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Too Cheap to Meter

The Promise of Unstored Solar Power

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Electricity provision in many countries remains a challenge. An even greater challenge is to mesh its use with development objectives. The year 2020 saw power purchase agreements for large utility-scale solar power generation reach prices as low as 1.5 cents per unit (one kWh) of electricity. At comparable scale of installation, 200 MW and above, Ethiopia obtained a power purchase agreement at 2.5 cents per unit. Solar photovoltaic modules are sold by the capacity of the module in watts; a module capacity range of 250 to 400 watts is common, and hence a large 250-MW capacity power plant (i.e., 250 million watts) would need 1 million of a 250-watt module. A 250-watt solar module capacity can produce anywhere from 1 kWh to 1.5 kWh per day during hours of sunshine. It is quite conceivable that at a much smaller scale of, say, 10 kW to 100 kW, capacity for each system installed (i.e., where 30 to 300 modules are installed in each system, if thousands of systems are procured and contracted for installation), could achieve a price point of 10 cents for electricity delivered to a home. This price would include operating costs as well as amortization of capital through loans at concessional terms. A provocative and bold proposition is that 30 kWh/month of daytime power could be made nearly free to the consumer. Consumers could be asked to pay the higher cost of power at other times. The combination would make power universally affordable. The approach would combine low costs with unmet larger power uses—an alternative or supplement to providing public subsidies for grid extensions that the poor would hardly use beyond basic evening and nighttime needs.

Our experience shows consumer willingness to use daytime solar electric supply if the price is right, and a willingness to coordinate power use schedules among a small group to ensure high utilization. This makes possible the prospect of a programmatic installation rollout after communities develop a local management structure, identify land on which to locate solar panels, and show willingness to contribute installation labor.

Could one potentially break through electricity cost barriers in rural areas with higher adoption of electric power for everything from irrigation, processing, cooking, commerce, drinking water, battery charging, and daytime thermal comfort requirements? To do this, one could imagine a complementary community-centric public-infrastructure provision approach that leverages local labor to install hardware and/or wire, as opposed to a commercial approach of building solar home systems best suited for evening/nighttime residential consumption. Systems of this kind may not be suitable for every community in a country. But an approach that frees itself of the constraints of existing transmission and distribution wire could allow early prioritization using community self-identification, commitment, contribution, and initiative. Community ownership and management is difficult to scale, and yet we have seen that this is not impossible if well thought through, perhaps with greater ownership residing with women. This initial entry point could be followed by a pay-as-you-go service for evening. Higher daytime consumption would be a down payment for the development benefits of such low-cost power.

The Revolution in Utility-Scale Solar without Storage

In 2020, the actual cost of electricity at a large utility-scale solar power generation plant fell below US$1/watt installed, comprising the solar modules themselves and what is called balance of system (BOS) costs. Note that at an installed cost of US$1/watt capacity, it becomes possible to supply one unit of electricity for 2.5 cents. The electricity is only produced when the sun shines, of course, but that electricity produced is competitive with the lowest-cost hydropower, cheaper than nuclear power and even coal-fired power plants. This transformative threshold, anticipated for decades, is not just an achievement for the solar industry, it is an achievement for humanity as the electricity is also clean.

With the exponential growth in production of solar photovoltaic (PV) modules, each time production doubled, the costs came down by 25 percent on average over a span of forty years, as reported by the Fraunhofer Institute. The term BOS is worth clarifying. When installations are utility-scale and designed to inject power into the electric grid, these costs generally do not include the cost of providing firm power—a term or trade for assured power over some time period. Capital equipment costs alone do not reflect the low prices of electricity produced. One also needs to lower the soft costs: financing costs that come down with use of proven technology and past experience and technical expertise, stable currency and exchange rates, import and transport logistics, and the cost of labor. It is these soft costs that meant that, as recently as five years ago, a solar power purchase agreement in a developing economy in Sub-Saharan Africa could have been 5 to 7 cents/kWh higher than that in a developed economy with a similar solar resource. The common explanations were around how developing economies experience higher costs of financing, worse inflation and exchange rate volatility, a poor and uncertain enabling policy environment, with a risk of contractual terms not being met. There was also a higher off-take risk in developing countries if the receiving end grid infrastructure was disrupted. So, a cause for celebration is that through a program such as Scaling Solar of the International Finance Corporation (IFC), the electric utility of a land-locked country such as Ethiopia, signed an agreement to buy power from a 250 MW utility-scale installation at a price point of 2.56 cents, or just 1 cent higher than a price point in places that combine financial stability with low costs of capital and labor. This dramatic reduction in the premiums in Sub-Saharan Africa through the IFC program demonstrates that, indeed, the soft costs can be managed, even though it is not necessarily easy to do so. These price points now offer a historic opportunity in Sub-Saharan Africa to bring nearly unconstrained low-cost supply when the sun shines.

