



**IMPACT OF PHOTOVOLTAIC WATER PUMPING SYSTEMS ON RWANDA
RURAL COMMUNITIES**

**Ndungutse Felicien, Shumbusho Jean Pierre, Bitegetsimana Gedeon, Tuyizere Samson,
Murangira Albert, Mujawamariya Agnes, Munyaneza M.Adolphe, Uwimana Josephine**
Emails: ndungutsefel@gmail.com ; ndafeli@yahoo.fr; shumbushojp2024@gmail.com

Abstract

This work intended to analyze the impact of photovoltaic water pumping systems on Rwanda rural communities.

Different technologies used in SISs are assessed and it has found that the result of using this technology depend on the choice of pump Motor, pump unit, solar module and solar irrigation method used for a particular region.

For small to medium size irrigation, Brushless DC motor is chosen and AC motor is good for higher power requirement irrigations.

A surface pump is chosen for water deepness less than 15m, otherwise a submersible type should be used. A floating pump is used when the water source is a large dam or other open source like a lake or wide open well. The respective efficiencies of drip, sprinkler and flood irrigation are 90%, 75% and 60%.

Surface irrigation is the cheapest but, once used, there is no uniformity of water distribution.

A SIS can either pump directly water from the source to the crops or use battery or water tank for storage. It has shown that the use of water tanks is more effective and less expensive than that of batteries and the automatic SIS reduces wastage of water and human intervention for farmers.

The system can also be a stand alone or grid connected depending on electrical connectivity network of concerned area.

For a quick diffusion of solar water pumps, Rwanda can learn a lesson from India which is among the reference countries that have promoted the solar irrigation systems by applying appropriate technologies with the help of the central government policy.

This study has shown that in India, multiple solar irrigation schemes have been implemented with the support of capital subsidies from MNRE which has increased the number of solar pumps installed in the country and the improved the rural community livelihoods.

1. Introduction

The economic development of nations has increasingly been influenced by electricity. It currently serves as the engine for many elements of public life. Availability of electricity provides countries investment opportunities, and raises living standards. Electricity is essential to current economic activity and an input for many public functions. Therefore, having a trustworthy source of energy is crucial for any country [1]. Today, a variety of energy sources are available, including solar energy, tidal power, geothermal energy, coal, nuclear, natural gas, hydroelectric, wind, and oil [2]. The decision of the power source to be used and the justification for that choice of power source is important.

Burning of fossil fuels to generate power is not sustainable since they release a lot of hazardous chemicals, the most remarkable of which is carbon dioxide, which causes global warming [3]. Energy producers earn more money as electricity use rises, but as conventional power plants are built to keep up with demand, pollution and other environmental issues increase. There is an alternative opportunity for lowering global warming emissions from the energy system while still satisfying the global request for energy facilities by using renewable sources of electricity. Given that hydropower has a longer history than other renewable sources of energy, it is used globally on a more widespread basis [4].

2. Background of the Project

The rate of growth of population in Africa is the highest in the world, as more than 1/2 of the world population growth is expected to take place in this continent by 2050 [5].

That quick growth of population would highlight the food security issue. Inversely, the sector of agriculture is more affected by change of climate because of variability of drought and rains that has led to serious insecurity of food in rural regions where farmers are still using traditional methods of farming.

The major input of agriculture irrigation is the energy and it is therefore becoming a focus for the management of water. In this regard, SPIS are being encouraged all over the world to replace traditional diesel or electric pumps [6].

The adoption of small-scale schemes is more preferred than other irrigation forms because of their low investment costs.

Conversely, public institutions as well as development partners are funding dam-based irrigation systems for large scale schemes. Their implementations require high investment costs and therefore, specific policy focusing on the promotion and development of SIS is imposed to intensify the agriculture production in Rwanda [7].

3. Problem statement

Rwanda has a land area of 26,338 square kilometers; it can be found at 2°00'S 30°0'E. Because of its small size, the climate conditions are roughly the same throughout the country. Rwanda's average solar power potential is 4.5 kWh/m² per day and has a solar peak of 7.5 hours. Precipitation is the most significant climatic variable in Rwanda because of its high altitude. Convergence zones and regional elements linked to Rwanda's diverse topography, various flora types, and lakes define the country's large-scale tropical climate.

