Productive Uses of Renewable Energy (Pure) for Uganda

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Abstract

Productive uses of renewable energy (PURE) technologies are mature, economical, and offer practical solutions that meet the needs of off-grid regions across the globe. Solar photovoltaics (PV) in particular are a mature, reliable, and economically practical solution for both on and off-grid PURE applications such as water pumping for irrigation, flour milling, milk chilling, and cold storage. Solar thermal technologies are practical for crop drying and process heat for agroprocessing. Access to affordable clean energy especially for rural communities is not only economically feasible but also a social justice issue. This paper discusses Productive Uses of Renewable Energy (PURE) impacts in Uganda for rural communities using solar water pumping, solar mini-grids, solar chilling, and solar crop crying.

1. Keywords: photovoltaics, solar energy, water pumping, mini-grids, chilling, milling, food preservation, UgandaIntroduction

We coined the brand Productive Uses of Renewable Energy (PURE) technologies to extend the original PUE concept to indicate further use of clean energy sources such as solar, wind, geothermal, and hydropower to meet local energy needs for economic development. PURE technologies are clean and affordable and often the most economical way to energize processes for locations that otherwise do not have access to conventional energy options such as the national power grid. PURE technologies use local energy that in turn helps create local jobs and community economic growth.

The U.S. Department of Agriculture Foreign Agricultural Service (USDA FAR), the Uganda Solar Energy Association (USEA) and the Government of Uganda (GoU) have helped lead in the application of PURE technologies in the country. Solar through direct applications or mini-grids is a well-developed, mature, and more economical alternative to grid expansion and diesel generators, especially in rural Uganda. There is often an excellent match between seasonal solar resources and seasonal energy needs. When it is dry and sunny, the needs for water and chilling increase along with the available solar energy to power them. USEA has been working with GoU on a number of PURE projects and activities, including developing a roadmap for PURE promotion in Uganda, as well as a national market assessment (GoU, 2023).

2. Uganda Energy Landscape

Only 28% of Ugandans are connected to the national power grid and they are mainly in urban areas; this is one of the lowest grid-connection rates in all of Africa. Only about 2% of the total Uganda energy consumption is from electricity. The total installed grid generation capacity is about 1,400 MW, with a peak demand of about 650 MW. Hydropower remains the nation’s leading power source, representing 80 percent of total electrical generating capacity (IEA, 2023).

Biomass accounts for 90% of the energy used in the country, with about 90% of Ugandans reliant on fuel woods for cooking and heating. The National Environment Management Authority estimates that about 2.6% of Uganda’s forests are cut down annually for firewood, charcoal, and agriculture, and that the country will be completely deforested in another ~25 years if there is no usage change (GoU, 2023).

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The Uganda Ministry of Energy and Mineral Development (MEMD) is responsible for overall national energy policy direction and guidance. MEMD recently updated its 20-year-old energy policy in 2023. For the first time ever, the MEMD-updated energy policy specifically calls for the use of productive uses of energy with an emphasis on renewable energy (GoU, 2023). PURE promotes local economic development using clean energy solutions that offer greater energy security, local jobs, and energy independence.

3. Solar Water Pumping

Solar water pumps (SWP) are one of the earliest PURE technologies, providing water for crops, livestock, and community water supply. SWP system costs have declined significantly over the past decade to < $3 per peak watt (with pump) installed today. SWPs are about five times cheaper to operate than traditional diesel pumps, and less than half the cost of electric pumps powered by the conventional power grid. One of the authors of this paper has installed AC SWPs in Mexico that have operated for 25+ years with little maintenance besides an inverter replacement after about 15 years. NMSU was one of the first three U.S. Department of Energy PV experimental stations in the nation. It has early Block 5 PV modules installed on its facilities in 1981 that are still operational at about 60 percent of name plate rating.

