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An Intelligent Hybrid Energy Systems for Irrigation : A Review of Environmental Impacts, Technical and Economic Feasibility

Hicham Mhamdi*, Omar Kerrou, Mohammed Aggour

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Abstract: This study examines the utilization of Hybrid Energy Systems that combine renewable sources, such as photovoltaic and wind, with conventional source, such diesel and battery technologies, in order to address power supply challenges in a comprehensive manner. The focus of this investigation is on the application of these systems in general and in the context of irrigation in particular. The present study investigates a wide range of recent scientific articles and studies. The current research highlights the technical, environmental, and economic benefits of hybrid energy systems. The analysis of these criteria has shown that hybrid energy systems demonstrate more powerful cost-efficiency in comparison to both diesel only systems and systems reliant solely on a single renewable energy source. Furthermore, this type of system that combine renewable and conventional offers enhanced reliability, reduced emissions of greenhouse gases, and decreased running costs. It also demonstrates the most favourable Net Present Cost and Cost of Energy when compared to the other alternatives that were considered.

Keywords: *Renewable energy, Conventional energy, diesel generator, wind turbine, photovoltaic, Battery, Cost of Energy, Net Positive Cost.*

1. Introduction

The primary sources of energy utilised for irrigation predominantly consist of conventional options, such as fossil fuels, particularly diesel, alongside electricity obtained from the power grid. The utilisation of these energy sources has gradually increased in tandem with the expansion of irrigation systems. Nevertheless, the escalation in the utilisation of conventional energy sources gives rise to apprehensions regarding the environmental implications associated with greenhouse gas emissions and the depletion of resources. Given the aforementioned limitations, it is imperative to explore sustainable alternatives, including conventional energy and renewable energy (RE) sources. The depletion of fossil fuels has prompted a worldwide exploration for alternative sources of clean and sustainable energy (Rafindadi et al., R.A.2018). Consequently, there is a global inclination towards RE due to its environmentally friendly nature, ample availability, and long-term viability (Inayat et al., 2019).

Hybrid energy systems (HES) have been identified as a potentially viable alternative for the provision of irrigation water. HES combine renewable sources such as solar and wind, with conventional source such diesel generators. The primary advantage of these HES lies in their ability to maintain a reliable and uninterrupted power supply, even in the face of weather fluctuations or resource availability.

The aim of this review is to conduct a thorough examination of the latest research on hybrid energy systems, with the examination of both the technical and economic aspects of these systems.

This paper is organized into six primary sections, namely hybrid energy systems, the assessment of the efficiency of hybrid energy systems, comparative analysis of energy cost among countries with similar meteorological conditions , results and discussion, critical analysis and recommendations, and conclusions. The review offers a comprehensive synthesis of various research studies pertaining to HES in order to present a comprehensive overview of the field.

This analysis aims to comparatively evaluate various types of HES, examining their respective advantages and disadvantages and the subsequent impact on the overall efficiency of these systems, conducting an evaluation of the cost-effectiveness of HES.

2. Overview of Energy Sources

The availability of a dependable energy source is of utmost importance in ensuring the efficient operation of irrigation systems. Traditional energy sources, such as diesel, have been extensively employed for this particular objective. Nevertheless, the exorbitant expenses associated with their implementation, detrimental effects on the environment, and reliance on finite fossil fuel resources have sparked a growing fascination with

Laboratory of Electronic Systems, Information Processing, Mechanics and Energetics,
Faculty of Sciences Kenitra, University Ibn Tofail Kenitra, Kenitra, Morocco
**Mail: hicham.mhamdi@uit.ac.ma*
Postal address: Ibn Tofail University, Faculty of Sciences, University campus, BP: 133, Kenitra, Morocco

sustainable energy alternatives, such as solar photovoltaic and wind power.

In order to enhance dependability, certain irrigation systems employ a hybrid approach by integrating multiple energy sources, such as solar photovoltaic, wind, and diesel. The hybrid systems possess the capability to adapt their energy source in response to varying weather conditions and levels of demand. In instances where there is an abundance of solar or wind power, there is a prioritisation of these renewable energy sources in order to minimise the reliance on diesel, resulting in reduced operating costs and carbon emissions.

1 The Diesel Generator for Rrigation System

Historically, diesel fuel has been widely employed as a primary energy source for powering irrigation pumps. The process of diesel combustion within engines produces an ample amount of energy, which can be utilized to operate pumps and facilitate the irrigation of agricultural land. Nevertheless, the reevaluation of diesel as the exclusive energy source has been prompted by the evolving environmental and economic concerns.

There are several notable advantages associated with the utilization of diesel for irrigation purposes. To begin with, it is widely accessible, thereby facilitating its distribution across numerous geographical areas. Furthermore, it is worth noting that diesel engines possess a high level of durability and are capable of functioning effectively in challenging circumstances, rendering them well suited for the rigorous agricultural settings. Ultimately, the considerable power output of diesel engines enables them to generate an ample amount of force, thereby facilitating the effective operation of pumps across extensive distances.

However, the environmental impact of diesel power groups is frequently subject to criticism, particularly concerning their contribution to GHG emissions and the release of polluting substances. Nevertheless, the progression of technology has played a pivotal role in enabling the enhancement of diesel generators, resulting in increased efficiency and a greater focus on environmental sustainability. Furthermore, the implementation of various alternatives, such as the utilization of generators fueled by biodiesel or natural gas, can effectively mitigate the carbon footprint.