Agriculture is one of industry that causes the most global warming because of its fossil fuels use to power machinery. The total energy consumed by agriculture sector in the world is approximately 7.7*10⁶ GWh/year and only 29.6 percent of renewable energy contributes to the total energy use. The increase of price of electricity and the depletion of fossil fuel reasons are conducting to invest in renewable energies [8].

Climate change is altering weather patterns, reducing rainfall predictability and negatively impacting on rain fed agriculture's productivity.

Irrigation system improvement is a key procedure to intensify agricultural productivity and stimulate the development of country economy for reaching the sustainability of agriculture [9].

The production of energy from the sun requires smaller land in comparison with to the one used for cultivation and therefore photovoltaic pumping system is one of the most encouraging solar energy applications [10].

For finding answers to the consequences of the patterns of erratic rainfall and drought that limit the growth of production of agriculture, Rwanda has just raised investment in of irrigation development.

The research will aid the government of Rwanda to strengthen the strategies to reach sustainable development and eradicate poverty by improving the increasing agricultural production and addressing the solutions of droughts consequences for farmers [11].

4. Objectives of the research

4.1. Main objectives

The principal objective of this project is to recommend the appropriate technologies and policies about solar water pumping systems that can be adopted by Rwanda for removing all barriers of quick diffusion of PVWP systems and for improving its impacts on the livelihood of poor farmers.

4.2. Specific Objectives

- Analyze different solar water pump technologies and their impacts on the irrigation system
- Identify the reference countries where solar pumping system technology is advanced and assess its socio-economic impact on their rural communities.
- Analyze SWPS operating now in Rwanda

5. Literature Review

The economic development of nations has increasingly been influenced by electricity. It currently serves as the engine for many elements of public life. Availability of electricity provides countries investment opportunities, and raises living standards. Electricity is essential to current economic activity and an input for many public functions. Therefore, having a trustworthy source of energy is crucial for any country [12]. Today, a variety of energy sources are available, including solar energy, tidal power, geothermal energy, coal, nuclear, natural gas, hydroelectric, wind, and oil [13]. The decision of the power source to be used and the justification for that choice of power source is important.

Burning of fossil fuels to generate power is not sustainable since they release a lot of hazardous chemicals, the most remarkable of which is carbon dioxide, which causes global warming [14].

Energy producers earn more money as electricity use rises, but as conventional power plants are built to keep up with demand, pollution and other environmental issues increase. There is an alternative opportunity for lowering global warming emissions from the energy system while still satisfying the global request for energy facilities by using renewable sources of electricity [15].

Some researches on PVWP systems are done on design and economic analysis of medium and large scale solar water pumping systems especially in Eastern province of Rwanda. However, there is no research done on design of smaller scale solar water pumping system that can be afforded by a big number of farmers for irrigation purposes in Rwanda, specifically in city of Kigali, the densest region in the country having wide cultivable marshlands but where the population is suffering from the shortage of food as consequence of poor agriculture production. In addition, the use of sizing tools from current industrial market would help in the good choice of appropriate, cheap, trusted, reliable, and updated equipments which would result in easy implementation of designed projects and would favor the diffusion of solar water pumping systems for irrigation purposes in Rwanda

6. Research Gaps

Many reviews on SIS for irrigation in different counties are done but up to date, there is no research done on the analysis of technologies and policies that favored the quick diffusion of PVWP systems in advanced counties, their impacts on rural communities, and the lesson that developing countries like Rwanda can learn from them.

7. Research method

This study is completed by using extensive literature review to analyze different technologies of SWPS, policies and subsidies used in advanced countries with their impacts on rural communities for identifying the strengths and experiences to adopt.

The information about pilot PVWP projects in Rwanda is also used, with the help of internal documents of the institutions in question, to derive their targets and therefore their effects on Rwanda population livelihoods.

7.1. Impact of Solar water pump technologies on irrigation system

SWPS uses photovoltaic technology that gives electrical energy from solar energy into to supply a motor pump that lift up water and send it to the crop field by rotating the attached shaft. The electronic system is used by current solar pump technology for regulating the present power from the solar generator to the solar pump and intelligent software that increases the overall efficiency and the output power of the SPIS [16]. Stand-alone SPWS has solar as the only source of power as shown in figure 1.

