank, and rechargeable battery. **Figure 1** illustrates the configuration of the solar pumping system.

2.1. Solar PV Panel

A solar PV (photovoltaic) panel operates on the principle of the photovoltaic effect, leveraging semiconductor materials, typically silicon, to convert sunlight into electrical energy. When photons from sunlight strike the surface of the solar cells within the panel, they excite electrons in the semiconductor material, creating an electric current. This generated electricity is in the form of direct current (DC), and each solar cell produces a small voltage, typically around 0.5 to 1 volt.

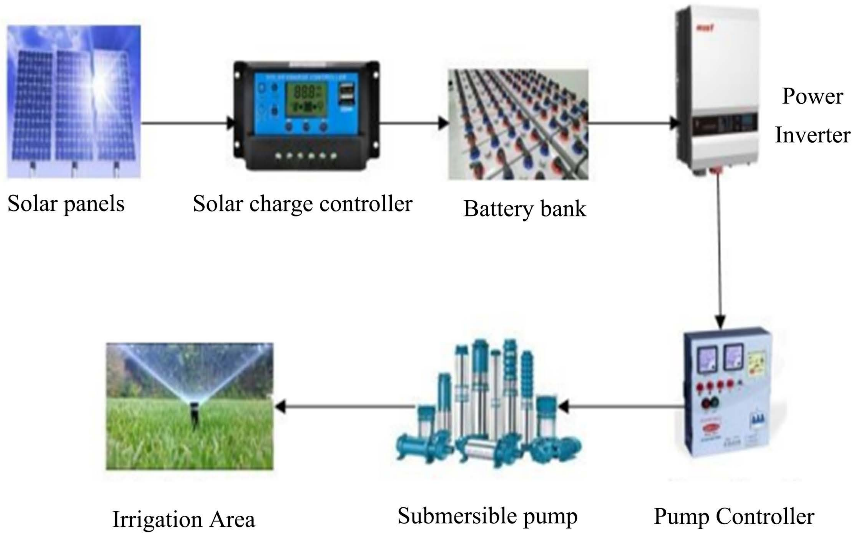

Figure 1. Solar pumping water system [12].

To make this electricity compatible with standard devices and the power grid, it undergoes conversion from DC to alternating current (AC) through an inverter. The AC electricity can then be utilized immediately to power appliances, lighting, and other electrical devices within a home or business. Additionally, in grid-tied systems, excess electricity can be fed back into the grid, contributing to the overall energy supply and potentially earning credits or compensation for the user. Furthermore, solar PV systems can incorporate battery storage, allowing the captured energy to be stored for use during periods of low sunlight or in off-grid scenarios, enhancing the reliability and efficiency of the solar power system.

2.2. Solar Charge Controller

A solar charge controller, a critical component in solar power systems, serves to efficiently manage the charging and discharging of batteries. This device plays a pivotal role in optimizing the performance and longevity of batteries by regulating the flow of electricity between the solar panels and the battery. Its primary functions encompass preventing overcharging, a condition that can inflict damage and reduce the lifespan of batteries, by disconnecting the solar panels once the battery reaches its maximum voltage. Conversely, the controller ensures that the battery does not discharge below a certain voltage, safeguarding it against potential damage from deep discharging. Some advanced controllers are equipped with temperature sensors, allowing them to dynamically adjust charging parameters based on temperature fluctuations. Additionally, many controllers incorporate load control functionality, enabling them to manage the power output to connected loads, preventing excessive discharge during extended cloudy periods. In essence, the solar charge controller acts as a vigilant guardian, maintaining optimal charging conditions, protecting batteries from potential harm, and enhancing the overall efficiency and health of the solar power system.

2.3. Battery Bank

In a solar pumping system, the battery plays a pivotal role in ensuring a continuous and reliable water supply, especially during periods of limited sunlight. Solar panels generate electricity intermittently based on sunlight availability, making energy storage essential for uninterrupted operation. The battery serves as an energy reservoir, storing surplus power produced by the solar panels during sunny conditions. This stored energy becomes instrumental during low or no sunlight periods, such as at night or on cloudy days, providing a consistent power source for the submersible pump and other system components. The charge controller, a crucial element, regulates the flow of electricity from the solar panels to the battery during the charging phase, ensuring safe and efficient charging. During discharging phases when sunlight is scarce, the pump controller draws power from the battery to operate the submersible pump, maintaining a steady water supply. Additionally, the battery plays a role in balancing energy demand, protecting against voltage fluctuations, and extending the system's overall reliability. The cyclical process of charging and discharging ensures the effective utilization of solar energy, making the solar pumping system a sustainable and dependable solution for agricultural irrigation in off-grid or unreliable power supply areas.

