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# Solar Water Pumping: Kenya and Nepal Market Acceleration

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**Abstract**

Solar water pumping is a mature, reliable, and economically attractive solution for off-grid irrigation, livestock water, and community water supply. With increasing reliance on water pumping for food security needs, and limited access to conventional energy sources for many communities most in need of water pumping, development programs around the world are accelerating market development for solar powered water pumping systems. Financial, managerial, technical, market access, and educational challenges exist. However, examples from Kenya and Nepal demonstrate how successful initiatives have developed to overcome such barriers. These examples demonstrate that challenges can be overcome through public-private partnerships that take advantage of relative cost savings, increased reliability of both solar power and irrigation systems, and improved technology access through innovative financing models. These interventions help accelerate solar water pumping adoption in Kenya, Nepal, and elsewhere.

Keywords: *Photovoltaics, solar water pumps, renewable energy*

## 1. Introduction

Solar photovoltaic water pumping (PVWP) is one of the most economically attractive solar energy applications with installed systems proven to provide 20 or more years of reliable service. There is an excellent match between seasonal solar resource and seasonal water needs (Foster, 2009). A wide range of water supply needs can be met by PVWP, from livestock and community water supply, to small and even large-scale irrigation needs. PVWP system costs have declined significantly, from over US$25 per peak watt over 15 years ago (Foster, 1998), to total PVWP system costs under US$5 a peak Watt possible today (Foster and Cota, 2013).

Irrigation is a critical tool in addressing food security challenges; however, conventional grid or fossil fuel energy sources are not adequate to meet global irrigation needs. There are new opportunities emerging in the transition from diesel to solar powered pumps to reach farmers who cannot access traditional energy sources. A significant shift has begun in the rural water pumping industry where previous diesel pump dealers now provide solar powered pumping systems that are outpacing diesel systems sales due to lower life cycle costs. Some vendors in South Asia that previously sold only diesel/gas pumps, have expanded their product lines to include PVWPs and now report selling more PVWPs than diesel pumps. Ambitious targets for PV water pumps in South Asia are indicative of the promise of this technology. Bangladesh's Infrastructure Development Company Limited aims to finance 50,000 PVWPs by 2025 (Rahman, 2015), the Alternative Energy Promotion Center of Nepal plans 500 PVWPs by 2017, and India's Ministry of New and Renewable Energy target is 100,000 PVWPs by 2015 and one million installations by 2021 (International Centre for Integrated Mountain Development, 2015).

Key challenges faced in markets where PVWP development has been implemented, as well as in those areas where it has not yet materialized, illuminate several challenges, including financial, managerial, technical, and market access challenges. A key challenge for PV water pumping systems is the upfront cost. The lifetime cost of irrigation varies depending on the system, its maintenance, and inputs. Analyses have shown PV water pumping systems have payback times of two to three years (Foster and Cota, 2013). PV capital costs require financing schemes that can help farmers realize financial savings in a few years and over the lifetime of the system. Many existing PVWP projects are subsidy driven, funded by grants, or financed through loans that farmers obtain from banks. The overall challenges are not just related to PVWP technologies, but the entirety of the system that the energy is a part of, including for irrigation, agriculture, and community systems.

## 2. Solar Water Pumping Advances

A PVWP system is similar to any other conventional water pumping system except that the power source is solar energy. PVWP systems have, as a minimum, a PV array, a motor, a pump, and normally a water storage tank. The PV arrays are sometimes mounted on passive trackers (which use no motors) to follow the sun throughout the day for increasing pumping time and water volume. Alternating current and direct current motors are used to power centrifugal, displacement like piston or helical rotor pumps. Water is more cheaply and effectively stored in a tank rather than storing electro-chemical energy with batteries. Pump motors are normally direct drive from the PV array using a maximum power point tracking (MPPT) controller, thus eliminating batteries, decreasing system costs while increasing reliability (Foster, 2009).