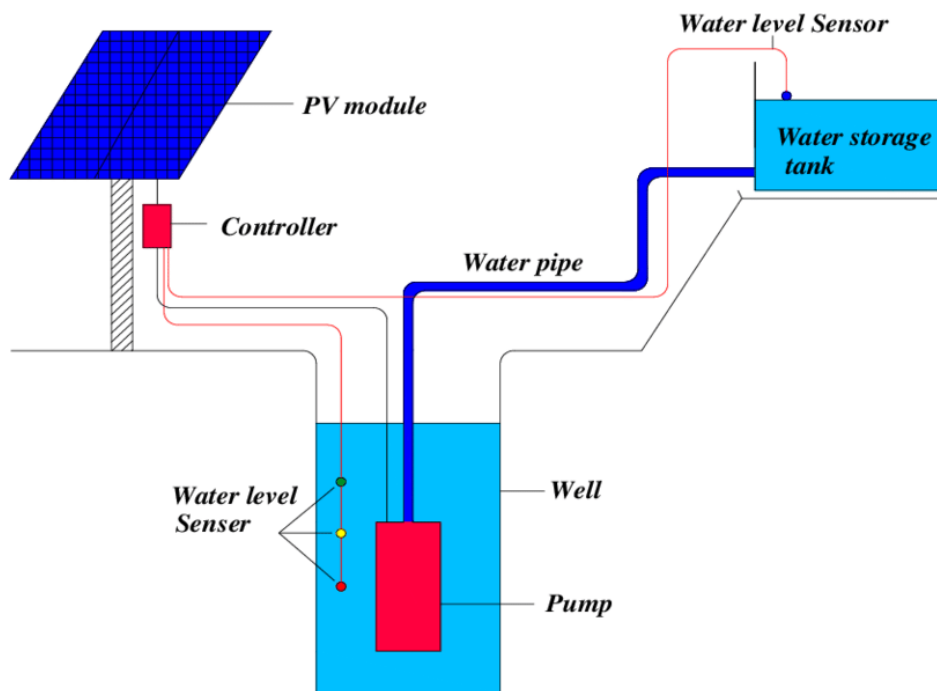


Figure 1: stand-alone SPWS [20]

During the day, Water is pumped and stored for later use during cloudy days or during night time when it is required. [17]

- The performance of SWPS depends on Total Dynamic Head, Solar radiation availability, rate of flow of water and total amount of needed water [18].

7.2. Effect of Solar water pump motor drive

The photovoltaic water pump system can be of various configurations based on the type of pump motor and its mode of operation. DC motors are mainly used for irrigation schemes below 5Kw,

while AC motors are preferred in applications where higher pumping power is required. A direct current motor can be brushed or brushless.

Frequent preventive maintenance is necessary for brushed DC motors and therefore they are prone to failure. Once a brushed DC motor is chosen, there will be a need to change brushes in every 2 years [23]. The lack of carbon brushes and commutator increases the lifetime of this motor by reducing brush sparks [19].

For a low power, PMSM brushless motor is proven to be the best choice instead of DC motor pump direct connected to a PVWPS. The size of motor is smaller in comparison with other alternating current motors. For those types of motors there are increases in lifetime, Improvement in efficiency and they are less noisy.

The cost and operation maintenance issues of direct current motors have led to the usage of IM. In this case, you should use an inverter between the solar array and the motor [20].

Asynchronous reluctance motors driven by PV array suggested a strategy of control to keep the voltage of the motor within tolerance and employ the solar arrays near the MPP. The motor is easily handled in case of emergencies and it is less expensive. It is proven that using this type of motor enhanced the output of the SIS [6].

7.3. Choice of the pump

Practically, the SWPs available are surface mounted, submersible and floating.

Solar surface pumps are recommended mainly when the water depth is less than 15 m and PV submersible pump is especially chosen if the water depth is more than 15 m [16].

Pumps are usually shaped like long cylinders to fit in the casing of the well. Most of them are planned for being installed in wells, but many can also be placed horizontally at the bottom of lakes and rivers. [17]

Generally, those pumps require more horsepower and larger solar installations, and tend to be more expensive.


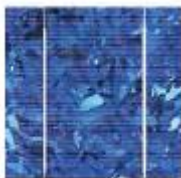
Floating pumps can be installed if the water source is an open well or large dam. The water pump unit is attached to the flotation device so that its inlet is placed in the source of water.

While these systems remove the need for suction lines and their associated challenges, floating pumps typically require pliable discharge lines as water levels change over time.