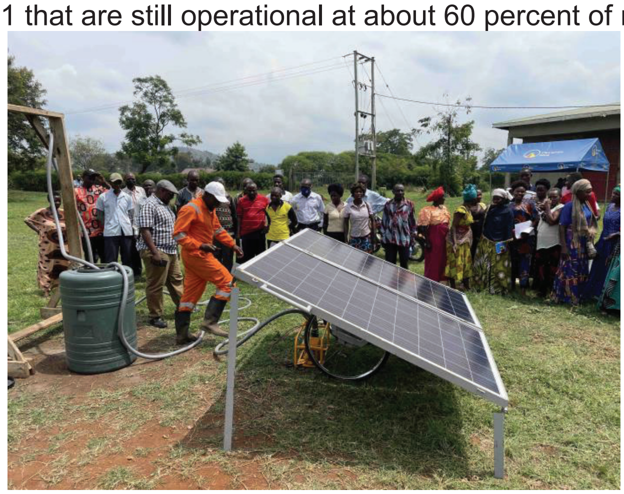

Fig. 1. The USDA farmer training by Green Powered Technology uses a portable solar water pump system with a folding array mounted on bicycle wheels for transportation. It was for crop irrigation that was shared between several farmers at the Rugendabara Coop in western Uganda in August 2022. It uses the world's only surface helical rotor pump, developed by Ennos. (Credit: Robert Foster)

In western Uganda, the USDA FAS partnered with Green Powered Technology, Solar Now, and Clean Energy Enthusiasts to introduce a new and innovative portable SWP with wheels that allows several farmers to share the same pump for irrigation that is wheeled from field to field as needed. This Sunlight SWP is an innovative high-quality surface ½ HP helical rotor pump from Ennos with a maximum total dynamic head of 40 m. This is the only surface helical rotor pump available anywhere. The expected lifetime for the DC pump is 10+ years. The Ugandan farmers irrigate maize, rice, bananas, and other crops.

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Fig. 2. The world's only helical rotor surface pump is the Ennos Sunlight, used in PURE projects sponsored by USDA FAS in western Uganda. (Credit: Robert Foster)

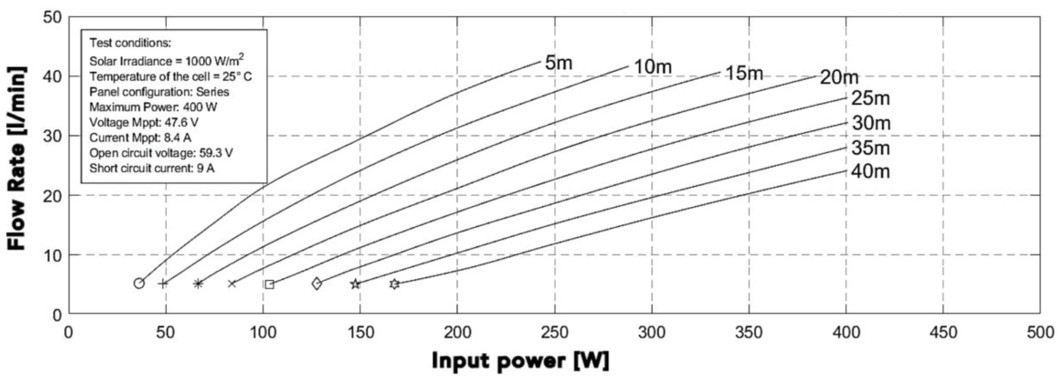

Fig. 3. Ennos Sunlight ½ HP pump curves. (Courtesy of ENNOS)

Micropower and low-power SWP systems provide affordable water even for smallholder farmers, by pumping throughout the entire day. The smallest SWPs have over 40 years of experience in commercial applications (e.g., Grundfos, Dankoff, Lorentz) and show the most technology diversity. They use displacement pumps and DC motors. The low-power range brings in greater use of centrifugal pumps and AC motors. The medium and high-power ranges use conventional centrifugal pumps with AC motors. The following figure summarizes how the various SWP mechanisms fit the full range of water lift and flow that is found throughout Uganda.

