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Evolution of photovoltaic energy systems applied to water pumping for irrigation

Evolução do sistema de energia fotovoltaica aplicada ao bombeamento de água para irrigação

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Abstract: The increase in the price of fossil fuels and the pollution resulting from their burning has encouraged the use of renewable energy to produce electricity, and their applications have increased in recent years mainly for use in irrigation. Photovoltaic projects have been implemented to analyze the feasibility of pumping water. Within this concept, the article aims to present a literature review, linking practical information with existing scientific knowledge, seeking to expand research on the topic and contribute with information on the use of renewable energy for pumping water for irrigation, emphasizing the rationalization of water consumption. With the aim of reducing dependence on fossil fuels, seeking solutions to improve the quality of life in the countryside, generating income for agricultural producers with increased productivity. The case study demonstrates the use of photovoltaic pumping systems for irrigation, which proves to be efficient.
Keywords: renewable energy, photovoltaic potential, sustainable development, rural energization, productivity.

***Resumo**: O aumento do preço dos combustíveis fósseis e a poluição decorrente de sua queima têm incentivado o uso de energias renováveis para a produção de eletricidade, e suas aplicações têm aumentado nos últimos anos principalmente para uso na irrigação. Projetos fotovoltaicos têm sido implementados para analisar a viabilidade de bombeamento de água. Dentro desse conceito, o artigo tem como objetivo apresentar uma revisão da literatura, relacionando informações práticas com o conhecimento científico existente, buscando ampliar as pesquisas sobre o tema e contribuir com informações sobre o uso de energia renovável no bombeamento de água para irrigação, enfatizando a racionalização do consumo de água. Com o objetivo de reduzir a dependência dos combustíveis fósseis, buscando soluções para melhorar a qualidade de vida no campo, gerando renda para os produtores agrícolas com aumento da produtividade. Assim, foi definida a eficiência no uso de sistemas fotovoltaicos de bombeamento para irrigação, de acordo com o banco de referência.*
Palavras chave: energia renovável, potencial fotovoltaico, desenvolvimento sustentável, energização rural, produtividade.

1. Introduction

Increased energy consumption, limited use of fossil fuels and stricter environmental regulations make renewable energies increasingly attractive (Sedaghat et al., 2017).

It is known that electricity is one of the most sought after commodities, with more than 70% of its global consumption being fueled by the burning of fossil fuels, such as oil, coal and natural gas (Initiative GE, 2014). With the growing demand for electricity as a result of population growth, economic and modernization of agriculture, fossil fuels are widely consumed to meet this need (Kalogirou, 2009), but as they are known, their reserves are finite. It should be noted that the burning of fossil fuels results in the emission of harmful gases, including greenhouse gases, leading to global warming (Sinha and Chandel, 2015).

In addition to the environmental concern, with greenhouse gas emissions, energy security becomes another important issue uniting states and non-governmental organizations in the joint exploration of energy alternatives to meet the energy demands necessary for economic development (Klemes et al., 2010).

Photovoltaic energy stands out for having a lower environmental load due to the practically zero environmental impacts associated with its operation, being a promising alternative for rural electrification, since many farms are isolated and far from the electrical grid installations, so the cost conventional electrification tends to be higher (Mérida García et al., 2019).

Also noteworthy is the considerable decrease in the initial cost of solar energy, which has already been pointed out as a disadvantage (Irena, 2018), and which has been occurring due to the sum of three factors, these being, the drastic increase in the price of electricity from conventional energy sources in the last decade (Lorenzo et al., 2018) the increase in oil prices (Nederstigt and Bom, 2014) and reductions in the production costs of photovoltaic arrays between 30 and 60% in the next 10 years, making the implementation of the photovoltaic system viable (Closas and Rap, 2017). In addition, according to Chilundo, et al. (2014), the low need for equipment maintenance, the relative ease of installation and displacement, autonomous operation, adaptation to the greater need for water and the combined increase in solar irradiation values and easy cleaning make the photovoltaic energy system a great option to supply energy demand for irrigation purposes.

