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A COMPARATIVE ANALYSIS OF SOLAR AND DIESEL-POWERED IRRIGATION SYSTEMS IN BANGLADESH

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A B S T R A C T

In spite of Bangladesh's profound dependence on agriculture, where approximately 16% of its GDP is derived from this sector and nearly 60-70% of its population relies on agriculture for their livelihoods, the nation has been slow to embrace modern technological advancements in farming practices. The landscape still features outdated farming equipment such as traditional diesel pumps and aging tractors, posing a formidable challenge to the advancement of agriculture. The environmental impact and sustainability concerns associated with conventional irrigation systems have garnered heightened international attention, particularly due to the escalating demand for irrigation. In light of these challenges, transitioning from traditional Diesel Power Irrigation Systems to Solar Power Irrigation Systems (SPIS) emerges as a prospective solution. This study meticulously delves into existing literature to conduct a comprehensive assessment of the feasibility of these two systems, encompassing economic and environmental considerations.

1. INTRODUCTION

Out of the world's estimated irrigated land spanning 301 million hectares, approximately 38% relies on groundwater for irrigation, with the majority of these irrigation systems dependent on pumping technology. (Siebert et al., 2010). Nevertheless, the energy demands associated with water pumping constitute a significant aspect of agricultural development. Currently, the primary sources of energy utilized worldwide are oil, coal, and natural gas. Nonetheless, there is a growing trend toward the adoption of solar energy, with photovoltaic (PV) generators emerging as an intriguing option to curtail electricity expenses. These systems can be custom-sized for on-site applications, enabling autonomous operation while concurrently diminishing the environmental impact (Michaelson, & Jiang, 2021). A potential viable substitute for the use of fossil fuels in pumping systems is the use of solar energy.

Despite being primarily an agricultural country, Bangladesh faces challenges in achieving self-sufficiency in crop production. The nation has persistently encountered issues related to food security and various other challenges. With a land area of 147,570 km² accommodating approximately 170 million people, the pressure on agricultural resources has intensified due to rapid population growth (Khatun & Paul, 2019). Consequently, agricultural land is diminishing each year. The northwestern region of Bangladesh faces significant challenges when it comes to cultivation and agriculture. Specifically, the Barind region in the northwestern part of Bangladesh is recognized as a drought-prone area (Hossain et al. 2016). Moreover, the floodplain along the Teesta River and its neighboring areas are highly susceptible to sudden flash floods and rapid erosion (Mondal et al., 2020). Nearly every year, the northwestern part of Bangladesh experiences severe flash floods, resulting in property damage and the disruption of livelihoods. Nevertheless, as a nation, we must

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confront and endure these challenges with the limited resources at our disposal. This underscores the critical importance of embracing modern technological advancements to bolster our country's resilience and sustainability. Therefore, in the agricultural sector, adopting smart farming practices and embracing new technologies is not a luxury but an imperative necessity. Bangladesh has a good climate for installing solar PV because of its average daily sun radiation of 4-6.5 kWh/m^2 (Miah et al., 2020). It is suitable for replacing diesel generation and meeting energy needs in isolated places. In Bangladesh, there are three different solar installation options: solar household systems, hybrid systems, and centralized PV power plants. Solar water pumping systems to supply water to rural regions are another common PV installation in Bangladesh. The government of Bangladesh has initiated a program aimed at replacing 18,700 diesel-powered irrigation pumps with solar-powered ones, each having an average capacity of 8 kWp (Islam et al., 2017). All around the nation, more than 300 solar pumps have already been built. In the year 2020, the total cultivated land for rice amounted to 10.28 million hectares (Zonayet et al., 2022). Most paddy field irrigation systems employ a diesel generator to power the pump's electric motor. The issue is that Bangladesh's diesel prices are unstable. For irrigation, farmers primarily employ diesel and electric-powered pumps. In the country, there are more than 1.57 million irrigation pumps in use, 80% of which run on diesel and 20% on electricity (Islam et al., 2022). Due to the absence of energy from the national grid in isolated agricultural regions, the majority of pumps are diesel-powered. Bangladesh must therefore buy 1.06 million tonnes of diesel annually (Islam & Arfanuzzaman, 2018). In August 2022, the government raised fuel prices by more than 50% in just a week (Rony & Hossain, 2023). Currently, the price of diesel stands at BDT 109 per liter, equivalent to USD 1/L. Looking at our neighboring countries, we observe distinct patterns in irrigation practices. In Myanmar, approximately 77% of their total irrigation relies on diesel-powered pumps (Frenken, 2012). Meanwhile, India directs 18% of its overall electricity consumption and over 5% of its total diesel usage specifically toward irrigation purposes (IRENA 2016). In Pakistan, the operation of irrigation pumps consumes an astounding 6 billion kilowatt-hours of electricity and 3.5 billion liters of diesel (Qureshi, 2014). In Bangladesh, plantations located in remote areas, often beyond the reach of the local electrical grid, rely primarily on diesel generators for electricity-dependent activities. Much of the water needed for these plantations is pumped from underground reservoirs. However, fuel consumption constitutes a substantial portion of the overall economic cost in agricultural operations. As a component of the Fourth Industrial Revolution or IR 4.0 innovation era, solar-powered irrigation solutions have garnered growing global attention. This is reflected in the growing interest among agricultural institutions in developing countries, which are increasingly seeking support for the installation, financing, and training related to these systems. Solar technology is emerging as a prominent sustainable alternative to traditional irrigation systems, receiving substantial recognition. The utilization of sustainable solar energy through photovoltaic (PV) cells for water pumping in irrigation represents a novel and effective approach (Cevher et al., 2021).