The use of diesel as energy source necessitates careful optimization and reconsideration in light of contemporary environmental imperatives. To guarantee the sustainability and resilience of the irrigation sector, it is imperative to adopt energy efficiency practices and gradually shift towards cleaner energy sources. By integrating the benefits of diesel fuel with the potentialities presented by renewable energy sources, there is a possibility to strive towards a more environmentally system.

2 PV Standalone for Irrigation System

PV solar energy is acquired through the direct conversion of sunlight into electrical energy via the utilization of solar panels. This environmentally friendly and sustainable technology presents a viable alternative to traditional energy sources in the context of powering irrigation systems.

One of the primary benefits associated with the utilization of PV solar energy is its inherent characteristic of being a renewable and inexhaustible resource. In contrast to fossil fuels, solar energy is characterized by its abundant availability and absence of detrimental emissions. Furthermore, following the installation of solar panels, the electricity produced is essentially costless, thereby leading to a substantial reduction in operational expenses for farmers. The utilization of PV technology provides farmers with enhanced energy autonomy, enabling them to produce their own electricity on their premises.

The adaptability of PV systems to irrigation requirements is evident as they can be tailored to suit the unique irrigation needs of various agricultural establishments. PV systems can be customised to facilitate efficient and precise irrigation, catering to a range of agricultural land sizes, from small plots to expansive tracts of farmland.

The integration of storage systems is a viable solution to ensure a consistent water supply, particularly during periods when solar energy is not available. This can be achieved by incorporating energy storage systems into PV installations. Batteries have the capability to store electrical energy generated during periods of ample sunlight, which can then be utilised during times of increased water demand when solar energy availability is inadequate. The integration of PV systems with energy storage presents a dependable and consistent solution for agricultural irrigation.

The benefits of a photovoltaic pumping system are many. It helps pump water during dry days and sunny days, enabling farmers to harvest more water from low yield wells. The solar pumps also have a longer lifespan, which makes them a viable option for irrigation systems. Moreover, solar pumps have a low maintenance cost (Odeh, I., et al., 2006). Aside from that, the PWPSI has a very long lifespan advise using diaphragm pumps with direct current motors for low flow pumps , Helical pumps can be used for delivery heads of 50-150 m.

3 Hybrid Energy System

HES encompass the utilisation of both renewable and conventional power sources, exemplified by the integration of wind turbines and batteries, or solar panels and batteries.

The utilisation of HES provides enhanced reliability in terms of the power output per unit of installed capacity compared to relying mainly on either wind or PV technology. Additionally, the integration could involve the utilisation of RE in conjunction with conventional energy resources.

The literature reveals a growing body of research dedicated to examining the benefits of HES in terms of cost reduction, energy efficiency, and environmental sustainability. The incorporation of diverse methodological approaches and strategies in this study improves understanding and promotes the efficiency and ecological sustainability of these systems, thereby effectively addressing future energy demands. Figure 1 shows main sources of HES.

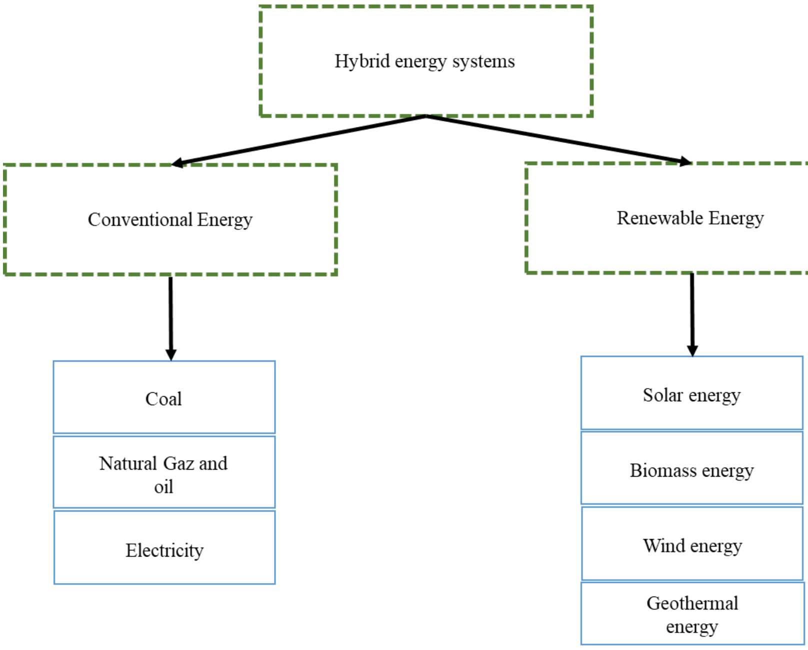

Fig 2: Main sources of renewable and conventional energy.

3.1 Hybrid Energy System Design for Irrigation

The widespread adoption of solar energy in the agricultural industry has prompted a multitude of initiatives. Multiple countries have extended assistance to farmer-led irrigation initiatives, engaging in experimental studies on solar pumps and providing financial incentives for their adoption. Despite the financial consequences, the technology has become easily accessible to farmers who are economically disadvantaged. Development partners in regions such as the Middle East and North Africa (MENA), Southeast Asia (SEA), and Africa are actively promoting the adoption of solar irrigation systems owing to their manifold benefits (Lefore, N., et al., 2021).

The optimization of photovoltaic, wind, diesel generator, and battery is a crucial element within the HES. The objective of the HES is to optimize the cost and the efficiency of the system (Almutairi, al., 2021) .

As depicted in Figure 2, an illustrative representation of an approach diagram is provided to illustrate the flowchart to optimize the design and the size of a Hybrid energy system for irrigation.