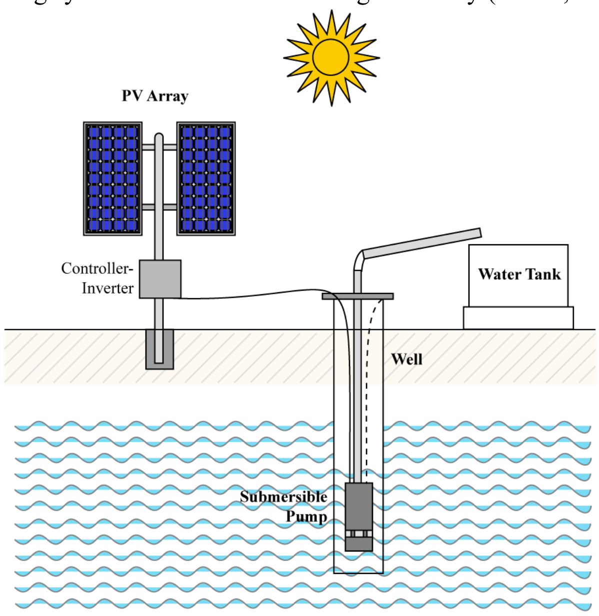


**Fig. 1: Typical PV water pumping system components.**

General size categories of PV water pumping systems are based on motor power output (Watts or kW):

- *Small* >50 W to < 1 kW
- *Medium* 1 to 5 kW
- *Large* >5 to 100 kW

The size categories tend to correlate with the differing technologies used for solar pumping. Small PVWPs have the longest history for commercial application and show the most technology diversity. Small, low-power systems can provide large amounts of water by pumping throughout the entire day, which provides affordable water pumping solutions for even poor, smallholder farmers in remote regions.

### *2.1 Helical rotor water pumps*

One of the most important developments to advance PV water pumping over the past 15 years has been the development of helical rotor submersible pumps. The helical rotor is a positive displacement pump mechanism that is mounted to a submersible motor. The motor is similar to that used for centrifugal submersible pumps. Like the centrifugal submersible pump, the helical rotor submersible pump can last for many years with no regular maintenance required. Most new PVWPs use this type of design. Table 1 provides a comparison of basic advantages and disadvantages for different pump types.

**Fig. 2: Example helical rotor pump end commonly used for solar water pumping.**

**Tab. 1: Typical operational characteristics of different PV water pump types.**

| Type of PV Water Pump | Advantages | Disadvantages |
|---|---|---|
| Submersible centrifugal | •Simple, with one moving part.<br>•Regular maintenance not required.<br>•Efficient at high flow rates or low lift.<br>•Good tolerance for moderate amounts of sand and silt.<br>•Most conventional, widely available. | •Poor efficiency at low volumes (<30 liters per minute) or high lift.<br>•Capacity is reduced disproportionately at low speeds (in low-sun conditions).<br>•Impellers can fill with sediments and may require periodic cleaning. |
| Helical rotor, submersible or surface | •Simple, with one moving part.<br>•Regular maintenance not required.<br>•Highly efficient at low flow rates (4-50 liters per minute).<br>•Maintains full lift capacity at all speeds.<br>•Good tolerance for moderate amounts of sand and silt. | •No major disadvantages. |
| Diaphragm, submersible or surface rotary vane | •Relatively low initial cost.<br>•Efficient at very low flow rates (4-20 liters per minute).<br>•Maintains full lift capacity at all speeds. | •Requires preventive maintenance.<br>•Poor tolerance for sand and silt.<br>•Requires filtration (rotary vane pump). |
| Surface centrifugal | •Relatively low cost.<br>•Efficient for low lift and high flow rates.<br>•Easy to inspect and maintain due to surface location.<br>•Good tolerance for moderate amounts of sand and silt. | •Suction limit is about 6 meters or less.<br>•Requires priming (filling the intake).<br>•May be damaged by running dry if it loses prime. |

### *2.2 Affordable solar water pumps*

PVWP system costs have rapidly declined due to the decreasing cost of PV modules. PVWP system costs are now one quarter of what they were 20 years ago (Foster, 1998). PV module prices have dropped by over 80 percent over the past 8 years, and are expected to drop about another 50 percent in the next five years or so. This cost decrease has made it possible to obtain small-scale PVWP systems for only a few hundred dollars. These systems are cheaper to install than competing diesel systems or often even electric grid options if no power is already on site.

Typical mid-size PVWP systems range from 1-2 kWp and cost about US$4,000-7,000 installed depending on location. Payback for many PVWP systems is typically only two to three years, with expected lifetimes of over 25 years for alternating current pumps, while direct current pumps need replacement every five to seven years, depending on water quality.

One example of an affordable small PVWP is the Futurepump manufactured in India, shown in Figures 3 and 4. This is an inexpensive piston pump that sells for about US$400 and operates on only an 80 Wp solar module. It is very simple to operate and can replace treadle pumps. Futurepump provides 900 liters per hour at six meter total dynamic head (TDH), or 2,000 liters per hour at one meter TDH. This pump is limited to about eight meter TDH.

