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Design and Performance of Photovoltaic Water Pumping Systems: Comprehensive Review towards a Renewable Strategy for Mozambique

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Abstract

The use of solar photovoltaic (PV) technology for water pumping systems (WPS) has been one of the most popular forms of solar energy application in recent decades in remote and desert areas, as well as in some urban areas. In this article, an advanced literature review on the design and performance of solar technology for water pumping is presented, exploring also the best perspective of transition for the developing countries energy needs. Additionally, this paper intends to analyze the Mozambique's perspective on renewable energy technologies setting the Mozambican scenario regarding photovoltaic water pumping systems (PVWPS) technology with the aim to identifying the main knowledge of PVWPS design and research gap. The results show that the most commonly used configuration of PVWPS technology is direct coupling systems without battery storage. These systems are simple and reliable, mainly used in small-scale pumping for small irrigations and domestic use. The mainly variables that influence the performance of PVWPS are: total dynamic head, quantity of fluid extracted, variation of solar radiation level, PV and motor pump technology. Yet, the efficiency of the PV and overall system does not exceed 10% and 5%, respectively. Looking at the designing, mathematical models, software-assisted is being predominant. Yet, as research gap, it is possible to understand from different authors that the dynamic nature of the end-use of PVWPS is not explored on methodology design of PVWPS, and the techno-economic optimum system configuration is not always the one that gives the highest annual system efficiency. For the Mozambican's context, PVWPS for irrigation have been expanding slowly but have gained expression since 2013. In turn, static models based on software of pump manufacturers for PVWPS design are the most widely used in Mozambique. In Mozambique, PVWPS match the perspective of different researchers regarding the availability of solar resource, boreholes and amount of water required for irrigation. The adoption of PVWPS is a means of increasing the sustainability of the rural communities.

Keywords

Photovoltaic Water Pumping Systems, Energy resource

1. Introduction

In a world struggling with climate change and global warming, renewable sources of electricity generation are a very important response to climate issues. In addition, they are also a key tool for developing countries, where a significant part of the population does not have access to the conventional electricity network [1]. In Mozambican's case, more than 70% of the population does not have access to the conventional electricity network [2].

Economists cited by Vann Koppen, Namara and Safilios-Rothschild [3] argue that agriculture is the engine of all economic growth, as a consequence, reduction of poverty throughout history. However, the irrigation process in modern agriculture is still based on the exploitation of fossil fuels [4]. Since agriculture is a vital activity for the maintenance of humanity, the adoption of self-sustaining agricultural production practices using renewable and endogenous energy resources becomes an essential element for the development of communities, either economically and socially [5].

New conversion methods are explored in order to minimize dependence on fossil fuels [6]. Thus, the direct relationship between the availability of renewable resources and water demand for irrigation urges researchers and local stakeholders to analyze the feasibility of WPS. The use of solar photovoltaic (PV) energy technology for water pumping systems (WPS) for irrigation has been one of the most popular forms of solar energy application, in recent decades, in remote and desert areas, as well as in some urban areas [7]. However, the evaluating of availability of solar and water resources before installing any PV system for irrigation is necessary in order to guarantee optimal solutions.

Fedrizzi [8] mentions different PV systems for water pumping developed around the world, and although some PV systems projects need some care and improvement, the number of systems already installed shows that the technology is technically mature (see Section 2.1). Andrade *et al.* [9] deepen the historical context and refer that these types of systems have been used in massive scale since 1977 in many countries of the world, mainly in developing countries of Africa, Asia and South America.

In Mozambican's context, PVWPS for irrigation have been expanding slowly but have gained expression since 2013 with significant development. The estimated capacity of PV solar energy installed is 2.250 kWp [10].

The main barriers to the implementation of PVWPS are related to technical aspects, and the sizing models of PVWPS for irrigation are based on estimates of daily water consumption and static models, and in economic aspects, the capital cost of PVWPS is still higher than the traditional system driven by diesel engine, although the operating costs are much lower. As challenges, it is necessary to adopt dynamic models design of PVWPS and policies that favor the massification of the technology and that in a way the systems are financially viable, besides technical measures that collaborate for the best technical use of these systems.

In this article, a comprehensive review of different published scientific papers on the design and performance of solar photovoltaic energy for water pumping systems is made, exploring the best perspective of transition for the developing countries energy needs. The main objective is identifying the main knowledge of PVWPS sizing, research gap and consequent driver for setting the Mozambican scenario regarding PVWPS technology. The article is organized as follows: Section 1 is the research introduction; Section 2 presents the principle of PVWPS, historical background and technology advancement; while in Section 3, an overview of performance analysis research of PVWPS is given; Section 4 explores the design methods of PV water pumping systems; and Section 5 reports the Mozambique's Perspective on Renewable Energy Technologies; while the final conclusions are given in Section 6.

2. Principle of Photovoltaic Water Pumping Technology—Literature Survey

WPS can be classified according to the energy source that drives the system. Therefore, five types of pumping systems are considered:

1) Photovoltaic pumping systems;
2) Wind pumping systems;
3) Pumping systems connected to conventional electricity grid;
4) Pumping systems driven by internal combustion engines;
5) Manual pumping systems.

In some cases, because of the intermittent character of some sources or the complexity of each system, hybrid sources can be adopted (a combination of two or more sources).

Solar PV technology applied to WPS is based on conversion of solar energy into electrical energy by solar panels to power a water pump. PV panels are connected to a DC or AC motor that converts the electrical energy received from the panels into mechanical energy and is subsequently converted into hydraulic energy [11]. As **Figure 1** describes, the PVWPS generally consist of:

- An area of PV modules mounted on a structure with fixed arrangement or manual/automatic tracking;
- Pumping system (motor-pump), which can be surface mounted, submersible or floating;

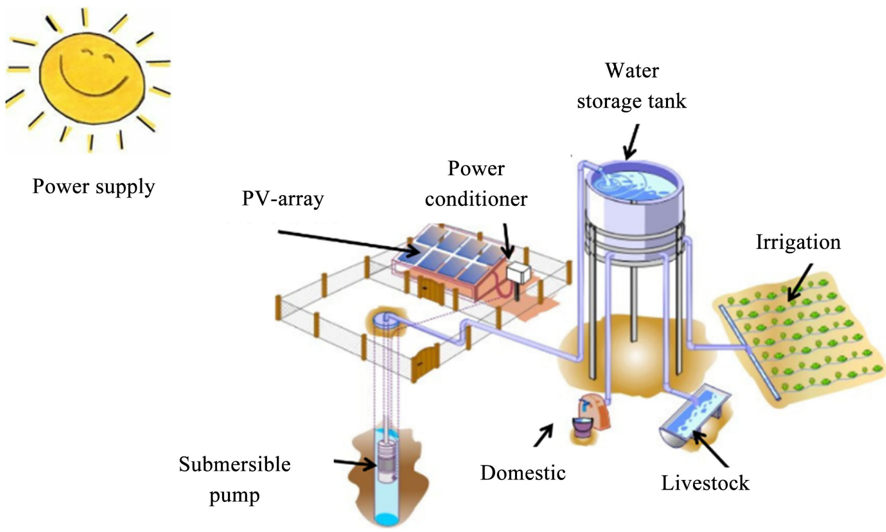

Figure 1. Photovoltaic pumping system[1].

- Power conditioning system, which generally consists of converter, inverter, controller, etc.; and
- Storage system which may be optional.

2.1. Historical Background and Technological Advancement

Solar PV technology for water pumping has been explored over 5 centuries ago. The conversion of solar energy into mechanical or electrical energy for water pumping is used since the 15th century, although the first reported PVWPS was installed in the Soviet Union only in 1964. The maximum power of the PV system installed at that time, to activate the water pump, was 373 W was developed in France [12].