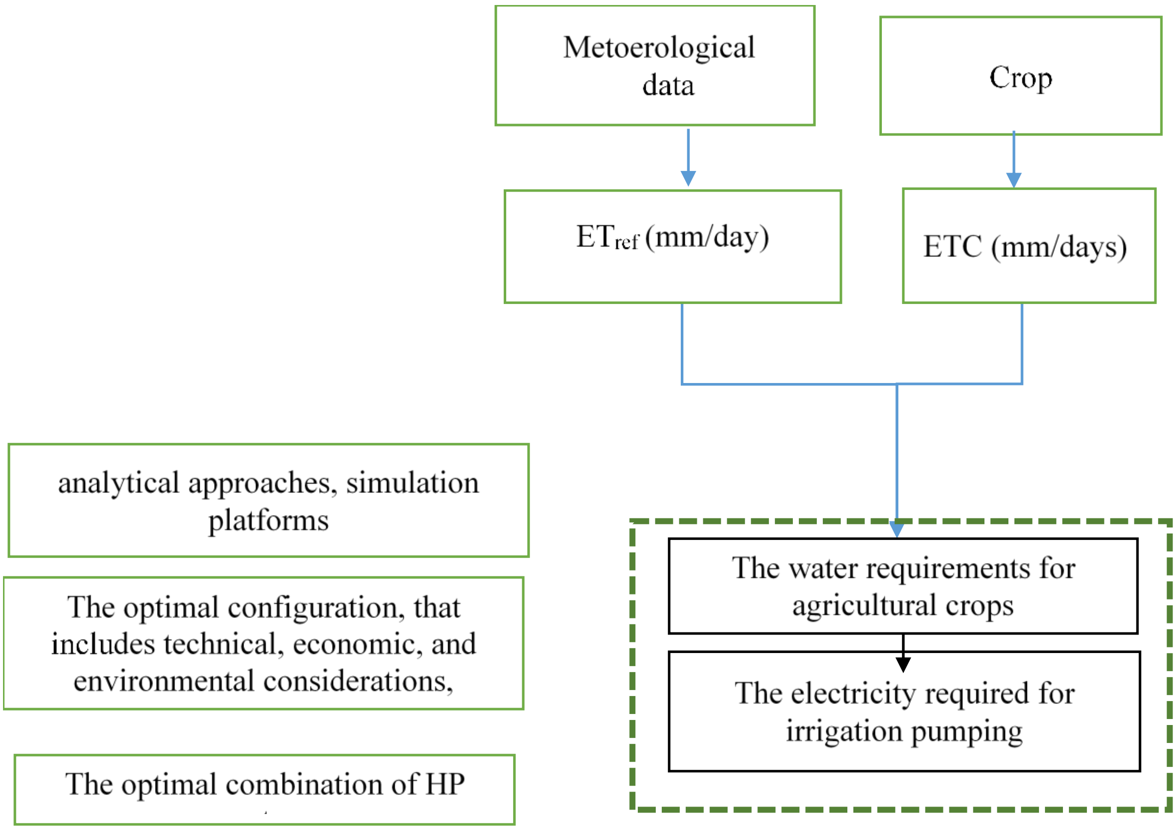

Fig 2: Management of optimally sizing HES for irrigation purpose.

The determination of an optimal sizing for HES is contingent upon the quantity of components present within the system, and the energy required to water pumping. The selection of components should be commensurate with the prevailing climatic conditions and the irrigation regimen in the area (MIT, 2019).

The design of the HES is based on an assessment of the necessary amount of water and the associated energy requirements. In order to fulfil the Total Dynamic Head (TDH) and water flow (m^3/h) requirements, it is imperative to optimise the pumping system. The quantification of energy requirements related to irrigation can be accomplished by taking into account various factors, including crop water requirements ,and solar radiation, among others. In circumstances characterised by reduced daylight hours and frequent cloud cover, the assurance of irrigation water availability can be achieved through the utilisation of a reservoir or battery system (Benghanem, M., et al., 2013; Agrawal et al., 2018).

The precise design of HES can contribute to the enhancement of economic efficiency in crop irrigation, while simultaneously mitigating environmental repercussions. (Better Cotton Initiative, 2015).

3.2 Daily Energy Demand

The daily energy demand refers to the electrical demand of the motor pump unit used for irrigation. This demand is expressed in terms of the necessary water and flow water to irrigate the parcel or the field. To estimate this daily energy demand several factors must be considered, among them are:

- ✓ Determining the total area of farmland to be irrigated is the initial step in the design. The water requirements for a given crop will vary depending on the specific crop being cultivated. Certain crops may necessitate a higher level of irrigation compared to others.
- ✓ Water requirements are determined by various factors such as the regional climate and specific crop needs. To ensure proper irrigation, it is necessary to evaluate the daily water quantity required. This will allow to determine the amount of energy needed to transport this volume of water from its source to the agricultural fields.
- ✓ TDH and pumping distance are important factors to consider when pumping water from a source, such as a well or reservoir. The power demand for the pumps will be influenced by this factor.
- ✓ The frequency at which irrigation is conducted has a direct impact on the daily energy consumption.