While some studies have explored the economic feasibility of Solar Powered Irrigation Systems (SPIS) in Bangladesh, there remains a significant gap in research that directly compares SPIS with traditional diesel-powered irrigation systems. This gap prompts the need for a comprehensive investigation. The main objective of this research is to perform an in-depth comparative analysis of Solar Powered Irrigation Systems (SPIS) and Diesel Powered Irrigation Systems (DPIS) within the context of Bangladesh. By examining factors such as economic efficiency and environmental impact, this study aims to offer valuable insights for stakeholders, policymakers, and farmers in the region. Additionally, this research seeks to fill a gap in the literature by providing a comprehensive assessment of the advantages and disadvantages of both irrigation systems. The study will contribute to the existing body of knowledge by filling the research gap and providing a detailed comparative analysis of SPIS and DPIS. Secondly, the findings will serve as a practical resource for future researchers and stakeholders interested in adopting sustainable agricultural technologies. Additionally, the research outcomes can inform decision-makers in Bangladesh about the most suitable irrigation system for sustainable and cost-effective farming practices, thus potentially enhancing agricultural productivity and reducing environmental impacts.

2. DIESEL POWERED IRRIGATION SYSTEM (DPIS)

Typically, Diesel generators are commonly used in drip irrigation systems. Drip irrigation, also known as micro irrigation, involves the gradual release of water onto the soil at a low flow rate, generally between 2 and 20 liters per hour. This process is facilitated by a network of narrow plastic pipes equipped with specialized outlets called emitters or drippers (Pandya 2019). Water is delivered close to the plant roots with drip irrigation, ensuring that only the soil in the immediate vicinity of the roots is moistened. This contrasts with surface and sprinkler irrigation methods, which wet the entire soil profile. Drip irrigation typically involves more frequent applications, usually every 1-3 days, which helps maintain consistently high moisture levels in the soil for optimal plant growth (Wibowo & Chang, 2020).

A typical drip irrigation system includes a diesel generator, a pump unit, a control head, pipes and lines, and may also feature additional components such as reservoir tanks and filters. In Bangladesh, three types of diesel-powered irrigation pumps are commonly used: deep tube wells, shallow tube wells, and low-lift pumps.

Table 1 highlights the differences in fuel consumption and capacity among these various types of diesel-powered irrigation pumps (Rana et al., 2021).