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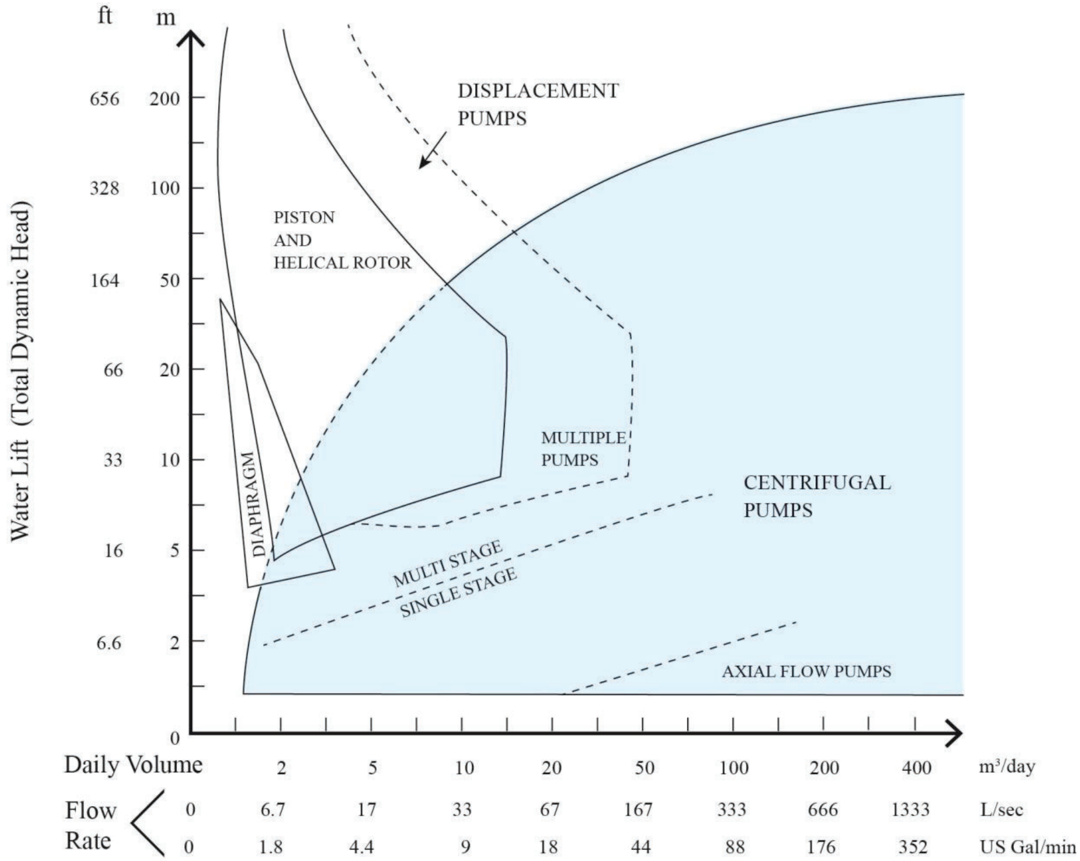

Fig. 4. Pump mechanisms in relation to vertical lift and water requirements. (Dankoff & Foster, 2022)

4. Solar Chilling and Cold Storage

Direct-drive solar refrigeration technology was introduced to western Uganda in 2022 as part of the USDA FAR PURE in support of the Power Africa program. The direct-drive refrigerator uses no batteries that use thermal phase change material (ice) energy storage.

The technology was originally developed in support of NASA's future planetary mission's refrigeration requirements, and later commercialized for vaccine battery-free refrigeration by SunDanzer and subsequently approved by the World Health Organization (WHO).

This is accomplished by integrating water as a phase-change material into a well-insulated refrigerator cabinet and by developing a microprocessor-based control system that allows direct connection of a PV panel to a fixed or variable speed DC compressor. By storing ice in the walls of the refrigerator, it eliminates the need for electrochemical energy storage.

The solar refrigerator uses a vapor compression cooling cycle with an integral thermal storage liner, PV modules, and a controller. The direct-drive solar refrigerator used in Uganda employs a variable-speed dc compressor. By storing ice in the walls of the refrigerator, it eliminates the need for battery storage. Ice never wears out and it provides sufficient energy storage to cool 40 L of milk overnight or other products. Pilot units were placed in Katairwe village near Kyegegwa area in western Uganda.

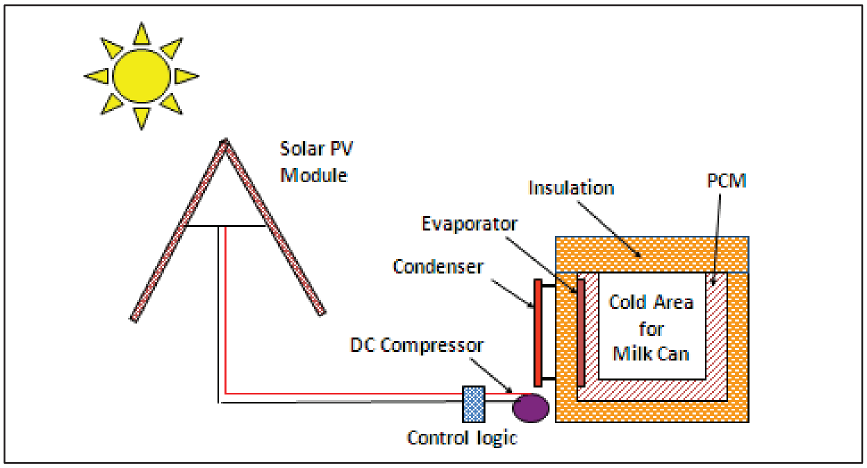

Fig. 5. Solar direct drive refrigerator with DC compressor and E-W “fixed tracking” array. (Foster, 2017)