**Fig. 3: The Futurepump piston water pumping system manufactured in India retails for US$400 with the PV module.**

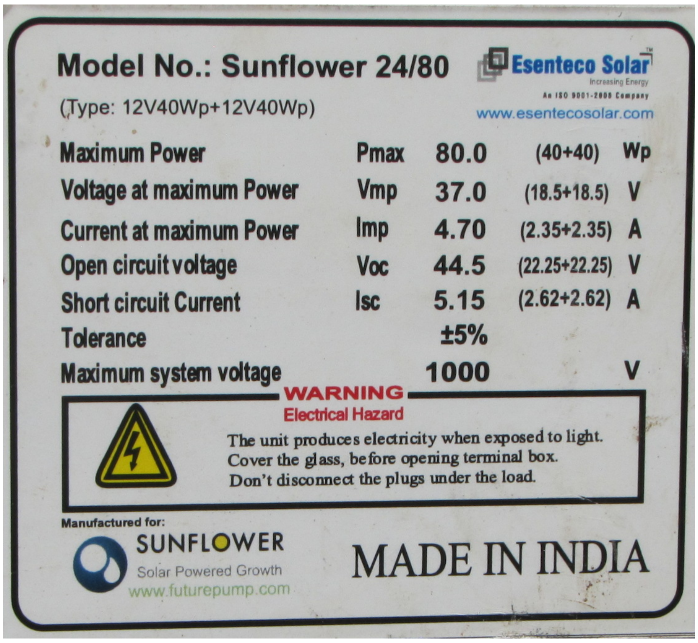


**Fig. 4: SunFlower 80 Wp module name plate used for the Futurepump PV water pumping systems.**

## 3. Kenya Smallholder Solar Irrigation

Agriculture makes up the largest share of Kenya's GDP (25%), but only 6% of agricultural land is irrigated. With a labor force of almost 18 million, 75% of which are engaged in the agricultural sector, Kenya has huge potential to increase its agricultural output if irrigation can be accessed for smallholder farmers. However, "[irrigation-based farming] is developed under large-scale irrigation schemes for crops like rice, a few farmers have their own irrigation systems for export crops like horticultural produce, and a limited number of smallholders practice small scale irrigation farming" (Aila and Atieno, 2006).

The U.S. Agency for International Development (USAID) funded Kenya Smallholder Solar Irrigation Project (KSSI) is being implemented by Winrock International (WI), in partnership with DuPont Kenya, SunCulture, Futurepump Ltd, the USAID-funded Kenya Agricultural Value Chains Enterprises Project (KAVES), and others. KSSI is part of the Renewable Energy Leader with Associates (RELWA) program, which aims to scale up access to, and adoption of, renewable energy globally, with a focus on increasing farmer access to renewable energy technologies that can improve agricultural productivity, sustainability, and income.

KSSI aims to improve quality of PVWP systems in Kenya while facilitating an increase in commercial sales of PVWPs to smallholder farmers who benefit by either eliminating use of costly diesel fuel or by converting from rain-fed to irrigated farming in arid areas that have never used pumps. KSSI is setting up PVWP demonstration sites around the country. Although the Government of Kenya is implementing an expanded rural electrification program, over two-thirds of the country does not have access to grid power. KSSI targets farmer groups that will not be reached by the grid in the next 5-10 years. As of September 2015, some farmers choose to buy the less expensive PVWPs even in areas where the grid is nearby. Some success factors of PVWP market acceleration in Kenya under KSSI are illustrated through the following examples.

### *3.1 Kenya PVWP market dynamics*

The market for PVWPs in Kenya is changing rapidly. In January 2015, a WI survey of PVWP retailers with products affordable to smallholder farmers identified several companies present in the Kenyan market. SunCulture sells a 300 Wp pump kit that retails for US $2,200. Futurepump Ltd has an 80 Wp SunFlower pump kit that retails for US $400. Davis and Shirtliff is the PVWP national leader and sells a small Shurflo direct current diaphragm pump for US$400 (pump only). This company has sold over 4,000 units and is now developing a 120 Watt solar pump kit to retail for US $700. A new company, KickStart, recently entered the market with a 120Wp MoneyMaker solar pump that retails for US $395. PVWP vendors in Kenya vary greatly in numbers of sales and maintenance staff, ability to respond to increasing demand for their products, and ability to reach smallholder farmers to raise awareness about their products.