Initially, solar pumping systems with direct coupling with the water pumps were introduced; however, they presented limitations in the performance of the system, by not operating at the maximum power point of the PV generator. Despite this disadvantage, this type of system is considered to be simple and reliable [13], being also efficient for use in small irrigations [14]. In the last decade, these systems have been improving their performance due to the addition of the maximum power point tracker (MPPT) and control systems [15].

The first generation of PVWPS was characterized by the use of centrifugal pumps driven by direct current (DC) motors and variable frequency alternating current (AC) motors, whose hydraulic efficiency ranges from 25% to 35%. The second generation of PVWPS considered positive displacement pumps, characterized by low photovoltaic power (100 Wp to 400 Wp) input, low capital cost and hydraulic efficiencies up to 70% [16]. Currently, the PVWPS of the first and second generation are equipped with electronic control systems, pump speed

[1]Source: Adapted from Arquivo gráfico do Laboratório de Sistemas FVs—IEE/USP (2011).

and maximum power trackers, to increase the overall system performance [17], whose hydraulic efficiencies reach values of 92% [18].

Some Projects of Photovoltaic Water Pumping Systems Implemented around the World

PVWPS for domestic end-users are frequent, however for agricultural production systems there is few systematized information made available. According to EPIA [19], in 2010 there were about 150,000 PV pumping systems installed around the world. Each system had an average PV power of 800 Wp, an average manometric height of 60 m and a flow of 40 m^3/day. In the specific case of Brazil up to 2002, 3.291 PVWPS have been installed, 32 of which were applied directly to agricultural production [20].

Having been identified the potential of PVWPS, numerous initiatives and programs were taken all over the world as a way to spark development in rural areas.

Between 1979 and 1981, a partnership between the United Nations Development Program, World Bank and *Intermediate Technology Development Group*, carried out a project to evaluate small irrigation PV systems (100 Wp to 300 Wp) used in small agricultural units in Mali, Philippines and Sudan [21]. Furthermore, between 1998 and 2002, the German Cooperation Agency, started the program *Photovoltaic Pumping Irrigation Pilot Project*, where 90 PVWPS were installed in Brazil, Jordan, Indonesia, Argentina, Philippines and Zimbabwe, prefacing a power of 180 kWp [22]. Additionally, the north Africa was also the target of multiple PVWPS projects: the Solar Regional Program for solar water supply to eight countries in Saharan region, installed 1040 PVWPS with a total output of 1.3 MWp [23]; while 50 PVWPS have been implemented in Morocco with support of European Union, totaling 173 kWp, in order to supply drinking water to communities, where part of the water surplus is used for practice of subsistence agriculture [24].

Following several PVWPS installed, Narvarte *et al.* [25], proposed procurement specifications and testing procedures in order to assure technical quality of these systems. To this end, a quality assurance procedure has been designed and implemented taking into account the common procedures for awarding public funding programs together with the need for a strong commitment from users, which generally constitute an obstacle to the extension of quality assurance and systems sustainability. All these actions were not enough to make the systems self-sustaining, getting the best gain.

2.2. Solar Energy Opportunities in Mozambique

The solar market has been expanding slowly but has gained expression since 2009. There are projects and initiatives carried out by the private sector and international cooperation agencies and by the Government through National Energy Fund (FUNAE). It is estimated that the current installed capacity of solar energy in the country is 2.250 kWp. In addition to a number of small-scale projects, there are two projects in the country for solar power stations in the central and northern regions that come from partnerships between the foreign private sector and government. Furthermore, since 2013, Mozambique has a local solar panel production industry for the local market and at a later stage for the international market [111], with the aim of expanding the electricity grid in the country through alternative and clean sources.

Solar PV technology for water pumping is clean and promising, given the autonomy and abundance of the solar resource in Mozambique with global horizontal plane radiation varying between 1.785 and 2.206 kWh/m^2/year (see **Figure 2**), values that are comparable to the best regions of the world in this variable. Thus, the implementation of small autonomous systems of electric power generation using solar PV technology appears as part of the solution in centralized and decentralized uses to:

1) Increase the food production and productivity in small agricultural units,
2) Rise incomes of rural, peri-urban and urban households,
3) Create jobs and normal operation of multiple services,
4) Pump water for different purposes, and
5) Develop nightly literacy and education programs for young people and adults (especially women) in places without access to electricity.

Until then, PV solar technology in Mozambique is being used for lighting purposes, charging mobile phones (more in peri-urban and rural areas), pumping water for domestic, electrification of schools, health centers, police stations and district administrations for basic purposes.

2.3. Photovoltaic Water Pumping Systems Configuration and Design Components

Figure 3 presents the various types of configurations of PVWPS, either in DC and AC, where the blue boxes represent the types of PV generator configuration, followed by gray color representing the types of power conditioning systems, and finally, the yellow color represents the motor-pump assembly and the possible couplings. The thick blue lines from the PV generator indicate the most used PVWPS configurations.

From **Figure 3**, it can be observed that the most commonly used motor pumps are asynchronous AC motor with centrifugal pump, or in alternative an independent excitement DC motor with centrifugal pump, whose generator structure PV is fixed [28]. Tracking PVWPS are more efficient, however they seem to be very expensive compared to fixed systems [29]. The same comparison can be made under the options of power conditioner. DC motors, somehow fit easily into direct-coupled pumping PV systems, for their compatibility with the power generated by the PV generator [30], being mostly implemented for water pumping needs below 7457 W.

Generally, pumps can be classified according to the principle of operation, which can be divided in: dynamic pumps and positive displacement pumps.

Dynamic pumps operate by developing a high velocity and liquid pressure in a diffusion flow passage. Centrifugal pumps and axial flow pumps are dynamic pumps. Positive displacement pumps operate by forcing a fixed volume of fluid from the inlet pressure section of the pump to the discharge zone of the pump.

