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Solar for small-holder farmers made affordable through innovative co-design and financing – lessons learnt

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A R T I C L E I N F O

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A B S T R A C T

A technological revolution in both the cost and performance of solar photovoltaic (PV) technology has transformed the landscape of generating electricity directly from the sun in the last decade. Innovation combined with government incentives and policies led to massive investments which in turn fueled a virtuous cycle of declining PV costs with ever larger production volumes. The core electricity producing technology is scale neutral- a single solar module roughly the size of a typical door in a building, or a solar power plant with thousands of door-sized modules, all rely on the same solar cells.

They are all equally efficient at converting the sun's energy into electricity. This paper describes a case study of using the solar PV technology for small farmers in Senegal to reduce their costs, carbon foot print and collaborate with other farmers. The paper also gives recommendations for farmers in other developing countries based on the lessons learnt in this study. The lessons include benefit from bulk procurement, significantly lower per module cost of installation, logistics, transaction costs and interconnection to the grid.

Introduction

A technological revolution in both the cost and performance of silicon-based solar photovoltaic (PV) technology has transformed the landscape of generating electricity directly from the sun in the last decade [1]. Innovation combined with government incentives and policies led to massive investments which in turn fueled a virtuous cycle of declining PV costs with ever larger production volumes [2]. The underlying PV technology is scale neutral- a single solar module or a solar power plant with thousands of the similar modules, are built with identical solar modules, each about the size of a typical door at home. While the underlying technology and cost of an individual module might be the same, large utility-scale installations with thousands of modules (even a million modules these days), do benefit from bulk procurement, lower per module installation, logistics and transaction costs.

A challenge in many parts of the world is that the grid may not immediately be cost-effective to extend to a cluster of homes or farms, or to a community. Yet, the electricity loads may exceed far beyond those from lighting and cell-phone charging needs. Such needs from electronics are much easier to serve by incorporating battery storage- since the absolute amount of such storage is small. The same is not true of one wants to meet higher power motor loads. Lessons learnt here from Senegal demonstrate how communities leveraged a shared solar resource using low-cost three phase buried cables to serve multiple higher power motor loads affordably by minimizing the need for battery storage.

Solar home systems: their promise and limitations

Many homes in low-income settings not reached by the electric grid that would have otherwise relied on kerosene, candles, or flashlights for lighting, today use a packaged unit called a solar home system, that is built around a laptop-size solar panel to provide lighting and power consumer electronics. The smallest amount of electricity that these systems provide each day turns out to be vital because of the enormous inconvenience and cost of lighting, cell-phone charging, or operating a small television in the absence of one's own households-scale source of electricity and battery storage. A small solar home system provides exactly that.

Yet the absolute amount of this electricity use is roughly a hundredth of what a home in the US might use. The ability of solar home systems to provide an immediate pathway for impacting the livelihood and income generating activity of that household is limited. The grid certainly does not reach the farm if it does not reach one's home; and even if it reaches a home the chances are high that it does not reach the farm.

The technical architecture of a solar home system cannot be scaled up to meet the larger loads of agriculture or livestock operations and the larger loads of agriculture-related enterprises for processing and cold storage easily. The price points that pencil out for the consumer as well as the for the service provider of small solar home systems, are simply unaffordable for the larger income generating activities that must compete in the marketplace beyond your own village and even your own country.

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So why is it that this remarkable innovation in solar PV has not seen pervasive use by the off-the-grid agriculture farms and agri-businesses in the same way? Why is that most farmers that do use mechanization, continue to do so either manually or with fuel-based power in low-income settings even though that is their primary entry point to income growth? Why is that some countries that have subsidized individual farm-level solar systems have yet to see high utilization of those systems?

This is the challenge that this policy brief addresses through lessons learnt in Senegal. The ideas evolved out of several conversations leading to actual field installations in Senegal, followed up by a local agriculture sector bank offering concessional financing.

Senegalese farmers find value in solar through cooperation

Adoption of solar systems, even for use when the sun shines, is a challenge when sized and installed for an individual farmer since the power requirements to lift water are determined by available pumps, depth of water and flow rates of water expected. But when one does that for an individual farmer, much of the solar power remains utilized which in turn degrades affordability. If the farmer whose requirements may be occasional or seasonal sizes batteries to store the surplus the systems get prohibitively expensive.

But what is expensive for an individual farmer to invest in can become affordable when a group of farmers come together and share that power from a common installation. They become increasingly more affordable if a diversity of loads is present allowing year around use. We were working with smallholder millet and maize farmers that were keen to grow a higher value crop of onions. Two onion harvests a year instead of millet could increase their income tenfold if they had a steady reliable supply of water. Not large volumes of water compared to growing sugarcane or rice, especially considering their small plots of land. Being small favored local access to water but being in a cluster within a few hundred meters of each other favored a shared solar system, a common power source despite the extra cost of wire. The shared system would see high utilization.