2.4. Power Inverter

A power inverter is a fundamental component within a solar power system, responsible for the crucial task of converting the direct current (DC) electricity generated by solar panels into alternating current (AC) electricity. This conversion is essential because most household appliances and the electrical grid operate on AC power. Beyond this primary function, the power inverter serves to regulate the voltage produced by solar panels, ensuring that it aligns with the requirements of electrical appliances and systems. In grid-tied solar setups, the power inverter plays a role in synchronizing the solar-generated electricity with the grid, allowing excess energy to be fed back for potential credits or compensation. Additionally, advanced inverters often feature maximum power point tracking (MPPT) technology, optimizing the solar panel system's efficiency by adjusting the electrical operating point under varying conditions. This technology ensures the system consistently produces the maximum available power. Furthermore, modern inverters frequently include monitoring and control capabilities, enabling users to track the real-time performance of their solar panel system, check energy production metrics, and identify and address potential issues. In essence, the power inverter is a versatile component that not only facilitates the seamless integration of solar-generated power with existing electrical systems but also enhances the overall efficiency and monitoring capabilities of the solar energy system.

2.5. Pump Controller

The pump controller in a solar pumping system plays a pivotal role in optimizing the utilization of solar energy for efficient water supply. Serving as the system's central intelligence, the controller interfaces with the solar panels, converting sunlight into electrical energy while incorporating Maximum Power Point Tracking (MPPT) technology to extract the maximum available power. This dynamic feature adjusts the operating point of the pump to the optimal position based on prevailing sunlight conditions. Furthermore, the pump controller regulates the submersible pump's operation, ensuring it operates efficiently and delivers water effectively. Beyond its basic functions, the controller often includes voltage protection mechanisms, preventing damage from overvoltage or undervoltage situations. Some advanced systems may incorporate variable speed control, allowing the pump to adjust its speed in response to varying solar energy levels. Safety features such as overload protection, short circuit protection, and over-temperature protection are also commonly integrated. Additionally, modern pump controllers may offer data monitoring capabilities, enabling users to track system performance, energy production, and water delivery. In essence, the pump controller serves as the orchestrator, orchestrating the harmonious interplay between solar panels and the submersible pump, ensuring optimal efficiency and reliability in providing water for irrigation or other essential purposes.

2.6. Submersible Pump

The submersible pump, typically enclosed within a stainless-steel casing, is commonly situated in a well pit strategically positioned at the convergence point of an open channel and the natural stream course. To facilitate a controlled water supply, a pump controller is employed, directing the pump to transfer water to a designated storage tank within predefined time intervals through the utilization of a control unit. The sizing of solar pumps is intricately determined by factors such as the overall depth of the well, longitudinal and local losses incurred in the piping system during pumping operations, and the desired water flow rate. This holistic approach ensures the efficiency and effectiveness of the solar pumping system in meeting specific water supply requirements.