### *3.2 Overcoming educational barriers to commercialization of PVWPs in Kenya*

WI found that the key barriers to increased commercialization of PVWPs are not technological but instead center around the need to directly reach thousands of smallholder farmers with information on cost, performance, installation, and maintenance of PVWPs. In this regard, WI functions as a neutral intermediary between farmers and PVWP companies. Working in partnership with large agricultural initiatives, such as the USAID-funded KAVES project and its 500,000 participating farmers, WI ensures that two or three PVWP companies attend farmer field days so that farmers can compare products and choose one that best suits particular farm needs. WI also set up PVWP demonstration sites for early adopter farms in several counties and is arranging for farmer groups affiliated with KAVES and DuPont to attend demonstrations at these sites. WI reaches out to banks and cooperative savings organizations to ensure that farmers have financing options for PVWP purchases and technical trainings for PVWP companies to ensure they can provide high-quality products, installation, and maintenance. Some example KSSI cases of PVWP in Kenya are provided in the following sections.


**Fig. 5: Winrock invited PVWP retailers Futurepump (at left, with green hose) and KickStart to display their mobile units at a KAVES Field Day in Kenya, October 2015.**

### *3.3 PVWP for drip irrigation in Nyahururu*

Patrick Mwendwa is a typical farmer in Nyahururu who owns five acres, one of which is for his homestead. He uses one acre for apiculture, two acres for onions under drip irrigation, and one acre for various vegetable crops for domestic use. Before installing a PVWP, Mr. Mwendwa hand watered his vegetable crops using a water can, which was cumbersome. Prior to the PVWP, he could not grow onions because of the high water requirements of the crop.

After attending a training facilitated by WI at a SunCulture (KSSI partner) demonstration plot, Mr. Mwendwa purchased a complete PVWP system with a one acre drip kit to improve his farm productivity. He financed the PVWP from his savings for a total cost of US$3,320, including the drip irrigation system. The SunCulture PVWP is set in a 20 meter hand dug well and fills a 10 cubic meter water storage tank at a height of four meters in about five hours.

Mr. Mwendwa planted onions, a high value crop, using the one acre drip irrigation system. He found ready markets for his produce and realizes high returns on his investment. He plans to expand his drip-irrigated acreage by another acre since the PVWP has additional capacity that he is not using.

**Fig. 6: One acre drip irrigation system using a PVWP on the Mwendwa farm in Nyahururu, Kenya.**

### *3.4 PVWP for drip irrigation in Bogoria*

The Noroloro Women's Group in Bogoria (Baringo County) was formed in 2006. This Group initially worked with livestock and later transitioned to fruit and vegetable production, which needed irrigation to be productive during the dry seasons. This Group began using an NGO-donated SunCulture pump in August 2014 to irrigate two acres through drip tape irrigation. The SunCulture PVWP pumps about 10,000 liters per day from a five foot depth pond which obtains water from a diverted canal.

**Fig. 7: The SunCulture 300 Wp PVWP, owned by the Noroloro Womens Group, provides 10,000 liters per day for two acres of drip irrigation.**

### *3.5 PV water pumping for aquaculture and irrigation in Kendu Bay*

WI is collaborating with Futurepump at a demonstration site in Kendu Bay and nearby farms, where farmer Joshua Okundi purchased a SunFlower PVWP. Mr. Okundi owns five acres of farmland, which he uses to grow corn, passion fruit, tomato, banana, French beans, sweet pepper, kale, carrot, potato, peanut, avocado, and mango. He also has two fishponds, with 1,000 and 1,500 fish each, in which he grows tilapia. Mr. Okundi uses the 80 Wp Sunflower PVWP for the following activities at his farm:

- Pump water from the canal to the elevated tank for later use irrigate his crops.
- Pump water from the canal to the tilapia fishponds for oxygenation.
- Furrow irrigate passion fruit, avocado, banana, and a mango tree nursery.
- Pump water from the canal for domestic use.

The PVWP has enabled Mr. Okundi to save about US$20 per day from avoided fuel costs for a diesel pump he used to run. The SunFlower pump was purchased for US$400, achieving payback in about one month. The PVWP also allowed Mr. Okundi to start four new money-generating farming activities at his farm, hence improving his income. WI is conducting a detailed cost-benefit analysis at these demonstration sites to document the income benefits of PVWPs.