A unique innovation of the SunDanzer direct-drive solar chillers is the east-west “fixed tracking“ array alignment of the photovoltaic array to optimize compressor run time instead of maximizing energy generation. This enables the direct-drive photovoltaic refrigerator (PVR) DC compressors to run longer by starting up earlier in the day and running longer in the afternoon than a traditional equatorial facing array would and thus lengthen daily chilling time. Tests at New Mexico State University found that the battery-free phase-change thermal storage (ice) system enables the PVR to stay cool for up to a week of cloudy weather.

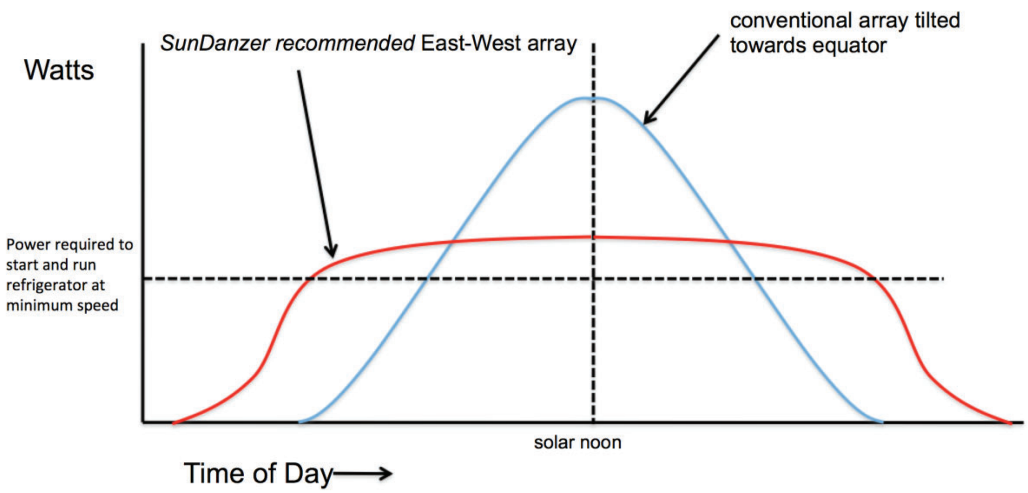

Fig. 6. A fixed E-W tracking array was designed to maximize compressor run time rather than maximum energy capture. (Foster, 2017).

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Fig. 7. A PVR Fixed E-W tracking array was installed in Katairwe village for a local convenience store that sells milk, meat, and cold drinks. (Credit: Robert Foster)

In order to maximize heat transfer, the PVR can also incorporate brine bags that do not freeze at 0°C. They are placed around the milk cans to increase heat transfer rates and cool milk quickly. Milk has some natural substances referred to as the lactoperoxidase system, that has both bacteriostatic and bactericidal effects against some milk spoilage microflora.

This natural system is effective and able to preserve the milk from microbial spoilage for about the first three hours after milking. Bacteriological growth is futher retarded when mik temperatures fall to about 10°C and stops at 4°C. The PVR chills 25 liters of milk down to 10°C in a couple of hours, and the milk temperature in the morning is about 4°C as shown in Fig. 9.

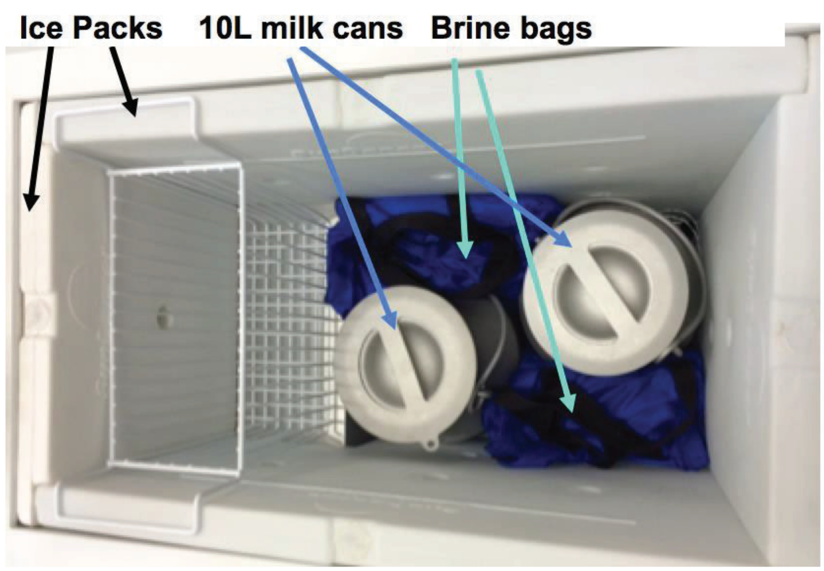

Fig. 8. The project used thermal ice storage and brine bags to chill evening milk. (Credit: Robert Foster)