3.3 Software Tools for Hybrid Energy System Optimization

Hybrid system design encounters various challenges stemming from factors such as technological considerations, methodological approaches, resource constraints, and model complexities. The existing body of literature has examined the progress made in simulation techniques, which aid in achieving an optimal technological dimensioning of the components for the hybrid system. This optimisation aims to minimise costs and ensure the long-term viability of the systems (S.M. Dawoud et al.,2017 ; S.M. Zahraee et al.,2016). Researchers utilising a range of software tools have conducted the design and implementation of hybrid systems (R. Luna-Rubio et al.,2012 ; A.A. Mas'Ud et al., 2014). Among the various software options available, HOMER software stands out as the most widely utilised, followed by Clean Energy Management Software (RETScreen), Transient Energy System Simulation Programme (TRNSYS), and Hybrid Power System Simulation Model (HYBRIDS). However, it is important to note that each software possesses distinct characteristics that are heavily influenced by the inputs it receives and the intended purpose for its use. Table 5 provides a comprehensive overview of the principal characteristics and constraints associated with these tools.

3.4 The Assessment Of The Efficiency Of Hybrid Energy Systems.

The assessment of a hybrid energy system's economic, technical, and environmental aspects is crucial in determining its viability and appropriateness. Nevertheless, meticulous assessment will be necessary In order to optimise technical advantages, minimise costs, and deal with potential adverse environmental impacts.

Hybrid energy systems are evaluated based on a variety of technical, economic, and environmental factors (Yazdani, H et al., 2023) . Parametric values are acquired by employing software simulation techniques. The determination of the remaining values is accomplished through the utilisation of algorithms and simulation software. Furthermore, the issue of carbon emissions originating from transportation is often overlooked. The evaluation criteria are as follows.

- **The technical criteria**

The technical criteria encompass a set of specific requirements or standards that are used to evaluate the performance, functionality, and efficiency hybrid energy system.

- ✓ The capacity factor (CF): The CF is defined as the ratio of annual energy production to the theoretical maximum energy production.
- ✓ The concept of the Renewable Energy Fraction (REF): The Renewable Energy Fraction (REF) can be mathematically defined as the ratio obtained by dividing the energy generated from renewable sources by the total energy generated.
- ✓ Efficient energy production: Efficient energy production strategies should prioritise minimising the operational duration of diesel generators while promoting the utilisation of renewable energy sources. Additionally, it is beneficial to place the diesel generator as the final charging option following the battery in the charging profile.

- **The economic criteria**

The economic criteria refer to the set of standards or measures used to evaluate or assess the economic aspects of a particular situation, system,

- ✓ The Net Present Cost (NPC): The NPC is defined as the difference between the present value of all costs and the present value of all revenues. The objective of this assessment is to appraise the fiscal sustainability of a project, taking into account all expenditures and revenues over its entire duration.
- ✓ The Payback Period (PBP): The PBP pertains to the length of time required to recover the initial investment costs of the system under consideration, relative to the reference system. The metric presented herein offers an approximation of the time period necessary for the initial investment to be recovered through the cost savings generated by the project.
- ✓ The concept of Return on Investment (RoI) : The RoI involves the computation of the ratio between the annual average discrepancy in nominal cash flows and the disparity in capital costs over the course of a project. The objective of this assessment is to appraise the fiscal performance of the project by juxtaposing the advantages obtained from it with the initial expenditures incurred.
- ✓ The concept of levelized cost of electricity (LCOE): the LCOE pertains to the average cost per unit of electricity generated by an energy system. This metric facilitates the evaluation of electricity generation costs across different energy sources and technologies.

- **The environmental criteria:**

The environmental criteria refer to the specific factors or standards used to assess the impact of human activities on the natural environment. These criteria are

In order to assess the environmental impacts of various configurations of hybrid energy systems, it is crucial to have a comprehensive understanding of the emissions of pollutants associated with these systems, including carbon monoxide (CO), sulphur dioxide (SO_2), unburned hydrocarbons (UHC), and particulate matter (PM).

3. Evaluation of Standalone Pwpsi Systems

According to the authors (Bain, D et al., 2020), The PWPIS can have positive economic and social effects, especially in areas with lower Total Dynamic Head (TDH) values. This is because the cost of maintaining irrigated fields is directly influenced by TDH, a lower TDH leads to lower costs.

Solar pumps exhibit higher initial costs in comparison to diesel pumps, specifically in terms of retail technology prices. However, they offer the advantage of reduced operational time and enhanced reliability. The initial investment required can differ across countries due to various factors such as differences in capacity value, distributed generation cost, and environmental regulatory compliance. Furthermore, it has been founded that the economic viability of PWPIS is contingent upon the availability of sunlight hours (Bain, D et al., 2020).

According to Hadidi (Hadidi et. , 2018), when designing a solar irrigation pumping system, it is important to use climatic data from the month with the highest irrigation demand, determined by the maximum evapotranspiration rate. The selection of a pump based on flow rate and TDH, as well as the choice of an inverter based on voltage and power requirements, are crucial considerations for determining the peak power output and number of modules needed for a PV system. Factors such as orientation characteristics and environmental conditions also influence the design of photovoltaic water pumping irrigation systems (PWPIS). Regular exposure to solar radiation

The technical and economic feasibility of PWPIS for rice, brinjal, tomato, and wheat in Bangladesh was investigated by Hossain (Hossain et al., 2015). The performance of the pumps was assessed based on various parameters, including solar radiation, voltage, current, flow rate, and TDH .The research employed both drip and furrow irrigation techniques. The efficacy of these techniques was observed to be favorable on eggplant, tomatoes, and wheat; however, their effectiveness was not observed in the case of rice. With the exception of rice, all crops necessitated an area of 0.5 hectares of land. The pump was powered by a solar panel with a wattage range of 1050 to 1440 Wp. The rice case study revealed a lifetime profit to cost ratio of 0.31. The pump is priced at 5700 $ and has a projected lifespan of 20 years. It is capable of discharging 100 l/min. The implementation of drip irrigation techniques for tomato and brinjal cultivation resulted in a 50% reduction in water consumption.