**Fig. 8: Mr. Joshua Okundi with his Futurepump PVWP, used to recirculate water for a tilapia pond for oxygenation and also to irrigate a banana grove. The farm is located near Kendu Bay on Lake Victoria in Kenya.**

### *3.6 PV water pumping for drip irrigation in Thika*

A SunCulture demonstration site near Thika irrigates two acres of land that is not connected to a grid. The SunCulture submersible helical rotor pump (from China) sits one meter below the water surface in a pond. The head is about 20 meters to reach the 10 cubic meter tank at the top of a hill. The tank is filled twice a week and takes about four hours to fill. The community uses water from the tank daily to drip irrigate two acres and a nursery. The PVWP was installed in July, 2015 for US$2,200 and was a more inexpensive option compared with connecting to the nearby electric grid which was quoted at US$3,700 along with an energy consumption charge of US$0.19/kWh. This cost is more than the amortized cost of a direct drive PVWP over 20 years (estimated at about US$0.12/kWh).

**Fig. 9: Thika solar water pumping system used for drip irrigation.**

## 4. Accelerated Commercialization of PV Water Pumping in Nepal

Nepal is an agriculturally dependent country with a majority of its people involved either directly or indirectly in agriculture. Traditional agriculture in Nepal is rain-fed and depends on rainfall during the summer monsoon season. Farmers generally grow cereal crops like rice and wheat during the monsoon season. In the dry season, from November to March, many farmers leave their land barren due to lack of water, while more wealthy farmers can grow high value vegetables using either diesel or grid powered electric pumps for irrigation. With the high cost of fossil fuel along with maintenance costs, farmers have to bear huge financials burden for operation and maintenance of diesel pumps. Nepal suffers from severe electric power shortages, which causes frequent power cuts and load-shedding, so grid powered electric pumps are often unreliable. PVWPs are a reasonable irrigation solution for the dry season to increase farmer incomes. PVWPs also provide opportunity for high value horticulture farming in the off-season, which can generate even higher incomes for farmers.

Market challenges in Nepal include: limited PVWP products options; relatively few PVWP suppliers; limited access to finance; inadequate information and understanding about PVWP among farmers hesitant to change farming practices; and lack of coordination between government agencies, the solar power industry, promoters and organizations working to improve agriculture and irrigation efficiencies. USAID funds the Accelerated Commercialization Solar Photovoltaic Water Pumping (AC-PVWP) project, implemented by WI, that focuses on capacity building and market development activities to expand commercialization and adoption of PVWP systems for irrigation, livestock watering, and community water supply. There is a large demand for water pumping, but due to the high initial capital costs, many Nepalese farmers are unable to afford the technology. WI is working with SunFarmer Nepal and local cooperatives for investment capital to provide equity and loans to farmers so they can obtain PVWPs and increase their farm productivity. Some example AC-PVWP cases of PV water pumping in Nepal are described below.

**Fig. 10: Winrock International demonstration PVWP unit at Khajura, Banke, Nepal.**

### *4.1 SunFarmer financial loan model for PVWP installations in Nepal*

The SunFarmer loan model is aimed at creating access to PVWP irrigation services for the farmers of Nepal through innovation in technology, finance, and long-term service commitments. The model serves as a platform to converge multiple stakeholders to accelerate commercialization of PVWP. Under this model, SunFarmer invests up to 50% of the initial capital for PVWP system installation and farmers pay off the loan in installments through the designated cooperative within the Power Purchase Agreement (PPA) period (e.g., two years). With this financing scheme, more farmers can install PVWP systems for irrigation. In addition to financing, SunFarmer performs technical and financial assessments to ensure that the system is properly installed and guarantees free repair and maintenance, to ensure system performance within the PPA period. SunFarmer supports farmers to identify the most affordable and reliable systems tailored their needs. Upon successful completion of the agreement period, SunFarmer hands over ownership of the project and PVWP system to the farmers.

### 4.2 *PV water pumping for vegetable farming in Pokharikada*

A demonstration PVWP unit with the Pokharikada Village Development Committee in Surkhet district was installed by Suryodaya Urja Private Ltd., irrigating 4.4 acres of land for a group of 20 farmers. The system consists of a 1.4 kW Grundfos submersible helical rotor pump, 1,260 Wp PV array, grounding system, and accessories as shown in Figures 11 and 12. The submersible pump is placed in an 8 $m^3$ water tank in a spring box. The system is designed to lift 10,000 liters of water 60 meters up to a 20 $m^3$ collection tank. The water is then fed to drip and sprinkler system and the farmers use the water in queue. The total cost of the system was US$4,988 and the civil component was US$4,260, which included the water tank, reservoir tank, and the distribution pipes. The demonstration system was financially supported by the Government of Nepal, the Village Development Committee, the Raising Income of Small and Medium Farmers Project (RISMFP), USAID's Knowledge-based Integrated Sustainable Agriculture and Nutrition (KISAN) Project, and AC-PVWP.