3. Comparison of Energy Consumption and Solar Pumps between Bangladesh and Other Countries

Several countries and regions have embraced the incorporation of solar power capacity into their electrical grids as a viable alternative to traditional energy sources. To gain insights from global practices and assess the solar energy landscape in Bangladesh, particularly in the irrigation sector, an extensive study was conducted, encompassing a comprehensive analysis of existing research and reports. This solar energy table consolidates development initiatives across various countries, with a particular focus on solar water pumping for agricultural irrigation. The global landscape of photovoltaic growth exhibits dynamic and diverse patterns across nations. Projections indicate that by 2020, around 37 countries worldwide will collectively generate over one gigawatt of cumulative solar power. As of the conclusion of 2019, the global installation of solar power reached a cumulative capacity of 629 gigawatts [13]. As of early 2020, China emerged as the frontrunner in solar power, boasting an impressive 208 gigawatts (GW) of installed solar capacity. This constituted a substantial one-third share of the global cumulative solar capacity at that time [14] [15]. By the conclusion of 2016, cumulative photovoltaic capacity had notably increased, reaching 75 gigawatts (GW) and surging to 303 GW by the end of the subsequent years. This substantial capacity was sufficient to contribute approximately 1.8% to the global electricity consumption. Notably, China, the United States, and India emerged as the primary installers of PV panels from 2016 through 2019 [16] [17]. Honduras currently harnesses its photovoltaic capacity to generate 12.5 percent of the country's electrical energy. In comparison, Italy, Greece, and Germany contribute approximately 7 to 8 percent each to their respective domestic electricity consumption through photovoltaic generation [18] [19] [20] (**Table 1**).

4. Solar Energy Use in Agriculture

Solar energy stands poised to fulfill and complement a myriad of energy needs on the farm. Here's a succinct exploration of various applications of solar energy technologies in agriculture.

4.1. Crop & Gain Drying

Utilizing the sun's natural energy for crop and grain drying has been an enduring and widely adopted application of solar energy. This eco-friendly and sustainable solution benefits agricultural communities by efficiently drying and preserving crops. One of the simplest and most cost-effective methods involves allowing crops to naturally dry in the field or spreading harvested grain and fruit under the sun. However, these methods expose the crops to potential damage from birds, rodents, wind, rain, and contamination by dust and dirt. To address these challenges, advanced solar dryers provide protection, minimize losses, expedite drying processes with greater uniformity, and yield higher-quality products compared to traditional open-air methods [32].

4.2. Space & Water Heating

Livestock and dairy operations, particularly in modern pig and poultry farms housed in enclosed structures, demand meticulous control over temperature and air quality for optimal animal health and growth. Efficient management of indoor air is essential to eliminate moisture, toxic gases, odors, and dust. The substantial energy required for heating this air can be mitigated through the strategic integration of solar air/space heaters into farm buildings. These systems, with thoughtful planning and design, contribute to preheating incoming fresh air and can supplement natural ventilation levels during warmer months, contingent on regional conditions. Additionally, solar water heating proves beneficial for generating hot water needed for cleaning pens or equipment and preheating water

Table 1. The activities of the different countries in the field of the use of solar energy and pump.

Country	Description	Description of activity	Data
China	The most extensive solar power plant construction initiative globally is underway, boasting a remarkable production capacity of 200 gigawatts. This ambitious program constitutes a significant one-third share of the total global installed solar capacity.	Nearly 99% of the irrigated areas utilize a combination of irrigation pumps and photovoltaic systems across various agricultural practices.	[21] [22]
Japan	By the year 2030, Japan envisions harnessing existing solar energy in space and transmitting it to Earth as part of an ambitious program. As of the conclusion of 2017, the cumulative capacity of this initiative reached an impressive 50 gigawatts.	Solar energy production experienced significant growth, increasing by 1.2 times within a single year.	[23]
Unite the States of America	The decision was made to deploy 10 million solar panels within the next decade, aiming to fulfill 10% of the electricity demand by the year 2030. As of the conclusion of 2017, the cumulative capacity had already reached an impressive 50 gigawatts.	The Nevada desert, historically known for nuclear tests, has undergone a transformation into the world's largest solar laboratory.	[24]
Taiwan	The long-term objective involves incorporating 6500 to 10,000 megawatts (MW) from renewable energy sources over the next two decades. As of the conclusion of 2019, the cumulative capacity for solar energy production had already reached an impressive 4 gigawatts.	Asia is currently undertaking the construction of the largest solar power plant in the region, spanning an expansive two hectares. This remarkable project is designed to yield a production capacity of one megawatt of energy.	[25]
Jordan	The accessibility of this technology to the public has seen a notable increase, with the precise count of installed pumps readily available. As of the conclusion of 2018, the cumulative capacity for solar energy production had reached an impressive milestone of 1 gigawatt.	Encouraging the adoption of photovoltaic systems for water pumps is a key initiative, emphasizing the need for expanded research in this domain.	[26]
India	The installation and operation of 10,000 photovoltaic water pumps are integral objectives of the PM-Kusum initiative in this country. As of the conclusion of 2019, the cumulative capacity for solar energy production had reached an impressive 37.5 gigawatts.	A total of 181,000 water pumps with photovoltaic systems have been successfully installed for agricultural areas.	[27]
Bangladesh	Utilizing just one percent of Bangladesh's agricultural land could accommodate the construction of around 50,000 MW of solar power plants. With an average capacity factor of 4.5 hours per day, this could generate approximately 82,000 GWh of electricity, surpassing the total consumption in 2020.	Comparatively, the financial benefits from fuel cost savings would be over five times greater than the output from three-cropped land. Any lost agricultural output from this one percent can be compensated by preventing spoilage through improved storage and processing facilities.	[28]
Italy	In Italy, solar energy is diverse, with small systems (<10 kW) comprising 19.6%, mainly in residential areas. The 10 - 100 kW range represents 20.9%, serving collective spaces. Systems of 100 - 500 kW power larger facilities, while those over 500 kW serve as district power systems. Despite the focus on large plants, installations under 0.5 MW make up nearly 80% of Italy's solar capacity in 2017. Almost all solar PV is grid-connected, with only 14 MW off-grid as of 2017.	Enel Green Power, established in 2008, operates globally across Europe, Asia, the Americas, Oceania, and Africa. Specializing in renewable energy, the company is actively involved in developing and managing energy generation activities from sustainable sources.	[29]