Table 1. Differences in fuel usage and pump capacity for diesel irrigation

Pump Model	***Outline***	***Typical Values***
Deep Tube Well	Capacity	55 hp
	Fuel Used	4.5 L/h
Low Lift Pump	Capacity	7.5 hp
	Fuel Used	1 L/h
Shallow Tube Well	Capacity	12.50 hp
	Fuel Used	1.25 L/h

According to BADC (Bangladesh Agricultural Development Corporation), in the year 2018–19, there were approximately 12,43,507 units of operational diesel irrigation pumps in Bangladesh. Among these, 85.89% were Shallow Tube Wells , 0.177% were Deep Tube Wells, and 13.92% were Low Lift Pumps. Bangladesh's average elevation above sea level is notably low, with a static head of surface water measuring less than 20–30 meters in most areas (Tulip et al. 2022). This characteristic is the primary factor driving the widespread preference for STWs as the predominant choice for irrigation in the country.

3. SOLAR POWERED IRRIGATION SYSTEM (SPIS)

The Solar Powered Irrigation System (SPIS) is a relatively complex setup that demands careful design. It involves not only selecting an appropriate photovoltaic (PV) pumping system and irrigation infrastructure (supply side) but also conducting a water demand assessment and developing an irrigation calendar (demand side). The typical SPIS configuration includes direct pumping, where PV panels are paired with a pump (equipped with either a DC or AC motor) and a controller. This system is complemented by a water storage tank and drip irrigation equipment (Parti et al., 2023). Utilized widely worldwide, this system incorporates Maximum Power Point Tracking (MPPT) along with various electronic and software enhancements aimed at optimizing efficiency. It is renowned for its versatility, capable of accommodating a wide range of sizes, irrigation methods, and specific requirements, and boasts impressive water-to-wire efficiencies exceeding 50% in highly efficient configurations (Mondaca-Duarte et al., 2020). The speed control is required for irrigation machines. The investment price of SPIS is more expensive whereby it has much cheaper on maintenance cost as compared to diesel-powered system. However, it is anticipated that when oil prices rise and solar panel prices fall, the profitability of the photovoltaic pumping system will rise.

PV panels are connected to either an AC or DC mechanism, where the electrical energy generated by the panels is converted into mechanical power. This mechanical energy is then transformed into hydraulic energy by the pump. The core principle of solar water pumping systems involves converting sunlight into electrical energy using photovoltaic cells. This electricity is utilized to power pumps that lift water from ground-level sources or deep wells. During operation, the PV system typically does not include batteries or alternative power sources, making it suitable for irrigation during daylight hours (Bruning et al,. 2022). This is because the intensity of solar radiation is the most significant factor limiting the effectiveness of solar water pumps. SPIS components consist of pumps, panels, inverters, panel boxes, storage tanks, pipes, and ground mounting.
The following is the details of SPIS components:

3.1 Photovoltaic generator

A photovoltaic generator is formed by connecting a group of solar panels together. It comprises a series of photovoltaic (PV) solar arrays that are interconnected either in parallel, in series, or both, to produce direct current (DC) and achieve the desired voltage.

3.2 Solar pump inverters and controllers

An inverter is an electronic power device that plays a crucial role in solar-powered systems. Solar panels typically generate direct current (DC), while pumps can operate as either DC or AC (Alternating Current) types. Consequently, when the pump operates on AC power, it becomes necessary to convert the DC output from the solar panels into AC power (Rehman et al., 2022). In addition, the pump necessitates a controller capable of aligning the power delivered to the pump with the power sourced from the energy provider. Typically, these controllers are equipped with overvoltage protection functionality. This protective feature enables the pump to be deactivated in cases of inadequate or excessively high supply voltages.

3.3 Solar Pumps

Various capacities of PV pumps are available to cater to specific water demand needs. Submersible pumps are predominantly used in regions where water is extracted from groundwater sources (Mondaca-Duarte et al., 2020).

3.4 Mounting Stracture

The supporting structure ensures the security and preservation of the installed solar panels against theft and environmental damage (Gora & Dulawat, 2017). The manual tracking system affixed to the support structure ensures optimal water flow.

3.5 Other Components

Another very important element for the installation of a solar pump system. It serves as the base for anchoring the support structure, housing the pump, and managing electrical connections, which include cables, junction boxes, connectors, and switches. Additionally, it includes a grounding kit for protection in case of lightning or a short circuit, along with pipes and fittings required for installation connections. (de Vrese & Hagemann, 2018).