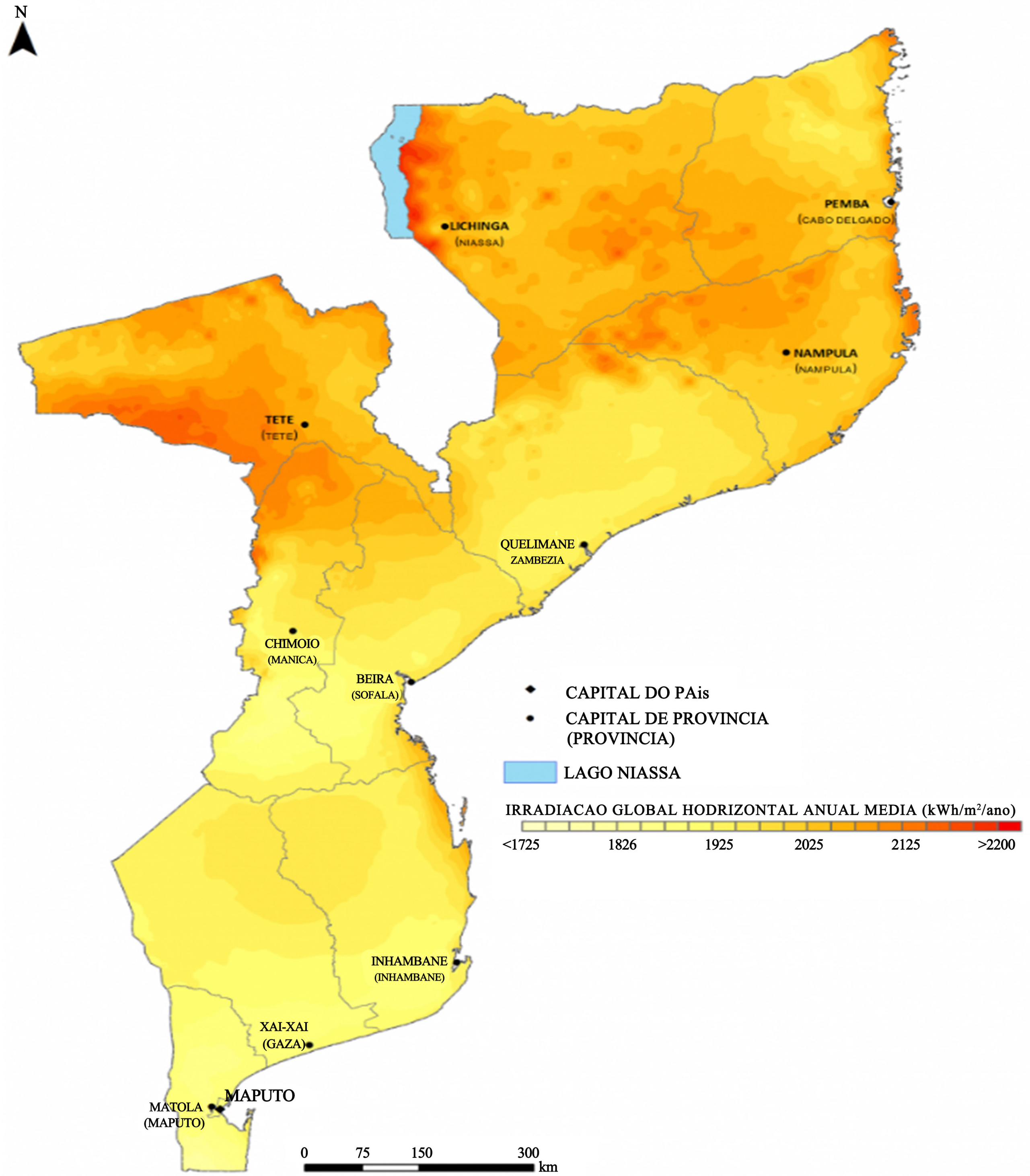

Figure 2. Map of distribution of solar energy in Mozambique [110].

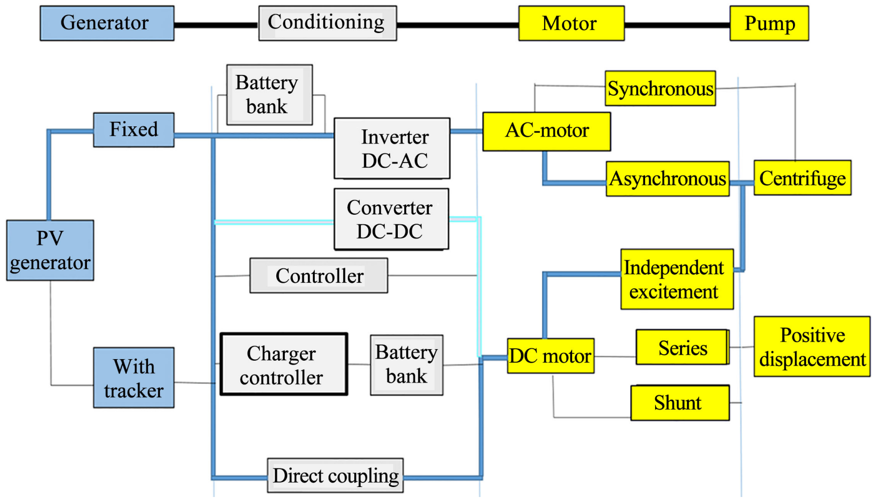

Figure 3. Types of PVWPS configurations: Adapted from [26] [27].

These pumps generally tend to be larger than dynamic pumps of equal capacity. Diaphragm positive displacement pumps (volumetric) are often used for low powers (up to 5 kWp), or even single or small stage centrifugal pumps, with DC type motors with and without brushes. In cases of higher power, multi-stage and helical positive displacement centrifugal pumps are used [31]. The solar pumps available in the market can pump water from 5 m to over 200 m with outputs up to 250 m^3/day, being used in boreholes of 15 to 50 m of depth [32] [33].

Most of the PVWPS have a water reservoir. The capacity of water reservoir (system autonomy) is determined by the type of supply (domestic, animal, and irrigation) and the financial constraints of the investor. In order to ensure that the water supply service is not impaired during periods of low or absent solar irradiance, the presence of a reservoir is of great importance, and require an analysis of the stochastic nature of the energy resource, flow and periods needs to meet the full demand [34]. However, the water source must recharge the reservoir faster than the water pumping rate, avoiding a reservoir drought as it could damage the pump.

2.4. Definition and Design of Photovoltaic Water Pumping Systems Parameters

As seen, the PVWPS have become attractive for livestock and agriculture applications in remote locations with limited access to conventional electricity [35]. In this order it is necessary to define the parameters of the system, even if it is by estimation [36]. Thus, the selection of a pump for PVWPS depends on the following variables that affect the performance of the system and overall system efficiency [37]:

Solar resource:

- Solar radiation availability,
- Ambient temperature at the location.

Water:

- Water to be pumped (m^3),
- Flow rate of water, which is influenced by weather conditions at the location, especially solar irradiance and air temperature variations,
- Size of water storage tank which depends on water to be pumped per day and daily water consumption.

Total Dynamic Head (TDH):

- Suction head (height from suction point till pump),
- Discharge head (height from pump to storage inlet), and
- Frictional losses.

PV system:

- PV array energy (kWh) and Power (kWp),
- Efficiency of PV technology used.

Pump:

- Pump power (kW),
- Pump efficiency (%).

The design of a PVWPS generally consists in determining the size of a system that will meet the needs of the user with minimum total investment costs, taking into account technical, economic and social issues, specific to each project. Although, the use of simulation programs allows solving problems of design and optimization PV systems, there are other identified methods such as: intuitive, numerical, analytical and intelligent techniques [38]. In case of autonomous systems, Hahn [39] advises the use of simple arithmetic method whenever the hypotheses are reasonable, based on relation between PV generators, energy accumulator and loads. However, as will be shown in Section 4, other models are also frequent and useful. The respective design procedures are presented in **Figure 4**.

Determination of the system parameters:

- *Solar Radiation Measurement*

Solar energy is the primary source of all energy sources. Solar radiation reaching the Earth's atmosphere can be decomposed in different ways for analysis purposes. For PV utilization, the most interesting is horizontal global irradiance, which quantifies the irradiance received by a flat horizontal surface [W/m^2]. It is composed of horizontal diffuse irradiance and direct normal irradiance. The solar radiation is usually measured with the help of a pyranometer that measures the global radiation, while direct radiation can be obtained with a pyrheliometer. The diffuse radiation can be determined by subtracting the measured direct radiation from the global radiation [40].

Studies show that two to three years of local measurement allow estimating the long-term average for global irradiance with an error margin of 5% [41]. Solar radiation data can also be obtained from databases available on the internet (NasaSSE, NREL, SolarGIS, ESRA, etc.) [42], although it is always preferable to have local measurement campaigns. Data resulting from measurements are reduced to mean values for various time scales (minute, hour, day, and month) and seasonal variabilities.

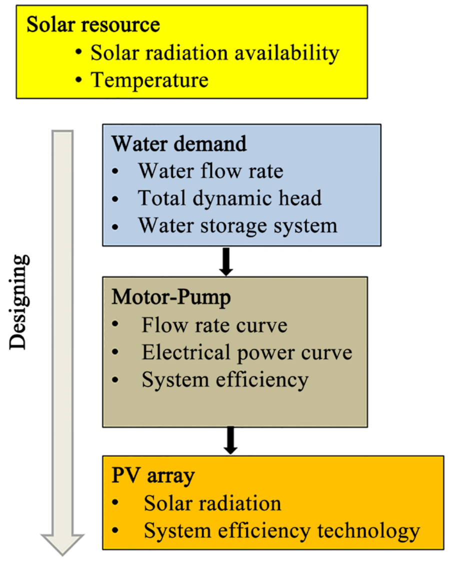

Figure 4. PVWPS design procedures.