Therefore, looking for energy sustainability, renewable sources are the parameters to be followed, as they have the flexibility to adapt to radiation levels of any latitude, producing the appropriate energy for the location, without depleting natural resources or even harming in some way the environment itself (Mérida García et al., 2019).

Along the same lines, Martins et al. (2008), highlights the real need to use other methods to generate energy, that is, the use of renewable energy sources that generate minimal environmental impacts, promoting sustainability and reducing the impact resulting from their consumption.

This study analyses the use of solar photovoltaic renewable energy as an alternative source for the use of fossil fuels in water pumping for irrigation. Aiming to discuss the updated status and different aspects of the photovoltaic pumping system to irrigation (PPSI). The main parameters of this revision work can be expressed as follows: introduction and elements of the PPSI, overall evaluation of PPSI studies, impacts in the field with the use of PPSI, and final remarks on the system.

2. Methodology

An irrigation system with photovoltaic energy has its basic configuration constituted by a photovoltaic generator, power conditioning equipment, motor pump, storage systems (which can be optional), and distribution system. The most simplified sets of irrigation systems with photovoltaic energy are configured with a generator connected directly to the pump in direct current and then connected to an irrigation system (Morales, 2011).

Among the water pumping alternatives, the photovoltaic option is suitable for sites without access to the grid, mainly for irrigation purposes (Andrade et al., 2017). Figure 1 presents a photovoltaic system configuration with a battery bank, as an energetic alternative for pumping water applied to irrigation.

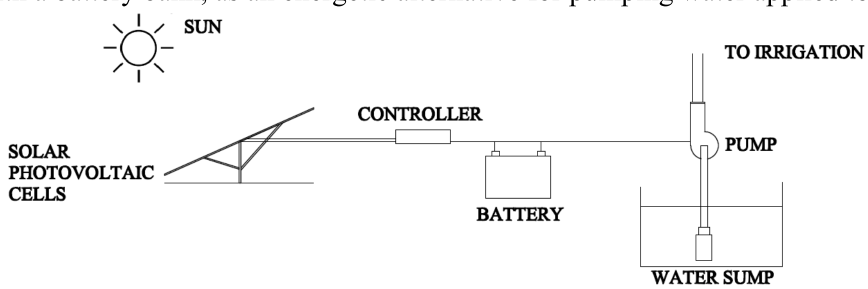

Figure 1. Solar-powered water pumping system with battery coupled with surface pump.

The photovoltaic pumping system without energy storage can also be an alternative for pumping water for irrigation purposes, the proposed system being constituted by a photovoltaic assembly (1), pump controller (2), and submerged pump (3), as shown in Figure 2 (Gad, 2009). It should be noted, however, that the initial investment figures decrease significantly, without the use of batteries.

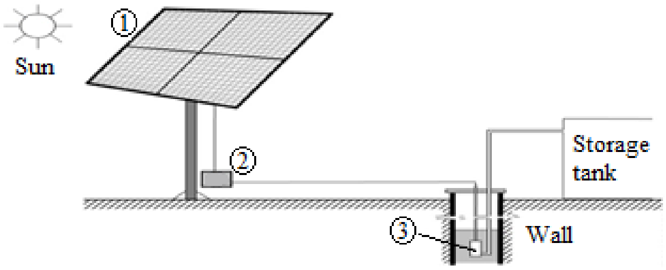

Figure 2. Schematic diagram of the photovoltaic water pumping system.

This system can be an alternative to families of small rural properties, with an emphasis on arid and semi-arid regions, always considering the importance of knowing the voltage, current and power generated by the panel, as well as the characteristics of the motor-pump assembly and the average irradiance of the region in all seasons (Michels et al., 2009).