7.4. Recommended types of solar panels

Solar modules change energy from solar into electrical energy using of photovoltaic effect. The dimension of the PV array depends on the required power by the pump system meaning that small changes in pump power will imply a large impact on the total cost of the system. Monocrystalline type has Better performance ratio, longer while Polycrystalline type is cheaper and low sensitive to temperature variations [18].

Table 1: SWPS panels [9]

Panel	Monocrystalline type	Polycrystalline type
Cell picture		
Appearance	dark blue and uniform Cells	clear blue
Maximum Performance ratio	17%	15%
Advantages	Better performance ratio and extended life	Cheap and Low sensitive to temperature variations

7.5. Pump Controller

The CU role is to match the load to the available power. A pump CU is an electronic linear current device that interfaces b the solar module and the pump [19].

Its main impact is the adaption the load to power available and variation the pumping speed as solar insolation varies [20].

7.6. Indirectly-coupled pumps and direct pumping system configurations

Many factors should be taken into consideration when determining the best SWPS for a special application [21].

Batteries increase the overall cost and reduce the overall efficiency of SIS while Water tanks are more effective and less expensive [22].

According to the battery temperature and state of charge, the voltage supplied by the battery can be 1-4 V lesser than the one produced by the module when the solar radiation is maximum. The simplest technique for SIS is to connect the pump to solar module through a power converter without the presence of batteries.

A big number of solar pump systems needs water storage capacity to increase their system efficiency. Storage tanks reserve the water during daylight time, and supply it at night, in cloudy weather, or during system failures [23].

7.7. Influence of irrigation system automation

For an automated SIS, a sensor circuit is controlling the valve of tank water outlet. Soil moisture is converted into a corresponding voltage by the sensor. This is provided by a sensor with a reference voltage that farmers can modify to program different moisture amounts for various crops [24].

Control pulses are received by means of the Moisture sensor and the controller and excite the stepper motor to rotate proportionally to the humidity level detected by the humidity sensor. The circuit can also opens and closes valves when detecting soil moisture in the fields [25].

Excess energy generated by PV array can also be fed to the grid with some changes to the system configuration. This provides to the farmers a source of income and solves the energy crisis issue.



Figure 2: Soil moisture sensor probe [25]

Although the overall profit is high and implementation of this technology is expensive, in the long run the system is economically viable and this can also save great amount water [26].

7.8. Impact of on and off -grid system adoptions

7.8.1. On-grid system

In a grid-tied system, the photovoltaic system is connected to the power grid. Grid-tied systems typically do not require battery backup. If the system produces more than required energy, it will be immediately transferred to the connected utility grid and the consumer will be compensated. This makes the system more and more popular in living spaces. If the system is generating too little power, consumers can get electricity from the grid and pay for the electricity they consume. [27]

Those systems are ideal for urban regions, easy to install, cost effective, and offers home users and businesses the opportunity to generate passive income from the excess energy generated by the system. However, grid-connected consumers may have to consider power outages

7.8.2. Standalone or off-Grid Systems

Off-grid systems are not coupled to the main grid power. They are suitable for electrification of small remote communities in countries without access to electricity due to the presence of separate and widespread populations over large areas [28]. This makes energy consumption 100% independent. This system has some drawbacks as it requires the purchase of

an expensive and environmentally unfriendly backup battery. However, consumers are independent and self-sufficient from the power grid and do not have to worry about power outages due to grid failures or shutdowns. [29].

7.9. Assessment of solar irrigation systems in advanced countries

Photovoltaic's growth of over the universe is vibrant and differs enormously by country [30]

In 2019, the advanced countries in PV capacity were [31]:

- China (205 GW)
- United States (76 GW)
- Japan (63.2 GW)
- Germany (49.2 GW)
- India (38 GW)

It will be interesting to see if the solutions proposed for these countries are also applicable to Rwanda and share the impact of solar water heating systems on rural communities.

7.10. Experience from India policies and subsidies

India Agriculture is tied to the energy sector because the principal source of pumping groundwater for the production of crops for food is electricity. The country is grappling with water, energy and food connectivity and relies primarily on demand management tools such as power distribution, agricultural power metering and institutional approval of new pumps. Since water is state subject and power is minor, different states have different policies on groundwater and power management [32]. Access to adequate supplies of irrigation water has an immense impact for both food security and the livelihoods of Indian farmers.