- *Determination of Hydraulic power*

For determination of water demand, it is necessary to consider the final use of water and/or user requirements. In case of crop irrigation, local and crop specificities must be taken into account. The crop's water demand (net irrigation requirement) depends mainly on the climate, the stage of development, the irrigated area and the efficiency of irrigation.

Valer [43], while reporting the different types of irrigation shows that the irrigation efficiency of micro sprinkler varies from 75% to 90%, of drip from 85% to 90% and for perforated tubes from 65% to 80%.

For cases in which an exact value of water consumption is not available,

Table 1 provides results illustrating water consumption information by some activities.

Hydraulic power, P_H (W), required to supply a water flow rate (Q) at a certain TDH, considering the end use of the water and/or user requirements is given by Equation (1):

$$P_H = Q \cdot TDH \cdot \rho \cdot g \quad (1)$$

where:

- Q is water flow rate (m^3/h);
- TDH is the total dynamic head (m);
- ρ is the water density (1000 kg/m^3 at 0˚C and 1 bar);
- g is the acceleration due to gravity (9.81 m/s^2).

In order to calculate the total head, the pressure head and suction head must be considered. Where significant, the pressure drop in piping and connections shall be taken into account. Usually these losses are given by the pipe manufacturers and connections.

However, if the hydraulic power varies from day to day or month to month, etc., due to varying water demand, the PVWPS should be designed for the worst-case combination of solar radiation energy and water demand [46].

- *Determination of the electric power needs*

The electric power to the input of the motor-pump unit, P_{EL} [kW], is given by Equation (2):

$$P_{EL} = \frac{P_H}{\eta_{MP}} \tag{2}$$

where:

- η_{MP}: Efficiency of the motor pump unit;
- *Determination of the photovoltaic power needs*

A simplified method proposes a simple arithmetic formula that can be used to determine the approximate value of the rated power of the Photovoltaic panel according to Equation (3):

$$P_{PV} = \frac{P_{EL} \times G_{REF}}{G_{Glob} \times F_Q} \tag{3}$$

where:

- P_{PV} is the peak power of the PV array under Standard Test Conditions (STC: radiance = 1000 W/m^2, AM 1.5, cell temperature = 25˚C) [kWp],
- G_{GLOB} is the global solar radiance on a horizontal surface [kW/m^2],
- G_{REF} is the incident solar radiance at STC [1 kW/m^2],
- F_Q is the quality factor of the system.

In the theoretical limiting case, supply and demand values are equivalent and the quality factor is therefore equal to one ($F_Q = 1$). In the case of measured value, for example, $F_Q = 0.75$ means that 75% of the electric power, which is converted from the incident solar power, is used whereas 25% of the electric energy is lost between the solar cell and the system output or it is not used. This helps to make a decision reasonably on the system type. The quality factors are then given in Table 2.

To obtain the PV system efficiency is used Equation (4):

$$\eta_{PV} = \frac{P_{PV}}{G_{GLOB} \times A_{array}} \times 100 \tag{4}$$

where:

A_{array}: area of the PV array [m^2].

The efficiency of the pumping subsystem (η_{MP}) is defined as the ratio between the output hydraulic power required for lifting a volume of water and the input electric power of the subsystem. The typical efficiency of the motor-pump assemblies in PVWPS is 25%. Table 3 illustrates some values of some motor pump configurations.

The overall solar water pump system efficiency is obtained by Equation (5):

$$\eta_{\text{total}} = \eta_{PV} \times \eta_{MP} \tag{5}$$

3. Overview of Performance Analysis Research of Photovoltaic Water Pumping Systems

In this section the performance of PVWPS is overviewed along different studies.

Table 1. Estimated average consumption of water by end use, in liters [44] [45].

Human[2] consumption	Liter/person. day	Animal consumption	Liter/animal. day	Cultivation[3]	Liter/ha.day
Survival	5	Cattle (milk)	70	Vegetable garden for subsistence	25.000
Large urban centers	10 - 100	Cattle (Cutting)	40	Tomato	46.200
Small farms	40 - 70	Sheep/goat	5	Corn (maize)	50.000
-	-	Swine	15	Bean	48.000

Table 2. Quality factors of components and different PV systems [47].

Component/system	F_Q
PV module (crystalline)	0.85 … 0.95
PV array	0.80 … 0.90
PV system (Grid—connected)	0.60 … 0.75
PV system (Stand—alone)	0.10 … 0.40
Hybrid system (PV/Diesel)	0.40 … 0.60

Table 3. Efficiencies of motor pumps in PVWPS [48].

Type of motor pump	*Efficiency* (%)
Surface Centrifuge	15 - 25
Submersible	25 - 35
Positive displacement	35 - 45

Considering the performance and dimensioning parameters for PV systems for water pumping, Odeh *et al.* [49] carried out a study of a PVWPS with a power of 4.5 kWp, in Jordan, activating 3 phases Franklin induction motor coupled to a centrifugal pump and a 55 m^3 water storage tank. The main goal was to develop a model that can be used for techno-economic system optimization. The authors identified as performance influencing parameters: the variation of TDH, the amount of fluid extracted, frequency of distribution of irradiance and size of PV modules. For irradiance values ranging from 100 to 500 W/m^2, volumes of 1000 to 3000 l/h of pumped water were obtained at a fixed head of 24 m. Achieving, PV array, subsystem and system efficiencies respectively of 3.27%, 39.7% and 3.76%. The techno-economic optimum system configuration is not always the one that gives highest annual system efficiency, it is necessary to take into account the best combinations of slope angles for different seasons throughout the year in irrigation facilities.

[2]Adapted from: Comissión Europea DG XII, "Manual de energización rural mediante energia fotovoltaica", 1996.

[3]Adapted from: Organización de las Naciones Unidas para la Agricultura y la Alimentación—"Las necessidades de água de los cultivos"—Caderno Técnico n. 24, 1977.

De Andrade *et al.* [50] analyzed a PVWPS, with installed power of 15 modules of 75 Wp each, activating a centrifugal pump. The system in question pumped 7900 l/day at manometer height of 35 m and 12,000 l/day, at manometric height of 18m. For the same pump under the same operating conditions, the higher the manometer height, the smaller will be the volume of water pumped.

Hamza & Tiha [51] worked with three submersible pumps, installed at three different locations in Sudan; with solar radiation conditions between 2.9 and 6.5 kWh/m^2/day. For each of these pumps, solar radiation in the plane of PV array, ambient temperature, PV array voltage and current, water discharge and water delivery pressure were monitored using a datalogger. Pumped water varies from 21 to 38.6 m^3 and subsystem efficiency of 30% and 36%. Solar pumps were found suitable and reliable for supplying water for the Sudan.

Setiawan *et al.* [52] suggested two important aspects in designing solar water pumping system: 1) analyzing piping system to determine the type of pump used and 2) the power system planning to ensure the system operates properly. The PVWPS will start at level of solar radiation around 300 W/m^2 and is able to lift water to 1400 m. The system uses 32 solar PV panels to produce 3200 Wp maximum power and operates 2 submersible pumps. The flow rate of water produced is about 0.4 to 0.9 l/s.

Abdolzadeh & Ameri [53] used a positive displacement surface pump with permanent magnet motor, with power 255 Wp and modules of polycrystalline silicon to evaluate pumping profile as a function of solar irradiance. The authors were able to obtain a mean flow rate of 479 l/h between 8 and 16 h of the test day, for solar irradiance values ranging from 400 W/m^2 (8 h) to 1000 W/m^2 (11.30 h). The PV, subsystem and global efficiencies obtained at TDH of 16 m are: 9.26%, 40.84% and 3.7%.