Indeed, like elsewhere for the poor, the cost of capital for farmers in Senegal is high, and solar does require a much higher upfront investment in solar panels than a small petrol-powered pump. Given how constrained the poor are with capital, an occasional innovative farmer had chosen petrol or gasoline powered engines to drive a pump. In conversations with them we evolved a scheme for sharing solar power- where they would collectively finance an investment so that their individual investment was lower compared to their own solar system. This shared system would ensure high utilization, and the shared system would ensure that the electrical motors they needed for their wells still had adequate power without the need to boost the power by using batteries. In the process they had overcome a major downside of solar power since the technology produces electricity only when the sun shines.

Isolated motor loads that utilize a diesel or petrol pump cost as much as \$0.50 to 0.75/kWh to operate. Their maintenance is finicky and supply chains for fuel are imperfect. Manual power seems free, but it turns out to be even more expensive to the farmer than fuel once one accounts for the explicit or implicit cost of labor. Both these options are however low in capital costs- the second option being virtually zero in upfront cost. Using mutual co-operation as a starting point, and the means to allocate costs to each farmer based on their use enabled them to benefit from solar power. They ensured high utilization by flexibly using the power when the sun shines rather than using it at any time of day which would have required them to store it in a battery. This lowered their cost of power to \$0.20/kWh and shows the pathway to even lower costs as these are modularly designed and installed. Storing the solar power in a battery would have cost them a lot more.

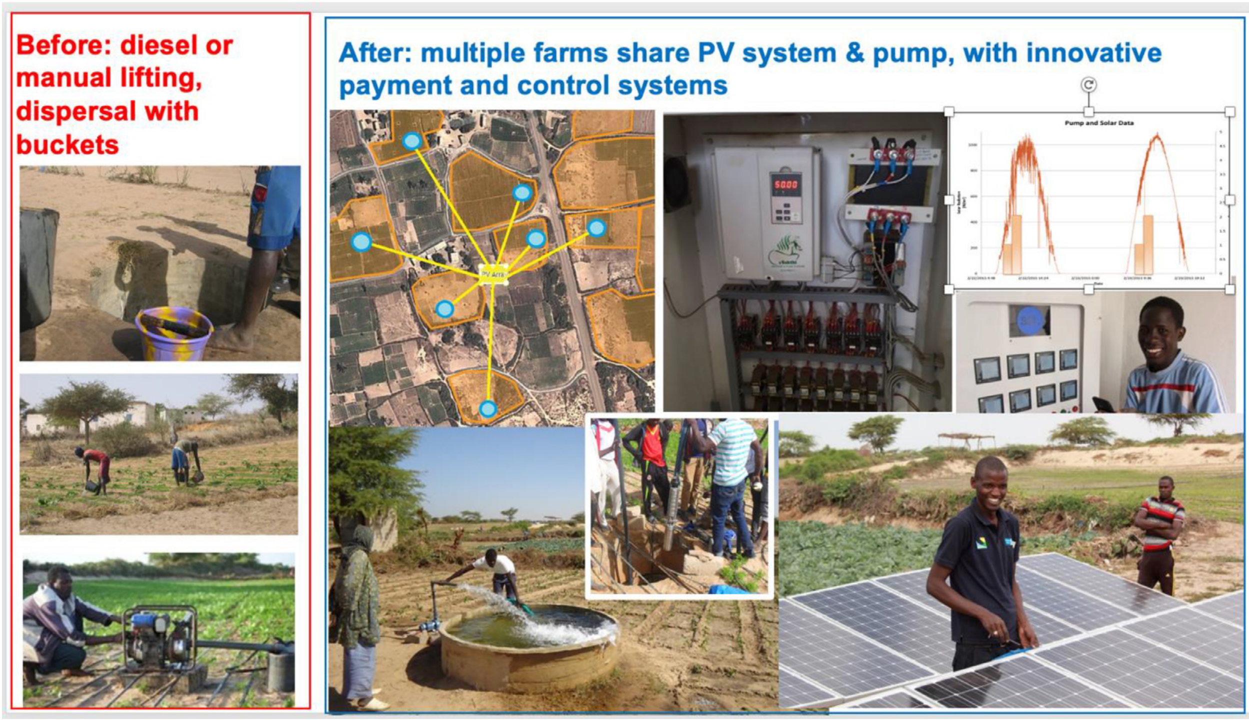
Farming itself is inherently risky. Making investments in solar, electrical hardware and wells- and only pays off in Senegal with high-value crops. But the returns to land and water for high-value crops are a lot higher when compared to cereal crops. A private sector partner we worked closely with has managed to convince a rural bank to extend concessional interest loans to farmers for such technology. Using international development funds channeled by the government to the bank, allowed the bank to offer no-interest three-year financing and one-year deferral for principal to farmers. These are time-consuming arrangements to put in place, but we need the kind of private sector business models as well as the public sector and international funds to invest in improving livelihoods.

