

Policy Brief: Solar without the big grid or battery storage. A step towards affordable power for productive uses.

Vijay Modi, Columbia University, modi@columbia.edu

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. 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. A solar PV cell is a solid-state device built upon Silicon, an abundant material; carries out a sophisticated task but does it by cost-effectively taking sun's energy and using it move electrons preferentially in one direction. Moving electrons is easier, and hence a similar-sized surface can lead to larger current densities and power outputs as opposed to much larger-sized ions that must move during electrolysis, or in a battery or a fuel cell. The core electricity producing technology is scale neutral- a single solar module roughly the size of a typical door at your home, 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. 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) benefit from bulk procurement, significantly lower per module cost of installation, logistics, transaction costs and interconnection to the grid.

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 to the user because of the enormous inconvenience and the high cost of lighting, cell-phone charging, or operating a small television in the absence of one's own source of electricity. A small solar home system provides that.

Yet this electricity provision is roughly a hundredth of what a home in the US might use. The amount of power does not provide an immediate pathway for impacting the livelihood and income generating activities that the household is engaged in. The grid certainly does not reach the farm if it does not reach their 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 small agriculture-related enterprises easily. The price points that pencil out for the consumer as well as the provider for lighting through small solar home systems, are simply unaffordable for the larger income generating activities that must compete in the marketplace beyond your own village and your country.

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? Why is that some countries that have subsidized individual farm level solar have yet to see high utilization of the solar output?

This is the challenge that this policy brief addresses. The lessons learnt 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.

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 meters 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 dialogue 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](#) to show where smallholder farmers are using any means available to them to use 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 250m by 250m, 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. Identifying clusters of loads is key to both minimizing storage requirements and ensuring high utilization of solar power.
2. Additional diversity of loads helps while ensuring that there is a dominant component of productive use loads that can be served at affordable tariffs. It is better to start small and then add solar capacity as new demands emerge, as opposed to start larger expecting new loads.
3. 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.
4. Distribution costs using safe buried insulated waterproof cables can be a fifth of those of pole mounted utility grade distribution when the consumer is willing to contribute through labor. In general, the utilization of local labor in building local infrastructure is under-valued.
5. Modular systems with minimum complexity that do not require time and resources to assess and carry out custom design and installation can save on total cost of ownership. Technologies to permit transparent internal cost allocation amongst a group are key but are now available.
6. Perhaps more important than the technical element, the key organizing and sustaining force for deploying technology is the leveraging of community-level social capital. This ensures high credit worthiness of the borrowing group, backed by rural banking and formal co-operative registration.
7. The single most important overarching goal must be finding out first what the livelihood enhancing energy needs are and then offering choices beyond what are accessible already so that the benefits are clear of an intervention.
8. Solar infrastructure does need high upfront costs, the practice of agriculture and high-value crops is inherently risky both from climate and market reasons, and hence concessional loans with generous terms are essential to unlock the benefits. Senegal has achieved this successfully.
9. In some local settings it makes enormous sense to connect the loads to the grid, and yet policy framework for the utility is exclusively targeted for household loads, which because of the nature of the demand, are either single phase or low-amperage un-grounded connections. A change in thinking at policy level is needed to ensure that

three phase higher power connections, even if utilized infrequently contribute to national level growth.

10. New business models that allow capital from private companies or NGOs to finance extensions in new service areas connected to the existing grid or to new loads combined with financing for quality and bulk sources end-use equipment while leveraging grid back-bone and grid operator billing and payment systems could inject new capital and new operational efficiency. Uganda is a successful example of such an approach.