Nogueira *et al.* [54] research addressed PVWPS with monocrystalline and polycrystalline panels, showing that the average daily volume of water pumped by both systems ranged from 3536.46 l to 4182.55 l, which is enough to meet the basic needs of a small farm in Brazil. The flow of water pumped was more susceptible to voltage variation than to current variation. The polycrystalline system presented higher global efficiency and lower cost per volume of water pumped. Photovoltaic panel efficiency was 9.40% and 6.57% for monocrystalline and polycrystalline systems, respectively. As for complete pumping system, the monocrystalline system showed an average global efficiency of 4.27%, whereas the polycrystalline system presented an average global efficiency of 5.00%.

Hamidat [55] presents the electrical and hydraulic performance of a surface centrifugal pump applied to irrigation under Sahara climate conditions. The components are DC/AC inverter and an asynchronous surface motor (750 W) directly coupled to a surface centrifugal pump. The installed power is 1500 Wp for tomato irrigation. The pumped water is 1012 m^3 for 135 days whose global efficiency is around 3.8% and subsystem efficiency varies from 30% to 35%.

Ghoneim [56] investigated the performance optimization of direct coupled photovoltaic powered water pumping system in Kuwait climate. The pumped water was desired to satisfy domestic needs in amount of 12 m^3/day. The monthly demand for water is 360 m^3 but the syphilis proposed by Ghoneim monthly pump just over 40 m^3 of unnecessary water and Nogueira [57] investigated the performance optimization of photovoltaic powered water pumping to satisfy irrigation needs.

Kolling *et al.* [58], evaluated the behavior of a PV system of water pumping with direct coupling, under different conditions of solar irradiance and submitted to different manometric heights. The system was composed of DC motor pump, driven by a PV module. The authors concluded that the useful power generated by module and the flow provided by motor pump are directly related to solar irradiance and manometric height. The average daily flow rate ranged from 6.52 to 10.91 l/min.

Benghanem *et al.* [59], investigated based on the optimal PV array the performance of a directly coupled DC powered PV water pumping system without battery and electronic controls. Four different pumping heads have been tested (50 m, 60 m, 70 m and 80 m). The best system efficiency has been obtained for the head of 80m. The flow rate depends on the pumping head and the global solar irradiation. The motor-pump efficiency did not exceed 30%, which is typical for a directly-coupled photovoltaic pumping system; yet such a system is suitable for low head irrigation in remote areas.

Pande *et al.* [60] designed and developed a Solar PV pump operated drip irrigation system for growing orchards considering design parameters like pumps size, water requirements, the diurnal variation in the pressure of the pump due to change in irradiance and pressure compensation in the drippers. The system comprises a PV pump with 900Wp PV array and 800W DC motor-pump mono-block, with discharge of 3.8 l/h. The system could irrigate 1ha area within 2 h.

Yet, in most of the studied systems, the average TDH vary from 2.5 to 250 m. For the Algerian case, TDH vary from 3 - 40 m and perfectly adapt to the reality of the water demand for irrigation [61]. When using DC motors coupled to positive displacement pumps, the lower the TDH the greater will be the volume of water pumped. The TDH is directly linked to the volume of water pumped and the type of motor pump used as discussed in Section 2.2.

The most commonly used configuration of PVWPS technology is direct coupling systems with water storage tank, whose water is used for household and irrigation purposes with DC motors coupled to a centrifugal pump for daily demands equal or greater than 10 m^3. On the other hand, for lower water demand, DC motors with volumetric pumps are used. It is important to note that DC motors, somehow fit easily into PVWPS, for their compatibility with the power generated by the PV generator. Direct coupling systems studies carried out by Koner [62] indicate that DC motor PVWPS without power condition is superior than AC motor. These systems are simple and reliable used in small-scale pumping (1 m^3/day to 25 m^3/day) for small irrigations and domestic use. In irrigation area, most of the studied systems have capacity to irrigate areas close to 1ha, which turn the technology in an alternative to supply water for irrigation and domestic use for developing countries as India and Sudan. DC motors with positive displacement pump using only a PV array without battery unit is desirable for socio-economic development in rural communities.

Yet, it is possible to understand, from different authors that the variables that influence the performance of PVWPS are: TDH, quantity of fluid extracted, variation of solar radiation level during a day and season, photovoltaic technology, type of motor pump and voltage variation. From the studies presented on the performance of PVWPS for irrigation, is observable that the different crop water needs and its dynamics along seasons and year are not taken into consideration as a factor that can greatly influence the performance of these systems. In turn, many authors only consider total or daily water demand, not discussing the surplus of the pumped water. The TDH is directly linked to the volume of water pumped and the type of motor pump used, what may presuppose the study of the influence level of TDH on the yield of PVWPS.

From the reviewed articles, it can be observed that the authors are focused largely on technical aspects of the systems and somehow in economic aspects. The social and environmental aspects are not properly exploited in the adoption and design of the PVWPS. Clear studies in these areas can specify how much can be reduced in the emission of harmful gases to the environment and how the involvement of society can contribute positively to increase the useful life of such systems and the development of communities when adopting this technology. All these aspects can contribute to the sustainable development of communities.

The energy efficiency of PV panels production is found to vary from 11% to 15% [63]. Despite, the average overall efficiency of studied systems is 4.1%. However, Koner [64] obtained efficiencies ranging from 4.3% to 4.6% when assessing the diversity of PVWPS for rural areas. Nevertheless, the PV and overall efficiency of PVWPS do not exceed 10% and 5% respectively; this factor must be associated with the number of hours of available sunshine, manufacturing technology of PV panels, methods of conversion, field factors and system design among other factors. Howsoever, it should be noted that the efficiencies obtained through theoretical and experimental cases are approximate, 3.76% and 3.7% respectively, which allows saying that optimization models are reliable, although some experimental results showed low global efficiency in the order of 2.3% [65].

Many studies of the performance of PVWPS and several projects have been carried out in developing countries of Africa, Asia and South America, in experimental form, which make it possible to assert that the technology is technically mature, although it faces some implementation challenges as sustainability.

In grid connected systems, feed-in tariffs are a policy mechanism that provides long-term security to renewable energy producers, typically based on the cost of generation of each technology [66]. Technologies such as wind power, for instance, are awarded a lower price per-kWh, while technologies such as solar PV are offered a higher price, reflecting higher costs [67]. Although in developed countries feed-in tariffs are in disuse, by considering isolated PVWPS as an alternative for developing countries, the price of pumped m^3 of water and technology are relevant to the economic feasibility of systems. This fact may lead to try to match the pump functioning to the solar PV peak power and explore the dynamic character of water demand for irrigation purpose.

Generally, the cost of PV largely depends on the government policies, social acceptability, and institutional setup to run the system, and energy demand in specific places. Fiaschi *et al.* [68] refers that to a 30 m^2 PV system (about 3000 Wp) and to a borehole of 100m, a commercial multi-stage submersible pump lead to a water sale price between 1.23 and 0.67 $/$m^3$. In turn, Niedzialkoski [69] when discussing the pumped water costs, by a PV system of 150Wp and a positive displacement surface pump for a TDH of 2.5 m obtained 0.077[4] US $/$m^3$. The electricity cost generated by solar PV technology varies between 0.13 and 0.17 US $/kWh [70].

Photovoltaic can play an important role in developing countries given the favorable financing terms in order to minimize the annual cost of energy of a particular crop and the access of energy for the community. PVWPS for irrigation will become an increasingly economically advantageous source of electricity over expanding geographical regions [71], considering that in many areas of developing countries there is not access to electricity and PVWPS can be adopted as part of solution. Sorensen *et al.* [72] points that in India, 1.5 kW PV panels do not cost more than the cost of any electric line of 1 km. **Table 4** resumes the analyzed case studies for site-specific application and performance of PVWPS.

4. Design Methods of PV Water Pumping Systems

As seen, proper selection of photovoltaic technology for WPS and its components is essential for the stability and efficiency of the system. In this perspective, in this section, design methodologies used according to the end-use of PVWPS are explored, reviewing different authors in order to identify to what extent the different models of PVWPS design consider the dynamic nature of the water demand of the crops.