According to (Chandel et al., 2015) the current technology uses devices that further increase the output power, performance, and overall efficiency of the system by allowing them to monitor storage levels or even control the speed of the pump.

2.1 Photovoltaic generator

The photovoltaic generator is a section of a ready-made power generation, where the photovoltaic cells are responsible for converting the energy from the sun into electrical energy. Silicon (Si) is the most widely used material in the manufacture of cells, with three usual forms available in the market: monocrystalline, with higher cost and yield; polycrystalline, with intermediate cost and yield; and amorphous, with low cost and low yield. There are also other components such as gallium arsenide, copper and indium diselenide, gallium, and cadmium telluriude, which have been gaining ground in the world market for solar cell manufacturing (Pinho and Galdino, 2014).

The arrangement of the photovoltaic system is essentially divided into two categories, i.e., insulated photovoltaic system and photovoltaic system connected to the grid.

It was also divided into three classes according to the type of silicon-based crystal used in the manufacture of the photovoltaic cell: monocrystalline, polycrystalline, and amorphous (Meah et al., 2008), in which the maximum efficiency found in the laboratory were 25% for Si cells and 37.7% for multijunction cells. Table 1 shows the efficiency of different photovoltaic cells.

Table 1. Efficiency of photovoltaic cells manufactured in the laboratory as of 2012.

Material of photovoltaic cells	Efficiency, %
Silicon	
Monocrystalline	25 ± 0.5
Polycrystalline	20.4 ± 0.5
Thin film transfer	20.1 ± 0.4
III A – VA compound	
GaAs (thin film)	28.8 ±0.9
GaAs (polycrystalline)	18.4 ± 0.5
InP (monocrystalline)	22.1 ± 0.7
Amorphous silicon/nanocrystalline	
Amorphous (a-Si) (thin film)	10.1 ± 0.3
Nanocrystalline (nc-Si)	10.1 ± 0.2
Dye sensitizing cells	11.9 ± 0.4
Organic cells (thin film)	10.7 ± 0.3
Multijunction	
InGaP/GaAs/InGaAs	37.7 ± 1.2
a-Si/nc-Si/NE-Si (thin film)	13.4 ± 0.4

2.2 Electrical characteristics of photovoltaic systems

Photovoltaic modules are characterized by the peak electrical power (Wp) given by the manufacturer under standard test conditions (1000 Wm² irradiance, air mass coefficient of 1.5 Am, and temperature of 25º C on the cell surface).

The modules have a characteristic curve (I-V), which has the following parameters: open-circuit voltage (Voc), short-circuit current (ISC), maximum power point (MPP), form factor (FF), and efficiency. Figure 3 shows the main characteristics of the photovoltaic module (Borges Neto and Carvalho, 2012).

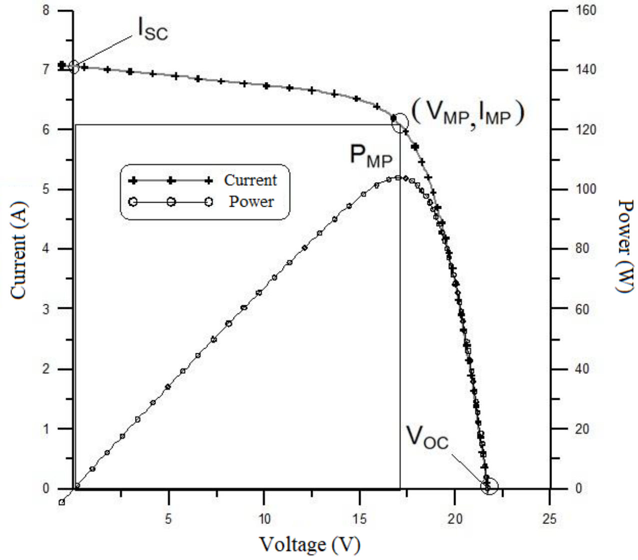

Figure 3. I-V characteristic curve and P-V power curve for a module with a nominal power of 100Wp. Source: Green et al. (2013).