Fig. 9. Solar milk-chilling test results for 40-liter milk cans. Bacteriological growth in milk largely becomes inactive below 7°C. There is about a 4-hour window before significant bacterial growth starts in milk. The PVR unit successfully meets this threshold. (Foster 2017).

The SunDanzer direct drive PVR can chill 25 liters of evening milk to 40°C overnight. Figure 10 shows the daily milk cooling cycle for milk temperature is repeatedly cooled to 5°C by early morning. Note that the farmer places the empty milk can outside in sunlight for drying after cleaning representing the daily peak outdoor temperature of 30+°C.

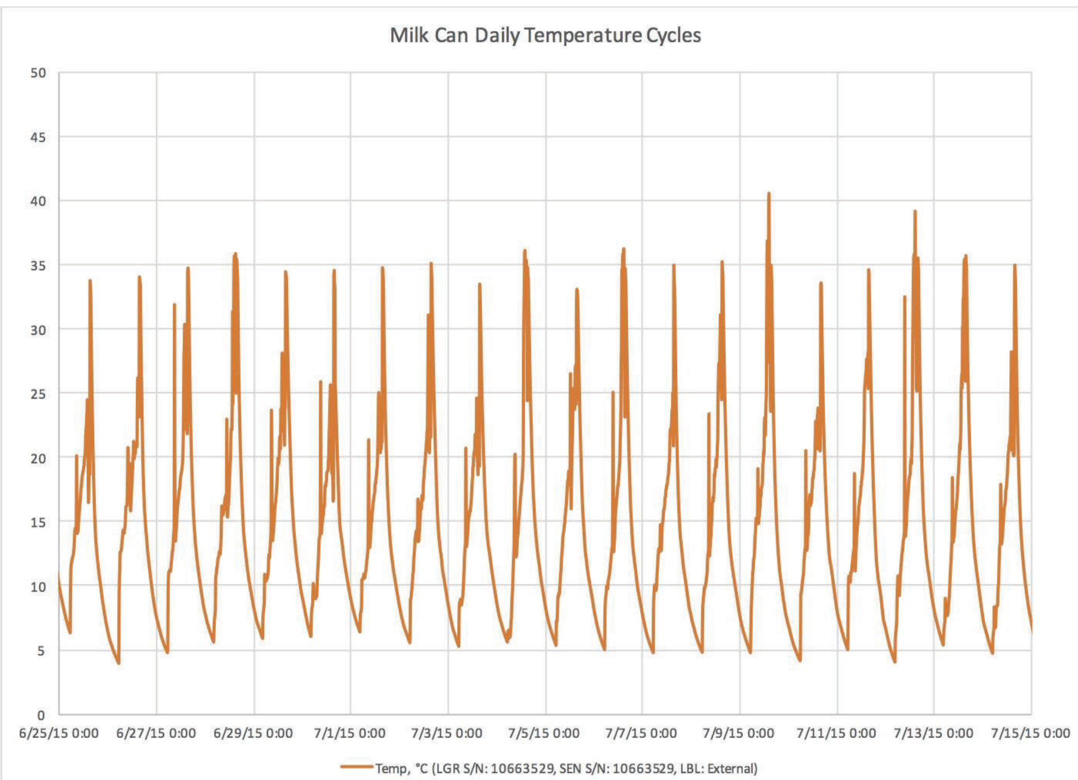

Fig. 10. Daily milk can temperatures show daily cooling cycles on a smallholder dairy farm. The farmers clean out the can daily and put it outside in the sun to dry during the day. (Foster, 2017)

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Fig. 11. Local Katairwe farmers during a USDA-sponsored PURE training event inspected a direct-drive PV refrigerator (PVR) with thermal storage used by a store to preserve meat and chill milk and drinks. (Credit: Robert Foster)

The PVRs are also equipped with two 5V USB charging ports installed on the refrigeration units so the users can charge cell phones, flashlights, or other devices as needed. These ports are sometimes rented out by the owners for a small fee to neighbors to charge cell phones.