4. ECONOMIC COMPARISON

The initial capital investment needed for a Solar-Powered Irrigation System (SPIS) is higher compared to that of a Diesel-Powered Irrigation System (DPIS) (Asci et al. 2020). According to a study, the primary cost components for a Solar-Powered Irrigation System (SPIS) are as follows: solar panels represent the largest portion, accounting for 45% of the total cost. This is followed by installation expenses at 18%, motor costs at 16%, pump costs at 10%, and pipe and fittings expenses at 4% (Hartung & Pluschke, 2018). Numerous global studies have investigated the economic viability of Solar-Powered Irrigation Systems (SPIS). For example, Kelley et al. performed a lifecycle cost analysis and concluded that solar-powered irrigation is an economically advantageous option in Saudi Arabia (Kelley et al., 2010). However, it's noteworthy that the substantial upfront investment in solar panels poses a financial challenge, necessitating adequate financing. Similarly, in Bangladesh, the initial costs associated with SPIS adoption present a barrier for farmers across different income brackets, including the poor, middle-class, and affluent. García et al. (2019) estimated that the economic payback period for off-grid SPIS in this context is approximately 8.6 years (García et al., 2019). By switching from diesel to clean, sustainable solar energy, 1300 solar irrigation pumps can save around $3.2 million yearly (Agrawal & Jain, 2019; Panel, 2018). Based on the research conducted by Rana et al. (2021), it was discovered that the Benefit-Cost Ratio (BCR) for users of solar-powered systems is higher at 1.313, compared to the BCR of users utilizing diesel-powered systems, which stands at 1.096. Furthermore, users who opt for solar-powered irrigation systems experience more substantial net profit margins. Table 2 presents a comprehensive summary of various economic analyses conducted on DPIS and SPIS systems.

Table 2. Research summary on the economic analysis of SPIS and DPIS

Researcher	*Country*	*Economic Analysis*	*DPIS*	*SPIS*
Rana et al. (2021)	Bangladesh	BCR	1.096	1.313
Islam, & Hossain (2022).	Bangladesh	IRR (%)	-	10
		Pay Back Period (years)		8.10
Sarkar et al. (2015)	Bangladesh	LCOE	-	$0.182/kWh
Chowdhury et al. (2022)	Bangladesh	LCOE	-	$0.158/kWh
Sarkar & Ghosh (2017)	Bangladesh	IRR (%)		12.95
		Pay Back Period (years)		8.26
Agarwal & Jain (2019)	India	Pay Back Period (years)		4-5
Guno & Agaton (2022)	Philippines	NPV ($/ha)		4517
		Pay Back Period (years)		2.88
Kelley et al. (2010)	Saudi Arab	Total Life cycle cost	$48,660,400	$3,406,700
Khan et al. (2014)	Bangladesh	Total PV (BDT)	1,26,350	2,67,590

5. ENVIRONMENTAL FACTS

The carbon dioxide (CO2) emissions stemming from irrigation pumps within Bangladesh's agricultural sector have been steadily rising. Between 1983 and 2012, these emissions increased significantly, surging from 705 thousand tons to 7814 thousand tons, marking an almost eleven-fold rise in CO_2 emissions from both diesel and electricity-operated irrigation pumps over the course of three decades (Al-Masum et al., 2017). One liter of diesel will emit around 2.7 kg of CO_2 and 0.7 kg of pure carbon (Biswas et al. 2010). Infrastructure Development Company Limited estimates that Bangladesh could save 450 million litres of diesel and decrease the emissions of one million tons of CO_2 per year by setting up 50,000 solar irrigation pumps (Rahman, 2015). The studies indicated that solar irrigation offers significant ecological advantages: up to a 26.5 tons of CO_2 equivalent decrease in GHG emission per hectare per year, and it helps in avoiding air contaminant discharges like carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter into the environment (Guno et al., 2022). In the specific case of Odisha, India, there is a noteworthy reduction in emissions, amounting to 4.34 tons of CO_2 equivalent per hectare (Ghosal et al., 2020). As per the 2020 report from the Gesellschaft für Internationale Zusammenarbeit (GIZ), the production of 1 kWh of power results in the emission of 16 to 32 grams of CO_2 gas for solar panels, 600 grams for grid electricity, and 1000 grams for diesel machines (Sass & Hahn 2020).