For each point in curve IV, the current-voltage product represents the power generated for that operating condition, also showing the power curve as a function of the voltage, which identifies the point with the maximum power value generated from the voltage and the maximum power current (VMP and IMP), known as the maximum power point (MPP).

Form Factor (FF) expresses how much the characteristic curve approaches a rectangle. The better the cell quality of the module, the closer to the rectangular shape the characteristic curve will be. Eq.(1) allows the calculation of FF (Borges Neto and Carvalho, 2012).

$$FF = \frac{I_{mp} V_{mp}}{I_{sc} V_{oc}} . \quad (1)$$

In which: FF = form factor; I_{mp} = current maximum power; V_{mp} = voltage maximum power; I_{sc} = short-circuit current; V_{oc} = open-circuit voltage.

The efficiency of the photovoltaic module indicates how much of the solar energy incident on the module is transformed into electrical energy. When this number is determined in the standard test conditions, the light power incident on the module can be calculated by multiplying the irradiance (G) by the module area (Am). Eq.(2) shows the calculation of the module yield.

$$n = \frac{M_{pp}}{GA_m} 100\% \quad . \quad (2)$$

In which: n = module yield; M_{pp} = maximum power point; G = irradiance; A_m = module area.

2.3 Charge controller

The charge controller is present in most photovoltaic generation systems, with the function of providing protection against reverse and overcurrent, regulate the charging voltage, recharge the batteries and the supply voltage of other devices connected to the system (Meah et al., 2008). Frequency inverters are recommended when conventional alternating-current pumps are used, these devices being responsible for converting the direct-current electricity (12, 24 or 48 V) to alternating-current electricity (127 or 220 V).

2.4 Power storage

In the case of energy storage, one option is to pump the water to elevated reservoirs so that it can be used by gravity, dimensioning it to provide the necessary amount for the crop to be irrigated, for example, by supplying water even on days of little radiation or at night (Chandel et al., 2017), irrigating wheat, tomato, sunflower, and potato crops. Another form of energy accumulation is via the use of batteries that supply the energy needs of the motor-pump assembly, charged by the photovoltaic system.

There are cases where there is not enough elevation to build a reservoir for utilizing the gravitational energy for water distribution, or when the project demands relatively large structures, thereby increasing the cost of building the reservoirs and making the system unfeasible (López-Luque et al., 2015).

The battery can also be a limitation, as it increases the costs of installing and maintaining the system, has a shorter useful life and low reliability, and raises environmental concerns when disposing (Grah, 2014).

2.5 Applicability of the pumps

With regards to their applicability, surface pumps draw water from shallow wells, springs, lakes, rivers or tanks, while submersible pumps withdraw it from deep wells. In turn, floating pumps are suitable for pumping water from reservoirs with level adjustment capacity (Chandel et al., 2015).

Also, according to the authors, centrifugal pumps represent the first generation of pumps used in photovoltaic systems and has proven reliability in the long term, lower maintenance requirements, and considerable hydraulic efficiency (25-35%). The second generation of photovoltaic pumping systems includes positive displacement pumps, which are characterized by hydraulic efficiency of up to 70%, low cost of acquisition, and low energy requirements. Positive displacement pumps such as diaphragm and piston are defined by a water output that is directly proportional to their velocity, making them virtually independent of the pressure.

The direct application in the pumping of water by solar energy is highlighted in diaphragm pumps, which are more adaptable to this system, although their operational behavior requires further studies (Kolling et al., 2004).

2.6 Overall evaluation of PPSI studies

In this analysis, the methodologies used were described to present results in order to establish an overview on irrigation using the photovoltaic energy system Table 2.

Observed in the Table 2 that the research developed by the authors positively characterizes the photovoltaic energy system for water pumping, from the optimization of energy generation, ease of use of the photovoltaic pumping system for agricultural purposes, including irrigation to reliability and durability of the system, making the application of photovoltaic energy for irrigation a safe investment with guaranteed return. System characteristics that are analyzed statistically from quality control and process capacity index (Andrade et al., 2017), proving the system's effectiveness.