Usually, in the sizing of residential PV systems, PVWPS or other, the main efficiency factors are technical, economic and external impacts [73]. The technical factors are related to the system performance, as efficiency, electrical power, TDH, among others. In turn, an economic evaluation of water pumping systems is based on the monetary values of the system, whose most used methods are especially, Net Present Cost (NPC) [74] [75], Life Cycle Cost (LCC) [76], Levelized Cost of Electricity (LCOE) [77], Internal Rate of Return (IRR) and Benefit-to-Cost Ratio (BCR). However, the external impacts evaluation

[4]Source: https://br.investing.com/currencies/brl-usd-converter, accessed at June 8, 2017: R$ to US$.

Table 4. Summary of PV water pumping system performance evaluation studies.

Country	PV power (Wp)	Motor pump type	Head (m)	Type of system	V (m^3/day)	System efficiency (%)	Type of study	Application	Author [Ref.]
Jordan	4500	AC-centrifugal	24	PV-*WST	30 to 100	3.76	Model	N/A	Odeh [49]
Brazil	1100	DC-Centrifugal	18	PV-*WST	12	-	Real implementation	Irrigation	De Andrande [50]
Sudan	1100	AC-Grundfos SP4-8	24	PV	32	5	Real implementation	Irrigation	Hamza & Tiha [51]
Indonesia	3200	DC-submersible Lorentz PS1800 HR-05 HL	250	PV-battery	-	-	Real implementation	Domestic	Setiawan [52]
Iran	250	DC-positive displacement surface	16	PV-*WST	3.8	3.7	Real implementation	N/A	Abdozaldeh [53]
Brazil	150	DC-positive displacement surface	2.5	PV-*WST	4.2	4.27	Real implementation	Irrigation (100 m^2) and domestic (small farm)	Nogueira [54]
Algeria	1500	AC-surface centrifugal	13	PV-*WST	1.01	3.8	Model	Irrigation (1.49ha)	Hamidat [55]
Kuwait	210	DC-centrifugal pump	15	PV-*WST	12	-	Model	Domestic (300 persons)	Ghoneim [56]
Brazil	710	-		PV-*WST	4.0	-	Real implementation	Irrigation (1ha)	Nogueira [57]
Saudi Arabia	1800	DC-submersible helical pump	80	PV	N/A	4.41	Model	Irrigation	Benghanem *et al.* [59]

*WST—water storage tank. N/A—not applicable. Real implementation = Experimental study. Model = Theoretical study.

method emphasizes non-monetary values, such as weather, vandalism, that can directly or indirectly affect the selected pumping system [78].

Rawat *et al.* [79] reviewed the technical and economic processes of designing and optimization techniques of different PV systems configurations. The authors conclude that if the availability of resource data is lower, the intelligent methods are preferable for PV sizing optimization. Furthermore, neural networks, genetic algorithms and fuzzy logic are highly accurate and reliable for sizing optimization but very complex to implement. Though, if long term data is available the numerical method is preferable, being that numerical methods include software and tools which are user friendly. The sizing methods used by the authors focus on the modeling of solar radiation, photovoltaic modules, hydraulic load, insolation and electrical configurations of motor-pumps set.

Gad [80] developed a mathematical model using Matlab software to predict the performance of a direct coupling (12VDC) PV pumping system and a pump controller, in Southern Egypt whose daily water demand was 8 m^3, for a total head gauge which varies between 30 - 40 m, and 300 Wp system power. The model simulates the hourly performance of the system for any day of the year and for different orientations of PV-array. Results have shown that the amount of pumped water is of 24.06 (7.77 hrs), 21.47 (6.48 hrs) and 12.12 (4.15 hrs) m^3/day in summer solstice, equinoxes and winter clear sky days respectively for solar irradiation of 500 W/m^2. The calculated PV array efficiency ranges from 13.86% in winter to 13.91% in summer. Albeit, the author did not specify the purpose of pumped water, the predicted quantity of pumped water per day is larger than the target value (8 m^3/day) all over the year with a minimum value at December, ranging from 12.12 to 16.4 m^3/day corresponding to operating hours 4.15 and 8.79 per day respectively. The variables considered by the author for the design the system were solar radiation data, optimal PV array tilt angle, PV array and pump.

Ramazan [81] studied a water pump system with mobile PV, for irrigation of 0.5 ha (5000 m^2) of apple orchard in Turkey. Irrigation of apple orchard is carried out in the months of May to October, with a daily water demand of 17 m^3/day, being supplied within three days of pumping per week. An angle of 22˚ and a power of 460 kWp of PV system, for TDH of 20 m were considered. The developed mathematical model and simulation shows that it is possible to obtain 21 m^3/day. Nevertheless, the study concluded that the submersible pump should be selected in order to operate with maximum system efficiency considering the latitude of the region, season and effective costs. The costs of irrigation (fuel cost, water cost, and electric costs) reach 30% of the total gains each year to 18,000 ha. Such costs can be reduced based on the use of mobile PVWPS. The author uses a submersible pump in a mobile system which can compromise the technical quality of the system.

The method of optimal sizing of PVWPS used by Gad and Ramazan can be considered as numerical method. The numerical methods use simulation-based programs for calculating size according to the time interval, usually hourly, considering different parameters. Generally the most used software is PVSYST [82], HOMER [83], Retscreen [84], SAM [85], etc. or in simulation environments are often used MATLAB [86], TRANSYS [87], LABVIEW [88], etc. Yet, Khatib *et al.* [89], when analyzing different size optimization techniques for PV systems, concluded that simulation based numerical methods are most widely used technique. The intelligent methods use artificial intelligence techniques such as artificial neural network, genetic algorithm, fuzzy logic etc. to solve complicated optimization problem [90].

Concerning intelligent methods, Loxsom & Durongkaveroj [91] developed and tested an algorithm to estimate the long term monthly performance of a solar photovoltaic water pumping system for irrigation in USA. This methodology uses the standard solar factor correlation equation to calculate the flow rate of a system with an insolation threshold and a pumping rate that has a nonlinear dependence on insolation by using average monthly solar insolation input data and estimated the total monthly volume of water pumped with hourly simulation.

On the other hand, Sinha [92] developed a mixed integer linear model for determining the cost-effective technology options. The energy required for irrigation is estimated by a mathematical model description. The authors also discuss the techno-economics of different energy resource and technology options for the irrigation sector. The technologies include solar photovoltaic, water pumping windmills, gasifier and biogas plants coupled to diesel engines operating in the dual-fuel mode, electric pump sets, and diesel pumps in the independent mode. The developed model is solved for typical conditions that exist in India.

Considering the reduction of time of return of the isolated PV systems of water pumping Corrêa *et al.* [93] seeks to extend and validate an alternative to reduce the return time of isolated water pumping PV systems, where it optimizes the efficiency of photovoltaic conversion using maximum power point tracking algorithm, and the losses in the induction motor. For this, an experimental prototype was developed whose results showed a gain of 8% in the input power.

Khiareddine *et al.* [94] analyzed a dynamic model for energy control and management in agriculture in Tunisia which consisted of a 1.5 kW PV panel, coupled with a 25 Ah acid lead battery, induction motor coupled to centrifugal pump. The simulation based on the Neuro-fuzzy controller showed the effectiveness of the proposed system, and if there is a surplus energy this will be stored in the battery.

Rahrah *et al.* [95], presents the modeling and design of a photovoltaic system for pumping with batteries. In order for PV generator operate at maximum power point; the authors used three optimization methods: Perturbation and Observation, Fuzzy Logic Controller and Neuro-Fuzzy Algorithm. The simulation was performed based on Matlab/Simulink. As result, the Neuro-Fuzzy algorithm showed better strength through response time.