Continued

Germany	Germany, a top-four country in installed photovoltaic solar capacity, reached 42.98 GW by 2017, contributing almost 6% to national electricity demand. The period from 2010 to 2012 witnessed a substantial boom, with Germany deploying around 22 GW, a third of global PV installations at that time	Germany's official aim is to elevate renewable energy's share in total electricity consumption, targeting 80% by 2030 and complete decarbonization before 2040 as part of their long-term goals.	[30]
Greece	As of September 2013, Greece achieved a total installed photovoltaic capacity of 2523.5 MWp, with 987.2 MWp added from January to September 2013, despite the financial crisis. Ranking fifth globally in per capita installed PV capacity, Greece anticipates that PV-generated energy will meet around 7% of the country's electricity demand in 2014.	In 2022, solar power constituted 12.6% of Greece's total electricity generation, a significant increase from 0.3% in 2010 and less than 0.1% in 2000, reflecting substantial growth in solar energy adoption.	[31]

before entering conventional water heaters. Recognizing that water heating constitutes a significant portion of energy costs in both households and dairy operations, a properly sized solar water-heating system holds the potential to substantially reduce these expenses [33].

4.3. Greenhouse Heating

Greenhouse heating is another notable application of solar energy in agriculture. While conventional commercial greenhouses often depend on the sun for lighting, they typically resort to gas or oil heaters to sustain temperatures conducive to plant growth during colder months. In contrast, solar greenhouses are specifically designed to harness solar energy for both heating and lighting purposes. This innovative approach ensures a more sustainable and energy-efficient solution for maintaining optimal conditions for plant cultivation. A solar greenhouse has thermal mass to collect and store solar heat energy, and insulation to retain this heat for use during the night and on cloudy days [34].

5. Solar Photovoltaic Array (PV Panel)

The design of a solar photovoltaic (PV) array involves a comprehensive process to ensure efficient energy production. Beginning with a thorough site assessment, factors such as solar resource evaluation and shading analysis are considered. Energy requirements are then determined, leading to the sizing of the PV array based on both load and available solar resources. Component selection is crucial, involving careful choices of solar panels, inverters, and additional equipment like charge controllers and batteries if energy storage is incorporated. The array layout is designed, optimizing tilt angles, azimuth, and considering available space and shading. The electrical system is carefully configured, accounting for series or parallel connections and addressing voltage and current considerations. The selection of a suitable mounting structure, compliance with local regulations, and adherence to safety standards are integral parts of the process. Additionally, economic analyses, including cost-benefit assessments and consideration of incentives, play a vital role in decision-making. System efficiency is optimized by addressing factors such as module temperature, soiling losses, and inverter performance. A focus on safety, compliance, and the integration of a monitoring system for performance tracking completes the design process. Overall, a well-executed design ensures the PV array's reliability, maximizes energy output, and considers the economic viability of the system. Professional expertise and specialized software often support this intricate design phase.