Table 2. Summary of PPSI studies.

Reference	Country	
Mokeddem et al. (2011)	Algeria	Low-cost photovoltaic system for water suction showed adequate values for low flow rate.
Moreira et al. (2012)	Brazil	Pumping system with photovoltaic energy accurately follows the linear equation, generating sufficient volume of water pumped into a small property.
Nogueira et al. (2012)	Brazil	Efficiency in water pumping for irrigation, simplified deployment, and accessibility to family agriculture.
López-Luque et al. (2015)	Spain	Reduction of the costs of the photovoltaic system and water saving for complementary irrigation of olive trees, leading to greater productivity and profitability.
Andrade et al. (2017)	Brazil	Excellent uniformity coefficients with and without energy storage, with satisfactory and reliable results according to statistical process quality control techniques.
Reca et al. (2016)	Tunisia, Spain, Jordan	The proposed system can be implemented to irrigate greenhouse crops.
Robert and Alma (2014)	India	The photovoltaic water pumping system is the best pumping technology option for farmers with minimal cost and maximum reliability.
Yahyaoui et al. (2017)	Sudan	Demonstration of the reliability of the algorithm for designing the pumping system with photovoltaic panel and battery, making water pumping feasible for Tunisia, Spain, and Jordan.
Shinde and Wandre (2015)	Sudan	Photovoltaic water pumping systems are economical at up to 3 kWp for village water supply and 1 kWp for irrigation, compared to diesel pumps.
Rezae and Gholamian (2013)	Iran	Considerable savings are observed in the pumping system of photovoltaic water compared to conventional systems.

2.7 PPSI performance factors

The performance of the photovoltaic pumping system is directly affected by the following parameters: panel power peak (Wp) under the normal radiation conditions; operating cell nominal temperature, which directly affects the efficiency and performance of the system due to the temperature variation on the panel surface; inclination of solar panels in relation to the horizontal plane and latitude; loss of cell wiring; cell type and mean monthly radiation and mean temperature.

Given the above, the performance of the modules is fundamentally affected by the solar irradiance and the temperature of the cells.

Since the current generated in the module is directly proportional to the solar irradiance, it keeps the temperature constant, as shown in Figure 4.