In addition to the optimal sizing of PVWPS mentioned above, there are other techniques that allow the optimal sizing of PVWPS that adopt various procedures based on the water consumption profiles, total head, tank capacity and photovoltaic array peak power. In this view, Hamidat & Benyocef [96] used a method of the load losses probability (LLP) to optimize sizing of the PVWPS with a similarity between the storage energy in batteries and water in tanks. The study for small scale of power located in southern Algeria, considered a total head of 20 m, showed that when the LLP varies from 0.01 to 0.1, the required power of the optimal photovoltaic decreases from 219 to160 W. For total head of 40 m, the required power of the optimal photovoltaic decreases from 350 to 260 W. This difference of the photovoltaic power (160 and 260 W), required to satisfy the needs, is due to the difference of solar radiation in localities.

The energy produced and the performance of the PV system depends on the number of environmental stochastic parameters which is consequently very important for the optimum reliability, technical efficiency, and cost-effective operation for the selection of best PV configuration for water pumping systems.

Table 5 resumes the analyzed design methodologies of optimal sizing of PV water pumping systems.

Table 5. Methodology/technique of optimal sizing of PV water pumping systems.

Methodology/technique (Evaluated variables)	Conclusion	Author [Ref.]
Mathematical model based on Matlab (solar radiation, PV-array, pumped water)	The amount of pumped water is directly proportional to the pumping time for the same solar radiation value.	Gad [78]
Mathematical model and simulation (PV-array, efficiency of PV-array, efficiency of overall system)	Submersible pump should be selected in order to operate with maximum system efficiency considering the latitude of the region, season and effective costs. Such costs can be reduced based on the use of mobile PVWPS.	Ramazan [79]
Algorithm to estimate the long term monthly performance of a PVWPS (flow rate)	Has a nonlinear dependence on insolation by using average monthly solar insolation input data and estimated the total monthly volume of water pumped with hourly simulation.	Loxsom & Durongkaveroj [87]
Mathematical linear model (for determining the cost-effective technology options and the energy required for irrigation)	The developed model is solved for typical conditions that exist in India, and it is shown that there are conditions in which alternative energy technologies make economic sense.	Sinha [88]
Maximum power point tracking algorithm and the losses in the induction motor (efficiency of photovoltaic conversion)	With the optimization technique developed it was possible to obtain a gain of 8% in the input power.	Corrêa *et al.* [89]
Neuro-fuzzy controller (energy control and management in agriculture)	If there is a surplus power it can be stored in the battery which in turn will add the power density of the system as a whole.	Khiareddine *et al.* [90]
Perturbation and Observation, Fuzzy Logic Controller and Neuro-Fuzzy Algorithm (time response at maximum power point operation)	The Neuro-Fuzzy algorithm showed better strength through response time (4.625 hrs) with efficiency of 79%.	Rahrah *et al.* [91]
LLP method (electric power of the motor (P_m) with volume flow rate and head)	Is possible to use a photovoltaic water pumping system for small-scale irrigation with an area smaller than 2 ha of crops in Algerian Sahara regions.	Hamidat & Benyocef [92]

Regard to the main knowledge of PVWPS models design, four methods can be used: intuitive, analytical, numerical and intelligent, as referenced in Section 2.3.1. The intuitive methods are based on the designer's experience [97], and in this method, simple mathematical equations are used and the estimation is usually oversized [98]. The analytical methods are simple and more accurate, with the support of empirical relationships to calculate the sizing of the components of PV array [99]. These methods employ developed mathematical modeling for design a reliable and/or cost effective PV system [100]. The choice of the appropriate method for the optimum design of the PVWPS depends on the existing variables and the complexity of the system in order to meet the needs of the user with minimum total investment costs, taking into account technical, social and environmental issues, specific to each project. Yet, the simulation programs and forecasts are sufficiently precise to performance of solar pumps.

Yet, as research gap, it is possible to understand from different authors that the design methodologies used don't explore the dynamic nature of the end-use of PVWPS. In case of irrigation systems are considered the maximum water demand only, which usually coincides with the flowering season of the crops. Not only, but also of the revised articles in the scope of PVWPS models design used is perceived the little exploration of social aspects, as far as the practices of the farmers in the field in order to develop models as close as possible to the reality of the farmers. Models that are close to the practical reality of farmers can contribute positively to the massive adoption of technology, although the initial investment costs are still relatively high and the environmental benefits will result from good agricultural practices. There is considerable separation between scientists and potential users of the solutions proposed by scientists.

5. Identifying Photovoltaic Water Pumping Systems Opportunities in Mozambique's Context

In view of the focus on models of design and performance of PVWPS, the study of renewable and specifically solar energy opportunities in Mozambique gains importance as a way to assess the feasibility of PVWPS implementation in developing countries.

Mozambique is a developing country located on the east coast of Southern Africa, where a large part (68%) of the population lives in rural areas. Significant part (more of 70%) of the population does not have access to the conventional electricity network and only 5% of the cultivated area is irrigated despite agriculture is accounting for almost 27% of Mozambique's GDP [101]. Diesel engines still dominate in irrigation sector, since the country suffers from lack of electricity. A gradual change from diesel engines to renewable energy would benefit the economy and the nation as a whole. In turn, photovoltaic water pumping systems for irrigation are being explored since the year 2013. In this context, the use of small and medium scale alternative renewable resources and definition of the policies that govern this strategy are part of the solution to the problems of Mozambique.

Electricity utility in Mozambique, identified the need for an investment of US $ 2 billion for the period 2011-2021, excluding new plants. However, this investment will reach a coverage of only 44% of the population [102]. It is clear that conventional electrification cannot satisfy the urgent need for universal access to modern sources of energy, as defended by the United Nations Millennium goals [103], even if investment capital is available.

To disseminate alternative decentralized sources of energy, the Mozambican Government created through the Council of Ministers [104] a resolution establishing the Policy and Tariffs for the Development of New and Renewable Energies 2011-2025 [105]. Nonetheless, Mozambique's access to international protocols and agreements also helps on the promotion of renewable energies. The policy developed defines the vision for the energy sector and guides planning for the development of relevant institutions in Mozambique [106], and establishes the role of private sector participation as key to the success of sector development and benefits cooperation.

The Regulation, which sets forth the Tariff Regime for New and Renewable Energies (REFIT), establishes the tariff model for new and renewable energies consisting of a "Renewable Energy Feed-in Tariff", with a view to promote and ensure the diversification of the energy mix and a safe local supply of electricity. These tariffs are applied to the electricity generated by independent producers using renewable energy sources. REFIT divides the tariffs to be applied in the selling of electricity based on respective source and according to generation capacity. Prices vary by technology, being the maximum and minimum limits for solar power plants 0.13 $/kWh to 0.22 $/kWh and is the highest of all technologies.

According to the National Energy Fund (FUNAE), about 13% of the population in rural areas has access to electricity through mini-grids or autonomous technologies of renewable energy [107].

Diverse incentives have been given to the promotion of renewable sources of electricity generation and special attention is given by the United Nations [108] to the diversification of the energy matrix, especially in countries where the electricity generation baseload it assured by hydropower plants, which compete directly in what matters to water for electricity generation, human consumption and irrigation.

The Electricity sector in Mozambique depends on 90% of hydropower (80% Zambezi River) [109], a renewable resource, being the rest of the supply complemented by natural gas, coal and other alternative sources of electricity generation. All of these sources have a long-term exploitation and require high costs for the implementation of infrastructure and subsequent exploitation. Although there is a large part guaranteed by renewable sources (around 90%), there is still difficult access to electricity, and therefore decentralized electricity generation has been adopted in many rural areas. In this context, solar energy has grown to respond different challenges, of which are solar water pumping systems.

In terms of available renewable resources, the country has a diversified spectrum that makes a total of 23.026 GW, of which the solar energy source is the most abundant (23.000 GW), followed by hydro (19 GW), wind (5 GW), biomass (2 GW) and geothermal (0.1 GW) [110].