Under section 4 of the NEA 2003, the Indian central government announced its rural electrification policy in 2006.

Under the compliance with Section 4 of the National Electricity Act (NEA) 2003, the Central Government published the Electrification Policy for Rural areas in 2006. Under section 7.9 of Rural Electricity Policy (2006), programs for energy-efficiency for irrigation are encouraged.

Similarly, the National Electricity Policy (2005), which is a subset of NEA2003, also focuses on promoting pump sets and water delivery systems for high energy efficiency. [33]

70.10.1. JNNSM

PV WPS was allowed a MNRE financial support through a 30% capital grant.

A 100 GW purpose of solar energy development and deployment was set by JNNSM by 2022. Many states have taken initiatives to implement SWPS using financial support and funds from state budgets. As of 2019, the whole installed solar capacity was 33.73 GW; Targeting 30 GW each in 2019-20 and 2020-21.

From the establishment of the scheme, the off-grid SIS number installed in the country has increased exponentially [34].

7.10.2. PM-KUSUM

The program had a central grant budget totaling US\$4.7 billion for states to deploy SIP by March 2022 and SWP for sustainable productive use in India. Through this scheme, farmers could double their agricultural income. The program includes of three components related to the mode of solar irrigation pumping system: A, B, C The program had a central grant budget totaling US\$4.7 billion for states to deploy SIP by March 2022 and SWP for sustainable productive use in India. Through this program, harvests could double his agricultural income [35]. The program consists of three components related to the mode of solar irrigation pumping system: A, B, C as summarized in table 2.

Table 2: PM-KUSUM Components

COMPONENT	MAIN TARGET	IMPACT
A	Setting up 10GW of decentralized solar or other renewable energy sources connected to the grid on barren land.	Creation of an avenue for a stable and continuous source of income for rural landowners. DISCOMs got a performance-based incentive of Rs 0.40/kWh for the first five years of the plan.
B	Installation of 2 millions standalone solar pumps.	Farmers are supported to install standalone solar pumps of up to 7.5HP capacity.
C	Solarisation of 1.5 million grid-connected pumps	Farmers can use the generated power to meet their irrigation needs and sell the excess available power to DISCOMs. Creation of thousands of jobs in the SWP supply chain

The Figure 3 shows the off-grid SIS number installed in the country for different years

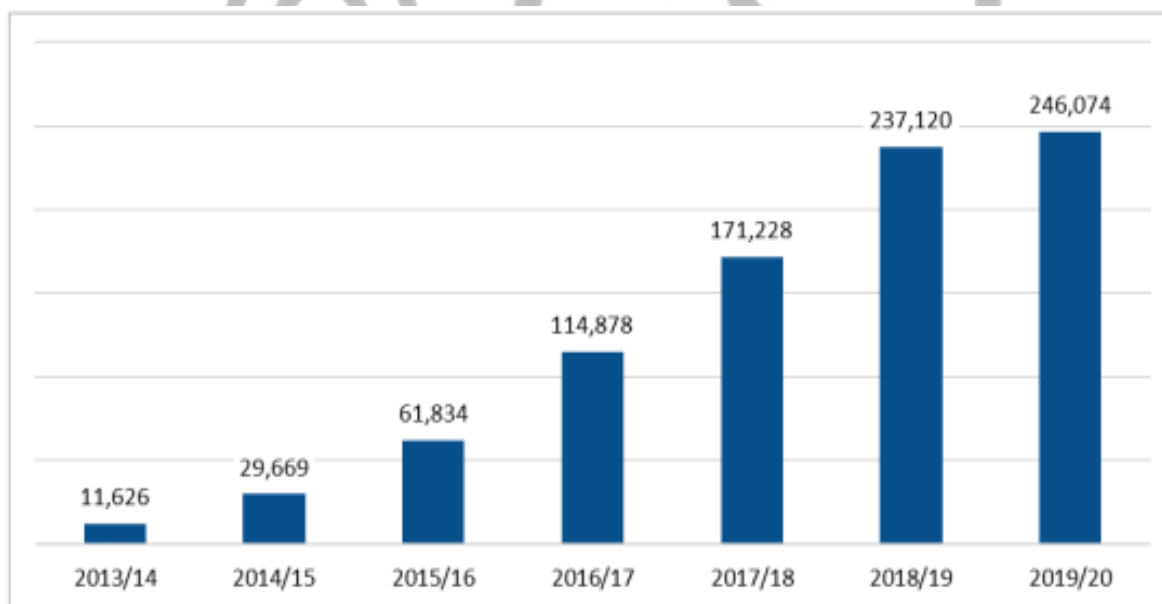


Figure 3: number of off-grid irrigation pumps installed [21]