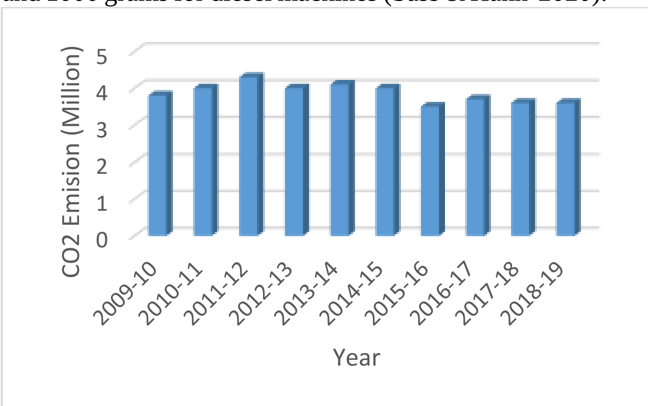

Figure 1. Variations in carbon dioxide emissions from diesel-powered irrigation pumps in Bangladesh over the years (Rana et al., 2021).

This data underscores that the solar system stands out as the most environmentally friendly choice for power generation among the three available alternatives. A study conducted in Indonesia has demonstrated that a Solar Pumping System without the need for batteries or diesel generators can lead to significant carbon emission savings, amounting to as much as 46,318.5 kilograms of CO_2 equivalent per year (Indriani, 2018). Figure 1 depicts the variations in carbon dioxide emissions attributed to diesel-powered irrigation pumps in Bangladesh over the years (Rana et al., 2021). It is evident that the highest emissions occurred in the 2011-12 fiscal year. Furthermore, throughout the past decade, the data illustrates a persistent trend of elevated CO2 emissions.

6. CONCLUSION

The study conducts a thorough examination of both the economic and experimental aspects of Solar Power Irrigation Systems (SPIS) and Diesel Power Irrigation Systems (DPIS). In this comparative analysis, SPIS demonstrates a slightly higher benefit-cost ratio (BCR) when contrasted with DPIS. Notably, prominent studies conducted within Bangladesh suggest an approximate 8-year payback period for SPIS adoption. However, findings from studies conducted outside Bangladesh reveal a shorter payback period, potentially attributed to the comparatively higher capital costs of SPIS components within the nation, presenting a notable obstacle. In this context, governmental and institutional support assumes a pivotal role, offering the potential to mitigate this capital investment barrier. It is essential to acknowledge that numerous other nations have made significant strides by providing government subsidies to promote sustainable initiatives. Therefore, policymakers in Bangladesh must consider similar measures to facilitate the widespread adoption of SPIS technology. Additionally, although the levelized cost of energy (LCOE) for SPIS appears favorable within the Bangladeshi context, it is crucial not to overlook the environmental dimension. Diesel systems, in terms of 〖CO〗_2 emissions per 1 kWh power generation, produce approximately 50 times more emissions compared to their solar counterparts. This underscores the urgent need for the comprehensive implementation of SPIS in modern agriculture, a goal that necessitates robust government and non-governmental organizational support. Given the growing global concern over the detrimental environmental impact and sustainability of conventional irrigation pumps, the demand for irrigation, policymakers worldwide are increasingly endorsing initiatives that promote renewable energy-driven alternatives, such as solar and wind pumps. This transition is crucial in setting the pace towards a sustainable water supply for irrigation purposes, and at the same time aiding developments in food security through sustained improvement in agricultural yield. Also, resorting to such renewable energy strategies aligns with the seventh SDG, which seeks to ensure that there is universal access to affordable, reliable, sustainable, and modern energy by the year 2030. Looking ahead, future endeavors should encompass extensive experimental and real-time analyses, offering a comprehensive comparison of the two systems. Solar power generation, due to its intermittent nature, experiences substantial variations in irradiation levels across diverse locations and under varying weather conditions. Consequently, conducting a comprehensive, year-long experimental analysis, coupled with rigorous data collection, becomes paramount to facilitate an in-depth assessment of the feasibility of both systems within the unique context of Bangladesh.

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