6. Differences between Solar Water Pump and Nonrenewable Water Pump

Solar water pumps and nonrenewable water pumps, such as those powered by diesel or electricity from the grid, exhibit key differences in their operation and impact on agriculture (Table 2). Solar water pumps, drawing energy from sunlight through photovoltaic panels, represent a renewable and environmentally friendly option. They have lower operational costs over time, reduce carbon emissions, and are suitable for remote locations, providing greater flexibility in deployment. Conversely, nonrenewable water pumps rely on fossil fuels or conventional electricity sources, contributing to environmental degradation and higher operational costs. While nonrenewable pumps may have lower initial setup costs, their sustainability and long-term cost-effectiveness are often overshadowed by the ecological impact and dependence on nonrenewable resources (Table 3). The choice between these two pump types hinges on factors like environmental considerations, operating expenses, and the accessibility of sunlight or electricity. In the growing emphasis on sustainable agriculture, solar water pumps emerge as a promising solution for farmers looking to reduce environmental impact and promote eco-friendly practices.

7. Research Result

The synthesis of literature and field survey findings revealed a robust case for the adoption of solar water pumps in Bangladesh's agricultural sector. The economic benefits, including operational cost savings and reduced reliance on imported diesel, emerged as key drivers for the widespread acceptance of photovoltaic pumping systems.

Table 2. Comparing solar pump and nonrenewable pump.

Feature	Solar water pump	Non-renewable water pump	Data
Energy source	Sunlight through photovoltaic panels	Fossil fuels or conventional electricity	[35]
Environmental impact	Lower, clean energy with reduced emission	Higher, combustion of fossil fuels contributes to pollution	[35]
Location independence	Suitable for remote or off-grid areas, greater flexibility	Dependent on fuel or electricity supply, limited flexibility	[35]
Sustainability	Promotes sustainable agriculture, reduces dependence on nonrenewable resources	Contributes to environmental degradation, less sustainable in the long term	[35]

Table 3. Compare to cost of solar pump and nonrenewable pump.

Feature	Solar water pump	Non-renewable water pump	Data
Initial cost	Higher upfront cost	Lower upfront cost	[35]
Operating costs	No operating costs, except for maintenance	Operating costs for electricity or fuel	[35]
Environmental impact	No emissions, environmentally friendly	Emissions from electricity or fuel production	[35]
Reliability	Can operate during power outages	Reliant on electricity or fuel	[35]
Lifespan	Typically lasts 10 - 15 years	Typically lasts 5 - 7 years	[35]
Maintenance	Lower maintenance costs	Higher maintenance costs	[35]
Suitability for remote areas	Ideal for remote areas without grid access	Not ideal for remote areas without grid access	[35]
Overall cost over time	Lower overall cost over time due to no operating costs	Higher overall cost over time due to operating costs	[35]

Comparative analyses with traditional diesel pumps highlighted the economic viability of solar water pumps over the long term. The survey data underscored high reliability and consistent water supply as reported by farmers using photovoltaic pumps. Furthermore, the potential carbon emissions reduction from large-scale adoption of solar pumps aligns with Bangladesh's commitment to environmental sustainability.

8. Conclusion

Bangladesh's agricultural sector stands at the cusp of a transformative era, with solar water pumps emerging as a compelling alternative to conventional diesel-powered systems. While initial costs may raise concerns, the long-term economic and environmental benefits far outweigh the initial investment. Solar water pumps offer operational cost savings, eliminating the burden of fuel expenses and ensuring stable irrigation costs. Their versatility extends beyond irrigation, harnessing excess solar energy for other farm operations and electricity generation, maximizing their economic value. Moreover, solar water pumps operate with zero emissions, safeguarding public health, preserving Bangladesh's ecological balance, and promoting energy independence. The widespread adoption of solar water pumps has the potential to revolutionize rural communities, enhancing agricultural productivity, improving livelihoods, and empowering women in agriculture. By embracing solar-powered irrigation, Bangladesh can not only enhance its agricultural productivity but also demonstrate its commitment to environmental stewardship and the empowerment of rural communities, serving as a beacon of sustainable agriculture.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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