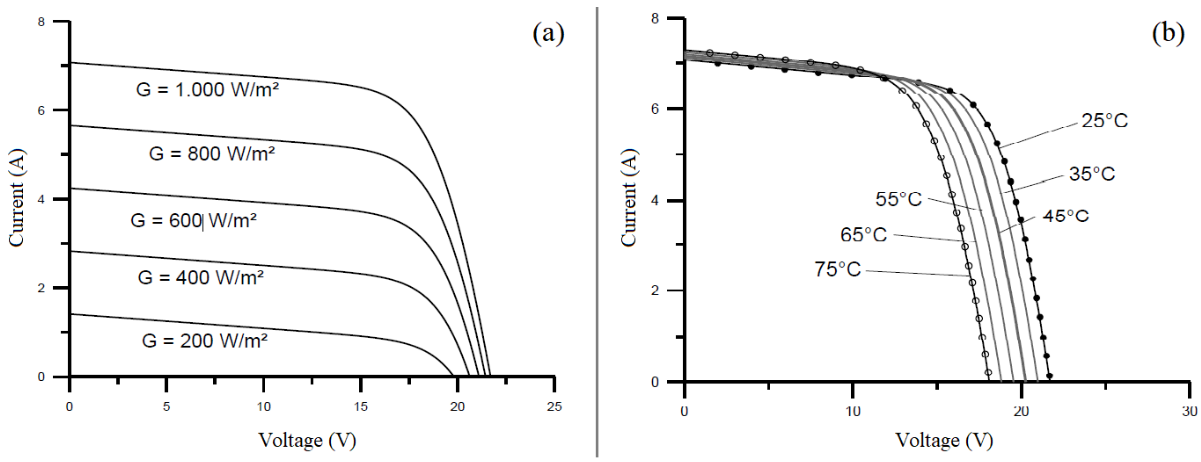

Figure 4. Effect caused by the solar irradiance variation on the characteristic curve of the crystalline Si modulus (constant temperature) (a) and effect caused by the cell temperature variation on the characteristic curve of the crystalline Si module at 1000 W/m^2 (b). Source: Pinho and Galdino (2014).

Considering the factors that may affect the performance of the irrigation water pumping system, this section will be focusing on studies that show such interference factors, such as search for better system performance, higher reliability, lower degradation, and optimization of modeling, for the application of the photovoltaic irrigation system.

In different locations and conditions, environmental parameters such as solar irradiation and the purpose of pumping are distinct, which determines the available energy and water demand during the day. Therefore, planning of the placement angle, power requirement, panel size, and fixed photovoltaic module and tracking are necessary parameters for estimating the performance of solar cells (Moreira et al., 2012) Table 3.

Table 3. Summary of PPSI performance factor studies.

Reference	Country	
Benghanem et al. (2013)	Saudi Arabia	Definition of system configurations for better performance, between maximum water pumping and power supply by the photovoltaic panel.
Setiawan et al. (2014)	Indonesia	Definition of two important aspects for water pumping system with photovoltaic system, piping, and planning of photovoltaic system.
Campana et al. (2013)	China	Mapping for sustainable development and increased productivity of pasture areas with irrigation system and photovoltaic system.
Flores et al. (2012)	Spain	Developed a software tool that simulates photovoltaic pumping systems with a sunlight tracker and the effect of the level of dirt on the surface of the photovoltaic panel. The results of the simulation are validated with experimental data.
Chandel et al. (2015)	India	The detailed wear analysis of the monocrystalline photosensitive generator exposed to the field for 28 years for solar water pumping system was performed in the western Himalayan region and reported an average wear rate of 1.4% per year.
Muhsen et al. (2016)	Malaysia	Proposed a multi-objective optimization algorithm based on differential evolution for optimal sizing of photovoltaic systems with high reliability.
Korpale et al. (2016)	India	The efficiency of the solar pump grows by up to 39% compared to a conventional powered system.
Khatib (2010)	Palestine	The addition of the tracking system for peak power and sun tracking increases efficiency.
Ramos et al. (2010)	Spain	The addition of standard programmable logic controllers (PLCs) for photovoltaic water pumping based on SFCs can overcome the disadvantages and increases system performance.
Yahia et al. (2011)	Indonesia	Program developed for the relationship between system reliability and system configurations.

Table 3 shows research from all scopes and regions, but maintains the ideal of improvement and advancement regarding the use of the photovoltaic energy system for pumping and irrigation. Like the work of Khatib (2010) who applied peak power and sun tracking, increasing the effectiveness of the system. Therefore, in addition to research on implanted systems, innovation projects seeking constant evolution and improvement of the system are extremely important for the advancement and consolidation of photovoltaic pumping.

4. Results

4.1 Reduction in the operating costs

The use of fossil fuels for pumping has a strong impact on farmers 'production expenses, therefore, so it becomes viable to install SFBAI in replacement of diesel generation systems, whose operating cost represented a good portion of the producers' monthly expenditure (López-Mata et al., 2010).

It is also noteworthy that with the increase in the price of electricity, while the cost of installing photovoltaic systems has decreased considerably (30-60% in 10 years; Closas and Rap, 2017), it makes the photovoltaic system for pumping water for irrigation economically resolute (Abu-Aligah, 2011).

It should also be noted that photovoltaic pumping has been used to supply water in places where there is no electrical network, since installation and operation are relatively easy compared to other renewable energy supply systems and there is no need for fuels that need to be moved to the site, reducing system maintenance and operation costs (Khatib et al., 2019).