Deveci (Deveci et al., 2015) have investigated and developed a PWPIS for a 1000 m2 project in Turkey with more than 100 trees. From June until October, the area was irrigated twice daily by an automatic timer. With the MPPT, they have been able to charge a battery buffer (14 Ah, 12 VDC) all day, greatly enhancing the efficiency of the photovoltaic conversion process. The batteries provided the energy for the pump, guaranteeing a steady supply of power and maximizing its efficiency.

Setiawan (Setiawan et al., 2014) conducted a study on a PWPIS in a local community in Indonesia to fulfill their water supply needs. The system comprised of 32 solar panels and 2 pumps. The TDH is 218.34 m, enabling the horizontal distribution of water to a distance of up to 1,400 m. Research findings have demonstrated that the PWPIS is a dependable and efficient alternative for providing water to the village that was previously dependent on rainwater.

According to Maurya (Maurya et al., 2015), it has been asserted that the PWPIS exhibits a low level of maintenance, possesses a lengthy lifespan, and can be easily installed. Furthermore, the synchronization of peak water demand with peak solar radiation is attributed to the fact that solar-powered systems are utilized for their operation.

The feasibility of PWPIS in Africa was investigated by Wazed (Wazed et al., 2018) . To optimize the cost and design of PWPIS, it is crucial to initially ensure that the water requirements of each crop are met during peak evapotranspiration periods (daytime) as well as during night-time. This can be achieved through the utilization of either batteries for energy storage or a raised basin for water storage. The implementation of a battery system can lead to cost reductions in certain scenarios, while in other instances, it may lead to increase the cost. it is important to note that the initial capital needed to install PV systems is higher, particularly for small-scale farmers.

Burney conducted a study on the PWPIS in the Sudano-Sahel region of West Africa (Burney et al., 2010). The implementation of the PWPIS has been shown to enhance various aspects of agricultural practices, including plot production, productivity, crop quality, and yields. Additionally, the PWPIS has demonstrated its potential to positively impact social conditions by contributing to increased household incomes. These improvements are most evident in periods of drought. PWPIS enables the efficient management of irrigation water by delivering the appropriate amount at the optimal timing, resulting in conservation of both water and energy resources.

Martins conducted a study in which they determined the appropriate size of the cistern for the implementation of the PWPIS (Martins et al., 2015). According to the findings, it has been suggested that the system has the potential to conserve approximately 120.15 kWh/month of energy and 20 m3/month of well water during the four months of low precipitation.

Zegeye developed a cost-effective PWPIS specifically designed for small-scale irrigation purposes in Ethiopia (Zegeye et al., 2014). The optimal tilt angle of photovoltaic panels coincides with the point at which the maximum electrical power output is achieved, which occurs when the evapotranspiration of the plant is at its peak and matches the irrigation demand. Therefore, the optimal power capacity was chosen to satisfy all irrigation schedules while simultaneously minimizing the cost of the PWPIS. The researchers reached the conclusion that the implementation of efficient water distribution policies in the context of irrigation has the potential to optimize a PWPIS.

In their study, Yu , examined the efficacy of PWPIS in preserving grassland areas within arid regions of the country (Yu et al., 2011). The researchers conducted an investigation into the feasibility of PWPIS, taking into account various factors including precipitation and groundwater. This corresponds to approximately 22.3% of the total area designated for pastureland. Additionally, it has been confirmed that an annual precipitation range of 300-400 mm characterizes the optimal locations for PWPIS installations.

According to study conducted by Compana , focusing on the optimal grazing sites for PWPIS in China (Campana et al., 2017). This study employs a spatial optimization model that is centered around cost reduction in order to optimize the supply distribution chain for livestock. The results suggest that the implementation of PWPIS has the potential to enhance productivity, yield potential, water requirements, and well depth of forage. Additionally, the authors express their interest in investigating various environmental and economic parameters. Due to the ability of water storage to mitigate immediate fluctuations, the consideration of daily, monthly, or annual averages suffices for the analysis of PWPIS. The findings suggest that the utilization of maximum performance ratios (PR) yields greater accuracy in the development and evaluation of PWPIS, compared to the use of average PR (Odeh, I., et al., 2006).

6 Evaluation of PWPSI Systems Versus Diesel Standalone Systems

Many studies have demonstrated that diesel generators exhibit a high level of efficacy in supplying power to irrigation pumps, owing to their capacity to deliver consistent and dependable energy. This enables agricultural practitioners to ensure a reliable water provision for their cultivated plants, a critical factor in optimizing agricultural productivity.

The operational costs associated with diesel power units can potentially be elevated because of increased expenditures on fuel and maintenance.

The researchers (Qoaider et al., 2010) conducted a feasibility study on the PWPIS in the southern region of Egypt. The researchers have reached the conclusion that PWPIS demonstrates superior efficiency and substantially less maintenance requirements compared to a diesel pump, Furthermore, the adoption of this system will lead to a reduction in the carbon footprint.

According to the study conducted by (Meah et al., 2008), it has been demonstrated that a PWPIS is the most optimal choice for irrigation purposes. In addition to its capacity for reducing carbon dioxide emissions, this approach also presents the potential to mitigate costs associated with grid expansion. Moreover, it exhibits greater cost-effectiveness compared to diesel fuel. The payback period is determined to be 9 years. The authors' conclusion indicates that the system offers a viable option for rural areas, thus representing a potentially beneficial investment prospect.