Advancements on Photovoltaic Water Pumping System in Mozambique

Indeed, the implementation of PVWPS has already began in Mozambique, with some pilot projects, for irrigation and domestic uses purposes, considering the Government and private ONGs efforts. A part of these results was obtained by means of duly accredited interviews and studies of internal documents of the institutions in question. Static models based on software of pump manufacturers for PVWPS design are the most widely used in Mozambique by PVWPS traders and government institutions working in this area, because the technology is being explored relatively recently.

In the period between 2006 and 2015, FUNAE [112] installed 58 PVWPS, of which 35 were installed during the year 2015 in Inhambane (20), Zambézia (7) and Manica (8) provinces. In the period from 2007 to 2012, UNIDO[5] installed PVWPS for irrigation and domestic uses in six villages in the District of Chicualacuala. On average the installed system capacity is 1.280 Wp. The Development Cooperation Fund, a Belgian social solidarity organization, in coordination with the Union of Farmers of Manica, also installed an PVWPS in 2011 at the administrative post of Mutefu (Manica Province), which benefits more than 500 families and another in Chimoio (Manica Province) that benefits a cooperative of more than 20 farmers [113]. The Kwaedza Simukai Manica Association (AKSM) has installed five solar systems for community water supply in Manica Province too.

In order to know the pumping profile of some PV systems installed in Mozambique (carried out by FUNAE), and setting the Mozambican scenario regarding PVWPS, **Table 6** presents data from some systems that are operational, built between 2005 and 2012 with their technical specifications, such as installed power, well depth and well capacity, defined at the time of installation of the systems.

The majority of PVWPS deployed in Mozambique have been installed for use in small-scale potable water as shows in **Figure 5**. Because the PVWPS technology is being exploited for less than 10 years, among other government policies, there are no published reports on the performance of the installed systems and the technical, economic, social and environmental evaluation. As referred, the majority of PVWPS were installed with pilot programs, which opens the window for researchers to evaluate the performance of the systems and to suggest models and methods to optimize the performance of systems installed and to be installed. Notwithstanding, it would help to evaluate and improve the overall installed systems performance, based on different mathematical models and simulation programs developed by researchers to predict the performance of PVWPS in developing countries in Africa, Asia, and South America [114].

Yet, the optimization design models for Mozambique can result in the proper selection of components and refinement of PVWPS; however, help in decision making regarding the best configuration of the systems, costs involved, life cycle cost of the systems, technology to use, etc. The role of communities is relevant in order to achieve the useful life of the systems.

The PVWPS enhances the adaptation of green energy while it substantially promotes to mitigate climate change by assuming as estimated that, it may realize

[5]UNIDO (2015). Interview with Jaime Comiche.2 September 2015, Maputo.

Table 6. PV pumping units in Mozambique [2].

Project Name	Water flow (m^3/day)	TDH (m)	Power (Wp)	End-use
Convenience store in Macossa	5	85	480	Human consumption
Cheline and Muabsa Electrification	10	45	690	Human consumption
Pumping system of Mudaca	17	54	600	Human consumption
Pandjane Electrification	15	70	900	Animal consumption
Chupanga Electrification	10	33	700	Human consumption
Tinonganine and Djabula Electrification	10	-	-	Human consumption

Figure 5. Water pumping stations driven by PV systems for human consumption in Mozambique.

a CO_2 reduction of 7.4 ton per ha [115]. In order to enhance the solar irrigation program, in Mozambique, more than 900 PVWPS for irrigation will be installed by the government through the National Irrigation Institute all over the country until 2021. This will be the first major government project in this area.

Mozambique has favorable conditions to enhance the use of PVWPS for various purposes, with regard to available solar radiation levels and definition of strategic policies. However, the PVWPS are not yet a massive solution in part due to high installation costs, weak incentives to popularize PVWPS, weak monitoring of local technicians which operate the systems and a lack of a performance monitoring of the many installed solar pumps accompanied by the vandalism of these systems in the communities.

For the Mozambican case, PV is not yet competitive with grid electricity because the main goal of government is to achieve rural areas without the electricity for lighting [116] and cannot create extra pressure on grid electricity and diesel price. PV systems can be cheaper than grid extension, due to the larger distance between customers and electricity network, highly dispersed population with little energy demand, making national grid extension often economically unreliable. Despite, PV still reveals great advantages in relation to the diesel systems due to fuel cost, fuel availability fluctuation, the difficulties of fuel supply due to the poor state of conservation of the roadways in much of the country, high costs of maintenance and operation, among others.

In the Mozambique perspective, which is the reality of many countries of the

Austral region of Africa among other developing countries, since PVWPS for human consumption is proven to be a successful experience, the massive use of PV technology for irrigation purpose can play an important role in the development of communities regarding the availability of electricity to the irrigation sector, improvement of the irrigation techniques, increase of food production, contribution for green economy and consequent social and economic improvement as a way to increase the sustainability of developing countries.

6. Conclusions

In the present paper, a literature review on the design and performance of PVWPS and Mozambique's perspective on renewable energy technologies was executed. The high number of PVWPS projects carried out in developing countries of Africa, Asia and South America, in experimental and theoretical form, shows that this technology is technically mature.

From the analysis made to the different reviewed authors, in terms of configuration, the most commonly used configuration of PVWPS technology is direct coupling systems without battery storage. These systems are simple and reliable used in small-scale pumping (3 m^3/day to 25 m^3/day) for small irrigations and domestic use. In irrigation area, most of the installed systems have capacity to irrigate areas close to 1 ha, which turn the technology in an alternative to the continuous and stable production of food and raw materials for the development of communities.

Regarding the parameters of a PVWPS, the variables that influence greatly the performance of the PVWPS are: the amount of fluid extracted, the variation of TDH, technology of photovoltaic modules and the range of solar radiation, which in turn are determinant to the choice of the pumping system technology.

The sizing models of PVWPS can be intuitive, analytical, numerical and intelligent. The choice of the appropriate method depends on the existing variables and the complexity of the system in order to meet the needs of the user with minimum total investment costs, taking into account technical and environmental issues and external impacts, specific to each project. Simulation programs and mathematical models based on the modeling equations, of technical, economic and environmental parameters has been the most used system to obtain the optimum performance of PVWPS. The techno-economic optimum system configuration is not always the one that gives the highest annual system efficiency. Other parameters, like social, must be introduced in order to obtain the best yield of the whole system.

Photovoltaic can play an important role in developing countries given the favorable financing terms and flexibility of technology. PVWPS for irrigation will become an increasingly economically advantageous source of electricity over expanding geographical regions, considering that in many areas of developing countries, there is no access to electricity and PVWPS can be adopted as part of solution for food production increasing, social and economic improvement and contribution for a green economy.

Different applications lead to conclude that PVWPS are seen as key tool for developing countries, including Mozambique with regard to water provision for irrigation in rural, peri-urban and urban areas, as well as in some areas without access to electricity as an opportunity to make possible access to electricity and to improve the irrigation systems used and life quality. Mozambique is advancing in the definition of concrete policies in the field of renewable energies, mainly in the photovoltaic technology and installation of PVWPS in the pilot phase, which, together with the favorable solar potential, can spark the rapid deployment of communities.

From different authors, it is possible to understand that the design methodologies used do not explore the dynamic nature of the end-use of PVWPS. In case of irrigation systems, they have only considered the maximum water demand, which usually coincides with the flowering season of the crops. The exploration of the dynamic nature of water demand for irrigation can be explored as an alternative energy source in order to minimize the high rates of lack of access to electricity in developing countries. Also, social and environmental aspects are not properly exploited in the adoption of the PVWPS. There is considerable distance between the solutions proposed by scientists for PVWPS and the real needs of potential users of the systems.

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Conflicts of Interest

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

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