**Figs. 11 & 12: PVWP system and water storage tank used for vegetable farming at Pokharikada, Surkhet, Nepal.**

### *4.3 Cooperative loan for PVWP installation at Chinchu*

Suryodaya Urja installed a PVWP demonstration unit in Chinchu, Surkhet to irrigate 2.8 acres of land for 10 farmers. The 1.4kW Grundfos submersible helical rotor pump, much like the Pokharikada system, is placed in a 5 $m^3$ water tank serving as a spring box. The system is designed to lift 10,000 liters of water 60 meters up to a 24 $m^3$ collection tank. The water is then fed to a drip and sprinkle system and the farmers use the water in queue. The total cost of the system was US$4,988 excluding the civil components. Small Farmer Saving and Credit Cooperative, a local cooperative in the village, financed US$3,000 for the PVWP system at an interest of 18%. In addition, the Municipality Office, USAID's KISAN project, and WI through the AC-PVWP also provided financial support. This system is able to irrigate several crops, such as tomatoes, cauliflower, cabbage, black eyed beans, string beans, potatoes, chile, cucumber, and bitter gourd. With PV water pumping, the farmers group is now able to irrigate throughout the year, have produced their first crop of vegetables, and have paid the first loan installment. It is expected that farmers will fully repay their loan within two years.

**Figs. 13 & 14: PVWP system and vegetable farming at Chinchu, Surkhet, Nepal.**

Demonstration projects in Surkhet have attracted other stakeholders, projects, and organizations working in the agricultural and irrigation sectors. Government agencies, including the District Development Committee, Village Development Committee, and Municipalities, as well as projects like RISMFP and High Value Agriculture Project (HVAP) have also shown interest in the PVWPs and plan to integrate PV water pumping technology in their projects.

### *4.4 PVWP for poultry farming in Chitwan*

A PVWP is used for pumping water for a poultry farm in Madi, Chitwan. The system was installed by Madi Saurya Urja, a local agent of the Rural and Alternative Energy Service Centre. The PVWP can provide 4,000 liters per day of water, as required by the poultry farm. The system consists of a 300 Wp PV array with battery storage using a 150 AH deep cycle lead-acid battery. The 0.5 kW alternating current pump operates from a 1 kVA inverter connected to the battery. The total cost of the PVWP system was US$830, excluding civil works and was purchased directly by the farmer from his operational profits.


**Figs. 15 & 16: PVWP system using a battery and inverter used at a Madi, Chitwan poultry farm in Nepal.**

## 5. Conclusions

The solar water pumping examples in Kenya and Nepal, along with others around the world demonstrate overcoming barriers for commercial sales of solar water pumps by taking advantage of relative cost savings, increased reliability of PV and irrigation, increased technical access through innovative financing models, and educating farmers on pump choices. These successes have been possible through technical and market advances that have lowered costs and increased market access for PVWP. The real challenges now for wide-scale adoption of PVWP are not technological in nature, but rather pertaining to market and educational barriers. When compared to diesel or grid-electricity powered pumps, solar water pumping systems offer better returns on investments and more reliable electricity and water supplies.

Efforts to commercialize PVWP technology for irrigation are on-going. By embedding the technologies in value chain productive use projects that support farmers to increase income by growing and selling off-season produce, there are increased opportunities to demonstrate financial benefits. Current commercialization barriers are overcome through public-private partnerships that emphasize quality systems, education and demonstrations, and linkages with innovative micro-finance institutions, and partnerships with technology providers.

The challenges and successes of PVWP initiatives demonstrate lessons learned that can be applied in other regions, such as Sub-Saharan Africa, where only four percent of land area is irrigated, despite having areas with potentially sustainable water supplies (Giordano et al., 2012). With continued expansion of irrigated land, and demand further still for irrigation solutions in food insecure regions, there is great potential for accelerating and commercializing PVWP systems for irrigation. The scalability and cross regional applicability of these technologies though will depend on the water resources, market linkages, financing options, and management systems.

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