The study conducted by Lorenzo (Lorenzo et al., 2018). Conducted a comprehensive economic evaluation in the Member States of the ECOWAS regarding PWPIS. Based on the available economic indicators, it can be observed that photovoltaic irrigation systems have outperformed both diesel-powered and grid-powered systems. According to the authors, it is asserted that the PWPIS demonstrates economic viability.

Santra carried out an economic analysis in India on PWPIS (Santra et al., 2019). The study found that the PWPIS is more economic and effective and the advantages of PWPIS are various over other diesel generator pumping systems. They state that The cost of PWPIS is cheaper than the diesel pump, and the operation costs are lower. And, unlike a diesel pump, a solar pump will not need to be serviced more than once, and it is more efficient and economical than the diesel pump.

The utilisation of solar irrigation pumps in rice fields of Bangladesh has the potential to conserve a significant amount of electricity, estimated at 760 MW, as well as approximately 8 billion litres of diesel annually (Feldman, David, et al., 2012) .

According to a study conducted by KPMG (KPMG , 2014) , the replacement of one million PWPIS with conventional pumps results in an annual cost savings of $300 million.

When comparing the costs of diesel systems pumping for irrigation purposes, Authors (Shinde et al., 2015)found that the cost of PWPIS over 10 years is 64% of the cost of the diesel pump. With a cost reduction of roughly 3 Kwp for drinking water in villages and rural regions and about 1 Kwp for irrigation pumping, solar pumps are often less expensive than diesel pumps. PWPIS is a low-cost, low-maintenance substitute for irrigation pump assemblies driven by electricity or fuel.

Shouman investigated Egyptian irrigation water pumps who looked at solar and diesel models (Shouman et al., 2016). Researchers used HOMER to modelize PWPIS design and economic analysis, using the best possible combinations and designs that Homer had recommended. In terms of energy cost and net present value, PV energy outperformed diesel. According to the study's findings, diesel pumps have cheap initial cost of capital but significant operational and maintenance costs. With solar, the initial costs are higher, but they decrease significantly over time. In contrast, solar panels create significantly less noise and air pollution than diesel pumps. Although a solar system is more expensive than a conventional one, it has a much longer lifespan.

Solar panels offer numerous advantages. In addition to producing electricity, they also have the capability of preserving water. Additionally, they contribute to the reduction of carbon emissions. The initial cost of PV system is approximately tripled higher in comparison to that of a diesel pump.

7 Evaluation of Hybrid Pv/Wd/Dg System Pumping for Irrigation

The integration of a hybrid PV/WD/DG system has the potential to serve as a highly viable solution for irrigation purposes. The study conducted by Hammad (Hammad et al., 1995) examined the economic aspects of water pumping systems powered by diesel, photovoltaic, and wind energy sources. The cost of photovoltaic and wind pumping systems exhibited a lower cost in comparison to diesel generation, whereas the cost of electrical wind pumping systems demonstrated a higher cost. PV is comparatively more economically efficient than alternative methods of power generation when operating at lower capacities.

Elkadeem conducted a study in Dongola, Sudan to assess the feasibility of implementing a hybrid irrigation system (Elkadeem et al., 2019) . The hybrid PV/WD/DG/BAT system exhibited superior performance in meeting the increasing energy demands. Based on the findings of the study, it was determined that the cost of the system exhibits a high degree of sensitivity to variations in wind speed and solar radiation intensity.

In their study, Abnavi (Abnavi et al., 2019) performed a techno-economic analysis on hybrid power systems consisting of off-grid photovoltaic, wind, diesel generator , and battery components. The focus of their investigation was a rural region located in the southern part of Iran. The findings indicate that the PV/WD/DG/BAT system demonstrates the highest level of economic viability, with a 61.4% share of RE .The proposed system demonstrates enhanced fuel efficiency and holds promise for mitigating CO_2 emissions.

The technology was initially assessed by the authors (Fadlallah et al. 2020). A study was conducted to assess the viability of implementing a hybrid PV/WD/DG/BAT for irrigation purposes in Shalateen, a city situated in the contested area between Egypt and Sudan. The study demonstrated that the implementation of this technology holds promise in substantially decreasing the reliance on diesel fuel within the agricultural. Given the appropriate policy framework and adequate support, there is potential for the project to be further developed and successfully brought to market.

Baseer conducted a study in Jubail Industrial City, Saudi Arabia, to analyse the techno-economic aspects of PV/WD/DG/BAT systems utilising lead-acid batteries (Baseer et al., 2019). The energy costs associated with photovoltaic, wind, diesel, and battery systems exhibit a decrease when there is an increase in demand. Conversely, these costs experience an increase from \$0.183 to \$0.24 per kilowatt-hour (kWh) when the demand is reduced from 11,160 to 3,288 kWh per day.

8 Environmental Impacts of Hybrid Energy System

According to Kaya (Kaya et al., 2016), the utilisation of RE for water pumping purposes is asserted to result in a reduction of GHG emissions. According ADB (ADB, 2018) it has been observed that photovoltaic systems with a peak capacity of 15.4 kW have the potential to mitigate approximately 1.2 tonnes of CO_2 equivalent emissions over the course of a 602.3-hour irrigation campaign in Spain.