Many projects have been developed in a practical way and evidencing the economic viability of using the system, as Vick et al. (2003) in the USA, Pande et al. (2003) in India, Senol (2012) in Turkey, Andrade et al. (2017) in Brazil. There are still some studies in the experimental stage of development, such as in Spain (Reca et al., 2016), a region that has great potential levels of global daily irradiation. Chandel et al. (2015) shows that one of the main biases in the incorporation of photovoltaic technology in irrigation is about the reduction in the energy consumption of the network, which has increased in value over the years (Abu-Aligah, 2011), so this technique is established to be economically viable (Pardo et al., 2019).

4.2 Increase in production

The irrigation system alone reduces the risks of harvest loss in relation to the rain variable, since the constant water supply throughout the cycle through photovoltaic irrigation does not affect future productivity due to the constant water supply. In addition, crops with an irrigation system provide the benefit of higher productivity compared to the rainfed agriculture (Pinto et al., 2015).

It is noteworthy, therefore, that the use of irrigation systems, properly planned, well used and with correct management, become instruments for increasing agricultural productivity (Mazzer et al., 2008). Pinto et al. (2015) state that the irrigation system has contributed to correct negative climate factors and substantially increase the yield of various crops, resulting in greater productivity and at different times of the year.

Research such as the one by Geisenhoff et al. (2015), on the productivity of broccoli with different irrigation systems, pointed out greater productivity with different irrigation, pointed out greater productivity with the drip irrigation system and with a smaller irrigation blade.

Silva et al. (2015) when analyzing the water consumption in the banana culture, they diagnosed that if there was a modification of the irrigation system and it started to operate with 90% efficiency instead of 75%, there could be an increase in the agricultural area in the order of 703 hectares using the same amount of water, efficiency that can be achieved with a localized irrigation system. Other studies such as de Oliveira et al. (2019) and Silva et al. (2019) pointed to a higher productivity of their crops for a greater irrigation blade used. Proving the importance of increasing productivity, as evidenced by irrigation.

4.3 Crop diversification

Another impact associated with photovoltaic irrigation is the constant access to water, which allows farmers to have a greater diversity of crops, ones with the best market value, thus increasing family income. Khatib et al. (2019) when presenting a form of rehabilitation of Mauritania's oasis using an ideal irrigation system based on photovoltaic energy realized the possibility of date palm production in oases in the African desert. In his field project, Morales (2011) installed a drip irrigation system in areas of 0.25 hectares, testing various consortia of plants such as bananas - beans, guava - passion fruit - melon, guava - melon - passion fruit - beans and soursop - passion fruit - jérimum - beans. The response to the proposed consortia showed good results from a technical and economic point of view.

Among the benefits of using the photovoltaic system for irrigation are the greater use of family labor, increased crop productivity and reduced electricity costs, with a consequent reduction in production costs and greater profitability. It was further defined that the investment made can be recovered from the third year onwards with the intercropped production of short-cycle fruits with subsistence crops (Santos et al., 2007).

4.4 Food security

One of the most significant impacts caused by the use of SFBI is the occurrence of food production security by increasing production and the wide variety of foods possible for cultivation. The result of these factors still causes an increase in farmers' income, improving the family purchasing power (Burney et al., 2010).

In studies aimed at improving local food production Liu et al. (2019) analyzed the frequency and amount of water for drip irrigation in tomato production. The result showed that when for the same water layer applied, but increasing the frequency of irrigation, productivity, water use efficiency and some nutritional quality indexes of tomatoes were significantly increased. Increasing productivity in tomato cultivation, modifying only the irrigation management, not changing the volume consumed. Zavala et al. (2020), when studying a pumping irrigation photovoltaic system in olive cultivation, they defined a linear programming model that was implemented to optimize the scheduling and operation of photovoltaic irrigation systems with independent direct pumping. Making it viable the photovoltaic irrigation, seeking better productivity of the crop in question. Thus, the use of a quality irrigation system with energy from renewable sources leads to the resolution of problems in areas without electricity or prolonged droughts, reducing production risks and consequently ensuring a constant production of food (Reca et al., 2016).