Inset in Red: Before with manual or gasoline/diesel pumps. Inset in Blue: clockwise from top left. Location of individual farm plots with buried cable extending from the shared solar PV installation shows as yellow box serving multiple pumps in blue, controller with variable frequency drive and electrical breaker box, solar supply and scheduling as each pump comes on to follow solar supply, local management and control of individual farmer scheduling for time of day and hours of supply and pre-payments, solar PV installation, three-phase induction motor and submersible pump, locally constructed water storage for distribution.

Engineering is perhaps the easy part, yet some innovations made this economically feasible. We showed farmers how to use variable frequency drives instead of inverters, lowering the investment costs. These drives allow the use of a pump at a partial performance even in the early morning and late afternoon sun. We deployed low-cost electrical devices that ensure that locally installed three-phase AC power lines can reach as far as 300 m from where the solar systems were installed. We showed farmers how to use their own labor to trench wire from the solar source to their own well. We developed tools to allow seamless scheduling to share power amongst multiple farmers on the same day and determine what their fair share of the system was. The systems achieved near full utilization of solar power produced within six months of commissioning. Farmer groups organized as co-operatives kept overhead costs low and were surprisingly adept at managing system operations.

The private sector and the government are keen to replicate such success. A key bottleneck was the need to identify clusters of such farmers that would benefit most immediately. Otherwise, the upfront cost of assessing the demand in rural settings can be high. Rural markets are thin to start with and innovations don't see adoption at the rate they could- given the chicken and egg problem of not having a supply chain because there is no market for the product and there being no product since there is no information, no finance and hence no buyer. Through farmer dialog the institutional approach we took for the specific Senegal setting was to work closely with farmer groups. Such groups were already benefiting from cooperation amongst themselves for marketing, transport of product, sourcing of seeds and other agriculture inputs. Note that for individual farmers in a low-income setting, the transaction costs are high given their small production volumes compared to farmers in high-income settings.

We have started an open access portal (https://qsel.columbia.edu/cwp-epu-data-platform/) to show where smallholder farmers are using any means available to them for irrigation. The information is free for others to use and place it on their own portals if they wish to do so. Such a portal could help governments, agencies and the private sector rapidly identify clusters of farmers. Navigate yourself to the map and then the tab for landscape predictions and then to Ethiopia. To visualize the prevalence of irrigation, move the map view over to Ethiopia and you are then able to zoom down to an area of 250 m by 250 m, or about 6 hectares of land tiles to locate higher density of such farmers. Note that most of these farmers are not currently using solar and hence are prime candidates for adoption. But at least they are entrepreneurial, they have found and developed the use of a local source and they have seen a local marketing opportunity for their higher value crop. They are ones who will be the pioneers to demonstrate this opportunity to others near them if there is assistance to technical support them, assistance to overcome the financing challenges of high upfront costs, and support to expand the market for their product beyond just the local area they work in. The first such detailed work was done by us for two states in Ethiopia-



Amhara and Tigray. Effort is underway to expand this approach to other geographies.

Recommendations

1. An important overarching starting point is first finding out what livelihoods the potential customer has identified and then offering options and choices that are meet their constraints and cost points, beyond what is otherwise available to them.
2. Identifying load clusters was critical to affordability. This way installations could minimize or eliminate battery storage and ensure high utilization of otherwise low-cost solar PV technology that produces power only when the sun shines.
3. Solar PV and distribution wire incurs high upfront costs; the practice of agriculture and high-value crops is inherently risky for both climate and market reasons, but there are clear wins for income, lowered emissions, and long lifetimes of equipment. Hence, grants and loans with generous repayment terms are essential to unlock the benefits. Senegal has achieved this successfully through existing rural banks and farmer co-operative structures.
4. Modular systems with minimum complexity that do not require bespoke "time and resources" to assess and carry out custom designs can save on total cost of ownership.
5. Increasing load diversity will allow anchoring mini grids around productive use and then adding commercial and/or household loads-increasing access in the process while ensuring income growth and bringing project economics closer to viability.
6. It is better to start small and then add solar generation capacity as new demands emerge, a paradigm of incremental infrastructure, as opposed to start large expecting new loads.
7. In case of motor loads, especially three-phase motor loads served by solar, the use of VFD drives, load clusters within a 300-meter radius of the power source are particularly low-cost to serve with distribution wire.
8. Distribution costs using safe insulated waterproof buried cables that leverage local labor can be a fraction of the costs of pole-mounted utility grade distribution wire.
9. Beyond technical elements, the crucial organizing and sustaining force for operation is building upon community-level social networks, ensuring high credit worthiness.
10. Business models must also flourish for the private sector that provide robust technology and maintenance support as needed. International technology transfer facilitation is important. So is support for bulk procurement and modularization. Technologies also exist for accounting for power use and leveraging billing/payment systems that can help inject new capital and new operational efficiency.
11. Existing old regulations or codes, or lack of regulations for interconnection with the main grid can be a disincentive for investment and financing of small scale solar PV systems, and set up of mini-grids [3]. Developing countries should review and update their grid connection regulations and codes as recommended by Mambwe et al. [3]
12. Scaling up such efforts does need bringing together stakeholders in agriculture, development finance, government policy support, and willingness of local banks and credit facilities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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