The authors (Todde et al., 2018) investigated the hybrid solar pumping systems. A study was conducted in Portugal and Morocco. According to the findings, the Moroccan system generated a total of 236 tonnes of CO_2, while the Portuguese system produced 285 tonnes. The utilisation of a diesel generator for nocturnal irrigation and during critical periods, prompted by adverse climatic conditions, cropping patterns, and other factors, leads to elevated levels of CO2 emissions. In the study conducted by Garcia (Fernandez Garcia et al., 2014) , an assessment was made on the environmental and economic implications of utilising solar energy for agricultural irrigation, both in grid-connected and off-grid scenarios, in comparison to conventional energy sources. The findings of the study indicated a reduction in the environmental impact over a period of five to 30 years.

According to Raza , the implementation of approximately 5 million photovoltaic pumps in India is projected to result in a reduction of approximately 23.3 billion kilowatt-hours of grid energy consumption annually, which is equivalent to approximately 10.3 billion litres of fuel. The reduction of CO_2 emissions amounts to 26 million tonnes (Raza, F et al., 2022).

4. Comparative Analysis of Energy Cost Among Countries with Similar Meteorological Conditions

The analysis of the table 3, suggests that Asian countries have a diverse mix of energy sources for electricity generation. While there is a growing use of renewable energies like photovoltaic and wind, there is still a reliance on fossil fuels such as diesel. The energy performance indices indicate varying levels of efficiency in the use of these energy sources. Overall, there is a need to improve energy efficiency and promote more sustainable solutions for electricity generation in these countries. The cost of electricity per kWh varies among these countries with hybrid energy systems; India has the lowest cost at 0.42 $.

Table 3: hybrid energy systems for some Asian countries

Country	Hybrid Energy System	Cost of Electricity $/KWh	Net Present Cost	Reference
INDIA	Hydro/ PV/WD/DG /BAT	0,42	674000	(Sohail et al., 2022)
Indonesia	PV/WD/DG /BAT	0,751	30921	(Kolhe et al.,2015)
Siri Lanka	PV/WD/DG /BAT	0,34	553000	(Halabi et al.,20147)
SUDAN	PV/WD/DG /BAT	0,387	2146000	(Elkadeem et al., 2019)
Malasya	PV/WD/ BAT	0,302	9345510	(Li, Chong, et al, 2020)
CHINA	PV/WD/ BAT	0,471	7735646	(Sohail, Madni, et al., 2022)

The table 4 illustrates the variation in electricity costs across different countries. The selection of HES is contingent upon various factors, including the availability of resources, economic considerations, and the pursuit of sustainable development objectives.

Table 4: hybrid energy systems for some Middle East countries

Country	Hybrid System	Cost of Electricity $/KWh	Net Present Cost $	Reference
Turkey	PV/WD/Hydrogen	0.83	11960698	(Kalinci, Yildiz, et al, 2014)
Saudi Arabia	PV/DG/ BAT	0.37	6278274662	(Ramli et al., 2015)
Egypt	PV/FC	0.058	50321	(Rezk et al., 2016)
Yemen	PV	0.334	62450	(Hadwan et al.,2015)
Turkey	PV/WD/ BAT	0.146	4430000	(Gökçek et al., 2018)
Iran	PV/ BAT	0.546	8173	(Haratian et al.,2018)
Iraq	PV/ Hydrogen / DG/ BAT	0.054	113,201	(Aziz et al., 2019)

The table 5 compares the cost of electricity and discusses the commonly used hybrid energy systems. Ethiopia has the highest cost of electricity at $0.383/kWh, followed by Nigeria at $0.348/kWh. Ghana has a cost of $0.281/kWh, while Algeria and Benin have lower costs at $0.26/kWh and $0.207/kWh respectively. In all the countries listed, the most commonly used hybrid energy system consists of photovoltaic panels, diesel generators, and storage batteries. The cost of electricity can be influenced by factors such as the availability and cost of fossil fuels, investment in energy infrastructure, regulation, maintenance and system management costs, and incentives for RE development. The cost of electricity can impact access to energy, with high costs limiting access for low-income populations and remote rural areas, while lower costs can promote greater access and contribute to economic.

Table 4: hybrid energy systems for some African countries

Country	Hybrid System	Cost of Electricity $/KWh	Net Present Cost	Reference
ETHIOPIA	PV/DG/ BAT	0,383	239756	(Getachew et al., 2009)
NIGERIA	PV/DG/ BAT	0,348	392000	(Muyiwa S. Adaramola et al. 2012)
GHANA	PV/DG/ BAT	0,281	3905600	(Adaramola et al. 2014)
ALGERIA	PV/DG/ BAT	0.26	617489	(Rezzouk et al.,2015)
BENIN	PV/DG/ BAT	0,207	555492	(Odou et al., 2019)

The analysis of the tables shows that Asia, the Middle East, and Africa have varying levels of reliance on different energy sources for electricity generation. The cost of electricity per kWh also varies among these countries, with some countries having higher costs than others. Factors such as availability of resources, economic considerations, and pursuit of sustainable development objectives influence the selection of hybrid energy systems.

5. Results and Discussions

Various configurations of the hybrid energy system, specifically the combination of PV and DG, are simulated using HOMER Pro software. Performance parameters are derived from the software output through estimation.

The utilisation of PV technology as a primary electricity generation method necessitates the implementation of expansive solar PV systems, along with the establishment of a comprehensive network of high-voltage direct current power lines on a global scale. A limitation associated with PV systems as a primary energy source is their inherent inconsistency in power output. Moreover, PV systems lack recyclability. The utilisation of PV/BAT configurations is anticipated to yield distinctive advantages, namely high carbon avoidance and minimal carbon emission.