4.5 Environmental impact reduction

The choice of photovoltaic systems instead of internal combustion engines in the generation of energy mitigates the emission of polluting and greenhouse gases. Accessibility to the use of renewable energy sources, which generate minimal environmental impacts, promoting sustainability and reducing the impact resulting from their consumption, has become a plausible bias (Martins et al., 2008).

By not using diesel generators, pollution of wells and soils by fuel leaks is avoided, also reducing the amount of plastic waste on the property, as is the case with fuel and lubricant packaging (Morales, 2011).

The change to localized irrigation techniques, on the other hand, reduces the infiltration and contamination of soil and groundwater, and mainly significantly reduces consumption, increasing the efficiency of water use. Warner et al. (2016) defined that the use of localized irrigation systems are fundamental practices for saving and preserving water resources.

Todde et al. (2019) when analyzing the installation of photovoltaic pumping systems for irrigation showed a saving of fossil energy of 67% for the Moroccan farm and 41% for the Portuguese installation avoiding the emissions of a large amount of greenhouse gases and the exploration of natural resources associated with the production of fossil fuels.

Thus, the use of photovoltaic energy to power water pumps emerges as an emerging technology, which can be applied in small and large scales of energy production, as a favorable environmental alternative when compared to conventional systems powered by fossil fuels (Kumar et al., 2010).

4.6 Economic barrier

However, there are some barriers in the implementation of photovoltaic irrigation systems, as with other types of technologies based on renewable energy, for both domestic and community application.

The main factor being the economic barrier, where the high initial investment for the acquisition of photovoltaic systems is generally superior to other existing options (Timilsina et al., 2012).

Since energy is an input for the production of goods and services, the cost of energy is usually passed on to the cost of the product, which can make the product not competitive in the market if this cost is too high. For this reason, one must study under which conditions the investment in photovoltaic irrigation systems is economically competitive compared to other options for power generation.

Although there are subsidy policies for some equipment for photovoltaic systems by the state and federal governments, these subsidies do not yet allow total competitiveness in relation to other local generation systems, and there is still a lack of own financing for the implementation of the system making it attractive and economically viable.

Therefore, in order to minimize initial investments, the autonomous pumping system for irrigation stands out for being applied anywhere, presenting itself as a favorable alternative, as it does not require a battery bank, significantly reducing initial costs (Mittal et al., 2012).

Current research seeks to maximize the efficiency of the autonomous system (Zavala et al., 2020) since it has a smaller number of equipment, implying an easier installation and reduced handling (López-Luque et al., 2017), making the system economically attractive and with reduced payback time.

5. Conclusion

Direct coupled PPSI without control systems are still suitable for low-pressure water supply requirements for livestock, pasture, and drip irrigation due to their low cost and few maintenance requirements.

It should be noted that for better performance of directly coupled PPSI, the use of a solar tracking system and electronic control systems that ensure the best location of the photovoltaic system are necessary for larger water supplies and higher flow rates for irrigation.

The efficiency values of the system as a whole can be improved by studying and properly dimensioning the photovoltaic array, optimal orientation, adequate pump choice, and compliance with the irrigation system, as well as the use solar tracking systems to avoid lower system flows at lower insulation times.

The study is of great relevance, since the diesel costs for supplying water pumps that use this fuel are increasingly high. Reach in remote places through the photovoltaic system has real significance, as it entails in several positive aspects such as improved living conditions for farmers away from the electricity grid, pumping water for various purposes such as irrigation, household use, and livestock, thus leading to an improvement in local agricultural production, as well as being a clean source and renewable energy.

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