The KUSUM project is one of the occasions that can enhance sustainable water use in agriculture and provide climate farmer resilient incomes. The project has the capacity of doubling the income for farmers by receiving energy of solar. [36]

7.10.3. Solar Irrigation lesson from Rajasthan

The program combines JNNSM, RKVY, NHM, WHS, and other different resources of Different states [33]. MNRE achieved 30% subsidy and RKVY 56%, in total subsidizing 86% for the cost of the SIS and its installation.

In 2010-2011, 50 test SWPs were installed and after two years of successful testing, the state government launched his 515 crore program for deploying 10,000 PVWPS in the Rajasthan state. Farmers are happy with the pump. They say the pump works better than other alternative pumps and they have to do no maintenance other than pump cleaning [37].

Ideally, even if farmers continue to use electric and diesel pumps, SIPs will completely replace other pumps. [38]

7.11. Impact of solar irrigation service provider pilot

The Aga Khan Rural Support Programme (AKRSP), in association with IWMI, implemented a solar-powered irrigation pilot in 40 Chak Haji villages in Samastipur district of Bihar in 2016. The pilot involved Solar Irrigation Service Providers (S-ISP) who installed solar powered submersible pumps and sold water to individual farmers. These pumps were funded through a combination of equity from the S-ISP and grant from IWMI/AKRSP. The Table 3 shows the impact of solar irrigation providers.

Table 3: Impact of solar irrigation providers [26]

Before	After
Electricity was available for only ~4-5 hours per day and was unreliable.	Solar power available for ~8 hours a day.
Water was drawn from shallow borewells using diesel pumps. This resulted in high cost of irrigation and increase in air pollution.	With solar powered irrigation system, clean, reliable and economic source of irrigation was available to farmers. Furthermore, water could be drawn from a greater depth, making it contamination free.
Lower discharge of water with higher pumping time	With solar pumps and bigger pipes, volume of water increased and pumping time reduced. Farmers were able to grow 2-3 crops in a season. This increased their yield and annual income.

Apart from the above, the annual income of solar irrigation service providers doubled or in some cases, tripled through sale of water to neighboring farmers. Value of leased agricultural land also increased with solar powered irrigation. Consequently, more farmers leased out their land, partly, to leverage this benefit. [38]

7.12. Impact on farmer livelihoods

Excess of electricity is fed into the grid, allowing multi-user farm owners to generate additional income, with an immediate effect on the farmers. The resulting advantages range from increased sustainable income and reduced hardship [27].

Farmers were using DG pumps before choosing SPVWPS. According to them, previously in the diesel generator pump for irrigation used about 8-10 liter of oil. After adopting solar water pumps, they Saved 40-50,000 rupees per year thanks to SPVWPS [38]

7.13. Improvement in crop production

A cotton and wheat farmer in the Nagpur district said that the utilization of SWPS has increased production of wheat by 7 quintals and by 13 quintals for that of cotton per acre . [39]

7.14. Environmental impact

Diesel pump units release hazardous emissions in the form of solid particles and gases that pollute the environment. Moreover, the constant and premature use of water pumps without the necessary importance for energy conservation and energy efficiency wastes precious government money and resources. [40]

7.15. Impact of solar irrigation pilot projects in Rwanda

In this part a summary on solar pilot projects in the country is given.

Since 2017, Hinga Weze has partnered with farmers, the Rwanda Agricultural Board (RAB) and local authorities to support over 1,200 households in accessing irrigation infrastructure that is affordable, appropriate and adaptable for smallholder farmers. The system is powered by solar energy, allowing farmers to eliminate their reliance on diesel and reduce their environmental footprints. Nine sites of 100 ha have been completed so far and two sites of another 100 ha are

currently under construction. Totally, the project aims to cover 300 ha of land, which will benefit thousands of farmers by significantly increasing productivity, improving incomes, livelihoods and ensuring food security [41]. A summary on pilot projects is given in table below:

Table 4: SWPS Pilot projects in Rwanda

pilot project	Partnership	Target	Impact
Hinga Weze (Ngoma)	USAID in partnership with RAB and local authorities	Nine sites of 100 ha have been completed and two sites of another 100 ha are currently under construction	Today, the land is fertile, and the additional crops grown on the sites have contributed to increasing incomes and food security.
Rwarri (Ngoma)	Rwanda Green Fund	20 hectares of plantation.	
Nasho (Kirehe)	Government of Rwanda in partnership with the Howard G. Buffet Foundation (HGBF)	irrigating 1,173 hectares belonging to 2,099 smallholder farmers	
Knowing water better (Rulindo)	Food and Agriculture Organization	The project delivered three solar water pumps	Farmers don't have to buy expensive fuel. Cut down of time-consuming and manual labor

7.16. Increase in production and improvement in farmer livelihoods

Before receiving the irrigation support from Hinga Weze, crops grown on these sites had low yields and were affected by land fragmentation and low productivity. The lack of water during the dry season contributed to these challenges, despite farmers owning their own small manual or diesel pumps. Today, the land is fertile, and the additional crops grown on the sites have contributed to increasing incomes and food security. In the last two seasons, the nine sites that have been developed produced over 400 metric tons (MT) of produce, with over 1,000 MT to be harvested by the end of 2020.

7.17. General impact of implemented solar pump projects on the regional economy

A report on Kenya, Rwanda, Senegal, Tanzania, Uganda, and Zambia carried out by the 60 Decibels team on the impact and experience of SWP customers showed that[42]:

87% of customers have seen improvement in:

- Their farming method
- Their Production
- Money earned

8. Findings and Discussions

The adoption of solar-powered irrigation systems is gaining a lot of attention around the world to enhance sustainable agriculture and eradicate poverty from rural societies.

This research has shown that the impact of this method of irrigation depends on the SIS technology used in particular place but the main driver remains the government policy about the PVWPS. This method of irrigation is playing a major role in improvement of agriculture in India and, through the country policy; a positive impact is being registered among a wide rural farmer community. Under the central government subsidies, many SIS scheme have been implemented and this has resulted in improvement of population livelihood as shown in Table 5.

Table 5: India subsidized schemes and their impacts

Scheme	Impact on rural communities
JNNSM	Increase in the number of off-grid solar pumps installed in the country.
PM-KUSUM	- Creation of source of income for rural landowners. -Installation of standalone solar pumps of up to 7.5HP capacity. -Farmers use the generated power to meet their irrigation needs and sell the excess available power. -Creation of thousands of jobs in the SWPS supply chain
Rajasthan SIS	Provision of 10,000 subsidized solar PVWPS across the state.

SISP in Samastipur	<ul style="list-style-type: none"> -Increase in daily power availability time - Availability of water from a greater depth -Increase in water volume and reduction in pumping time. -Growth of multiple crops in a season and increase in both yield and annual income.
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Rwanda can learn can lesson from India to set a policy that favors the adaptation of SIS and its implementation to improve the livelihood of rural communities.

9. Conclusion and recommendations

9.1. Conclusion

This study has analyzed the impact of photovoltaic water pumping systems on Rwanda rural communities and assessed the country site suitability potential for solar irrigation systems.

The social-economic effects of SIS depend on solar irrigation method used and the type of a compatible technology adopted for a specific region of the county.

The outcome of this type irrigation in a certain region is found to be dependent on choice of pump Motor , pump unit and solar module considering the corresponding temperature, soil texture, water source type, slope angle, depth to groundwater, size of plots etc.

For small to medium size irrigation, Brushless DC motor is chosen and AC motor is good for higher power requirement irrigations.

A surface pump is chosen for water deepness less than 15m, otherwise a submersible type should be used. A floating pump is used when the water source is a large dam or other open source like a lake or wide open well.

India is among the reference countries that have promoted the solar irrigation systems by applying appropriate technologies with the help of the central government policy.

Multiple solar irrigation schemes have been implemented with the support of capital subsidies from MNRE which has increased the number of solar pumps installed in the country and the improved the rural community livelihoods.

By adapting the SIS technologies and policies from India, Rwanda would increase the number of

solar water pumps in the country and the population livelihood would appreciably improve.

9.2. Recommendations

In this study, the analysis of impact of photovoltaic water pumping systems on rural communities has been done.

The government of Rwanda should encourage farmers and corresponding partners to implement PVWPS by fixing the amount of subsidies for both on and off grid SISs.

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