5. Solar Mini-Grids for Uganda

Mini-grids are independent small to medium-scale electricity generation systems serving a fixed customer base via a stand-alone electrical distribution grid. Mini-grids can fill the gap where the national grid cannot provide coverage for 70 percent of Ugandans without power. Mini-grids can supply reliable 24/7 electricity to villages where grid extension is unaffordable or impractical.

The Uganda electric grid of the future will become more decentralized and reliable using mini-grids to power electrical loads. There are about 50 mini-grids currently operating in Uganda, the majority of which use hydropower. But increasingly new solar mini-grids are under development to expand beyond hydropower regions. The Government of Uganda is promoting private investment for mini-grids in Uganda.

In 2023 the German bank KfW granted 35 million Euro to MEMD to install ~6 MWp of mini-grids in Uganda with construction starting in 2024. The Beyond the Grid Fund for Africa has recently signed agreements in 2024 to develop Uganda solar mini-grids, as well as direct-drive solar-powered refrigerators with ice storage.

5.1 Mbaata Mini-Grid for Cold Storage, Milling, Hair Salon, and Theater

The Mbaata 25 kWp solar mini-grid in western Uganda was installed in late 2022 by a UK developer. It provides power via three 8 kW SunSynk Inverters and WECO battery energy storage system. The mini-grid powers a milling machine, metal workshop, hair salon, and a small theater. Most importantly, it provides for a cold room chilled by two LG split room air conditioners with a cooling capacity of 6.4 kW each using dozens of cold water containers for cold storage in the insulated cold room to keep horticultural and other crops cool before shipping. This allows farmers to have options to achieve better pricing for their products since they are in a better position to negotiate with vendors.

Fig. 12. The Mbaata 25-kWp rooftop solar mini-grid powers a cold room, a milling machine, a hair salon, a metalworking workshop, and a small movie theater. (Credit: Robert Foster)

Fig. 13. A state-of-the-art Mbaata solar mini-grid control room consists of 3 SunSynk inverters (3-phase AC) and WECS lithium-based batteries. (Credit: Robert Foster)

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Fig. 14. The Mbaata solar mini-grid powers this milling machine used for cassava flour. The author [Which author?] left all his surgical masks behind so the operators will not breathe in fine cassava particulates. (Credit: Robert Foster)

5.2 Katairwe Mini-Grid for Bulk Chilled Milk Storage and Village Loads

The Kyegegwa Rural Electricity Cooperative Society Limited (KRECS) solar mini-grid serves the Katairwe community. KRECS partnered with NRECA International and USAID Power Africa to develop a solar mini-grid to provide PURE electricity. It developed a state-of-the-art solar mini-grid to power community needs for residences and businesses, including a milk-bulking station for the dairy farmers. These efforts have helped stimulate socioeconomic well-being while promoting environmental conservation. The mini-grid system was installed by NRECA and KRECS in late 2022. This is a 56-kWp solar mini-grid with a 5-kWh battery bank and a backup diesel-powered generator rated at 50 KVA. It is a 3-phase distribution system connected within a 4-km radius that serves 176 households and small stores, as well as four medium-scale commercial users comprised of two dairies with milk bulking stations, one coffee factory, and one telecommunications mast.

Fig. 15. The Katairwe village 56-kWp solar mini-grid was installed by NRECA in 2022 for USAID Power Africa and operated by the local KRECS utility. This system provides 3-phase power to 176 househlds, several small stores, two dairies, a coffee factory, and a telcom mast. (Credit: Robert Foster)

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6. Acknowledgments

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7. Conclusions

The USDA FAS Productive Uses of Energy project successfully introduced new and innovative sustainable PURE technologies to western Uganda. This included portable solar-powered surface helical rotor pumps (Ennos), which supply water for irrigation, livestock, and community water supply. Farmer ROI is only a couple of years through increased crop production from irrigation. The new portable design allowed the ROI benefits to be shared between several farmers. The USDA project also introduced direct-drive solar refrigeration with ice storage (SunDanzer) eliminating the need for batteries. Solar chillers help farmers and stores to preserve fresh milk and crops. Payback is less than two years. There are over 5 million smallholder dairy farmers in East Africa who can benefit from solar chilling technologies.

Conflict of Interest

There is no conflict of interest. The authors are not employed by any of the companies stated.

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