The HES that offers the greatest benefits is one that can efficiently generate sufficient electrical power to meet the required load demand while minimising costs. The cost of a HES is contingent upon various factors, one of which is the accessibility of water. Solar power is influenced by various factors such as weather conditions, time of day, and cloud cover. HES possess not only ecological advantages but also demonstrate technical and economic feasibility. The levelized cost of electricity associated with their operations is comparatively lower than the expenses incurred in procuring energy from the national grid.

The technical superiority of hybrid PV/DG/BAT over standalone diesel systems in terms of RE fraction and energy storage autonomy has been acknowledged. The PV/DG/BAT system exhibits superior performance compared to alternative configurations, as it offers the most cost-effective electricity generation.

The hybrid PV/WD/DG system possesses a multitude of advantages. The COE associated with this system is relatively low in comparison to alternative systems, and it exhibits a lower COE when compared to a hybrid PV/DG irrigation system. Additionally, it possesses an ample capacity with no shortage. Moreover, it is highly suitable for the purpose of irrigation.

The cost of a hybrid PV/WD/DG generator irrigation system exhibited a relatively higher cost, it is observed that the energy cost associated with this configuration is notably greater compared to hybrid PV/DG/BAT, and hybrid PV/DG.

6. Critical Analysis and Recommendation

With growing international concerns about the escalation of greenhouse gas emissions, the transition to the increasing use of renewable energy is becoming imperative in order to comply with strict emission regulations. Nevertheless, it is crucial to emphasize that future energy production will be heavily influenced by the use of renewable energy sources, mainly due to the rapid depletion of conventional energy. Moreover, several researchers have minimized the limits of hybrid energy systems, but it remains unable to completely eradicate dependence on traditional energy sources. Therefore, on the basis of a comprehensive review of hybrid energy systems research, it is advisable to:

- ✓ It is imperative to focus on reducing the costs associated with high-efficiency renewable energy (HES) to adequately meet the demands of the commercial market.
- ✓ The implementation of these systems does not receive state subsidies, unlike the subsidized diesel,

which encourages its use. on this, a policy should be put in place, to subsidize and encourages the establishment of these hybrid systems in particular for agricultural, or household use

- ✓ In order to improve the operational efficiency of HES, it is imperative to undertake optimization measures for these systems.
- ✓ Initiatives to improve the efficiency of hybrid energy systems through increased use of renewable energy sources are urgently needed. Such efforts would be used to reduce dependence on fossil fuels and reduce operating hours.
- ✓ The introduction of a hybrid system poses significant obstacles for small and medium-sized farmers, mainly due to the significant advance costs associated with the installation of a Hybrid energy system, unlike the use of diesel generators. The latter option is preferred by small farmers due to its relatively low cost and the absence of civil engineering requirements for its installation, as well as it is portable and not embedded in a civil construction structure.
- ✓ The availability of renewable energy sources may be limited in situations where there is a lack of sunlight or wind. Most large-scale agricultural operations rely on the power grid to facilitate their pumping activities.
- ✓ Rationalize legal transactions in countries that impose restrictions on photovoltaic and wind systems, while abolishing import duties on these products, especially those intended for agricultural purposes.
- ✓ The hybrid energy system should involve the use of sophisticated technologies, including energy storage systems, smart grids and artificial intelligence, to respond effectively to the intermittent nature of renewable energy sources and ensure a consistent and reliable supply of electrical energy.
- ✓ Raising public awareness: Informing and raising public awareness of the benefits of hybrid energy systems and the need to make the transition to a more sustainable energy model.

7. Conclusion

Hybrid Energy System that efficiently generate sufficient power while minimizing costs, such as a hybrid photovoltaic/wind/diesel generator system, offer numerous advantages including lower cost of electricity, ample capacity, and suitability for irrigation.

a hybrid photovoltaic/wind/diesel generator system offer numerous advantages over using a single energy source. They provide a feasible alternative for large-scale agricultural operations, reduce diesel fuel costs and CO_2 emissions, increase daily output and reliability, and are cheaper than typical PV systems. Additionally, well-managed hybrid PV/Diesel systems can boost irrigation power and save water. The PV/BAT systems can also reduce irrigation fuel costs, and solar pumps without batteries are suitable for low-volume daylight irrigation systems. Overall, HES offer a more efficient and environmentally friendly solution

In conclusion, using a HES that combines RE sources technology with conventional energy resources can improve power output reliability and efficiency compared to relying solely on one type of technology

Abbreviation:

RE: RE

HES: HYBRID ENERGY SYSTEM

WPS: WATER PUMPING SYSTEM

PV: PHOTOVOLTAIC

DG: DIESEL GENERATOR

COE: COST OF ENERGY (COE),

NPC NET PRESENT COST (NPC)

NPV: THE NET PRESENT VALUE

BCR: THE BENEFIT COST RATIO

IRR: THE INTERNAL RATE OF RETURN

PBP: THE PAYBACK PERIOD

LCC: LIFE CYCLE COST

PVPS: PHOTOVOLTAIC PUMPS

PWPIS PHOTOVOLTAIC WATER PUMPING FOR IRRIGATION SYSTEM

ECOWAS: ECONOMIC COMMUNITY OF WESTERN AFRICAN STATES

HP: HORSEPOWER

WP: WATT PEAK

MMPT: THE MAXIMUM POWER POINT TRACKER

PR: PERFORMANCE RATIOS

TDH: TOTAL DYNAMIC HEAD

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