The Emerging Revolution in Utility-Scale Solar with Some Storage

Until recently, utility-scale solar did not include the costs of battery storage. Just in the last year or two, some contracts are now for solar power with some storage at the power plant, to increase the ability to supply firm power at least through some hours of the evening and night. For example, the first phase of the Los Angeles Department of Water and Power (LADWP) solar plus storage PPA included 200 MW of solar generation capacity with 400 MWh of storage. In the case of Los Angeles, as in most other settings, these arrangements allow one to reduce the dependence on electricity from higher cost and/or higher emission gas power that must otherwise complement the daytime-only nature of solar power. The "solar with some storage" paradigm avoids the kind of sharp fluctuations in power that can occur even with the passing of a cloud; allows one to modulate what one draws from the solar power plant as electricity demand changes; and extends access to solar power into the evening hours of five p.m. to ten p.m.—that is, beyond the hours when the solar energy output starts to fade.

A good representation of the LADWP system is to imagine that for each 1 kW of solar power one has 2 kWh of battery storage. Let us say that 1 kW produces 6 kWh per day, of which 4 kWh is used during the day between about seven a.m.

and five p.m., while the other 2 kWh can be stored in the associated 2 kWh battery in order to be accessible from five p.m. to ten p.m. This allows about a third of the consumption to be in the evening. Given the costs and battery lifetimes today, it works out that the stored evening power in this arrangement is nearly four times as expensive as the daytime power.

In wealthier economies of the world, large interconnected electric grid networks can mix solar and wind power with sources that are capable of steady power delivery, such as nuclear, hydropower, gas, coal, or oil-fired generation. Such large networks allow one to overcome two hurdles; they make it possible to avoid expensive battery storage and they leverage aggregation of the electricity demands of millions of diverse customers, which makes it much easier to forecast the aggregate draw of power as it fluctuates through the day and seasons. In mixed systems, one can achieve a combination of reasonable cost of power and very reliable 24/7 electricity supply regardless of days without much sunshine. In the absence of other sources and solar plus storage, costs rapidly multiply. One cannot achieve both reasonable cost and reliable 24/7 access from solar and storage alone.

If you do not have the ability to build ecologically friendly hydropower, if geothermal resources are not present, if you do not have low-cost domestic natural gas, you might consider a grid of solar plus ample storage. You could also consider a combination of solar and wind power with some storage and diesel power for occasional backup needs.

The reason we are wedded to the solar plus storage combination for our discussion, is that it highlights the challenges of power generation in the absence of other low-cost resources. The paradigm is useful when we consider local grids that cannot easily integrate most other resources. Wind, hydro, nuclear, geothermal, natural gas, and coal-fired power are at too large a generation capacity to be viable as inputs into small-scale local grids. There is an option of including some liquid fuel (petrol, diesel, propane, or biofuel) generation, but, regardless, most such grids would end up with bulk electricity costs exceeding 50 cents/kWh.

There is another option: adopt solar with ample storage to obtain a reasonable but not complete reliability and accessibility. This way, disruptions from power could be limited to couple of hours a week and no more than a couple of days at a time, occasionally, during the year. In areas with good regular solar supply, the impact of power disruptions can be minimized.

Imagine: Utility-Scale Solar with Ample Storage without Other Energy Sources

Imagine a thought experiment, where the only power on a local rural grid in a developing country would be from this LADWP style mix of solar and battery storage alone, one of the many scenarios that engineers contemplate for a future without fossil fuels. The system would be much smaller in capacity than the LADWP system, but the solar and storage mix would be similar. To pull this off beyond just the engineering, some conditions must be met. For every kW of solar capacity, a full sunny day might produce 6 kWh of electricity, and this must be consumed in a roughly uniform electricity draw by the grid between seven a.m. and ten p.m. If there was a lot more use than 4 kWh during the day, there would not be as much to store as needed in the evening, and if the expected evening time use exceeds 2 kWh, then there would be inadequate amount in storage. In such conditions, even a single cloudy day that produced only 3 kWh instead of 6 kWh would make the entire arithmetic go awry. Hence an electric system that looks like the LADWP system has significant challenges, unless there are other supplemental power sources or a lot more storage.

If one wants to allow for some limited variations through the day in supply and demand, such as managing without disruptions even if faced with two cloudy days in a row, then every kW of solar modules would need perhaps 10 kWh of battery storage, instead of 2 kWh. This would significantly improve the probability of reliable power delivery through the year. Let us call this paradigm "solar with ample storage," ample enough to accommodate two very cloudy days in a row. Microgrids, local grids do exploit this paradigm, obviating the need for large distribution networks in favor of a local grid with a capacity that would be commensurate with a small community need as opposed to that of a large city or a region in a country. It is the larger proportion of storage, associated circuitry, and the shorter lifetime of the battery (compared to lifetime of solar modules) that, in turn, would make the cost of such electricity as high as ten times that of unstored solar power. Since commercial microgrids must also incorporate metering and revenue collection, the retailed price multiplier can be as high as twenty times now. It is this multiplier that must be kept low in order to benefit from low-cost solar.

Now Imagine: A Local-Scale or Home-Scale Solar with Ample Storage Approach

If you do not have large networked electric grids that reach every home, business, or farm, and the cost of extending the wire from that grid to your home or your farm is high, then you must rely on a local grid or your own private solution. The most common private solution today is solar with ample storage.

There are challenges with your own private solution: the electricity requirements vary over the year and your needs grow over a few years. There are diseconomies of small scale, in that an installation of a 25-watt capacity is 10 million times smaller than an installation of a 250 MW power plant.

In spite of these limitations, packaged home-scale solar with ample storage (also called solar home systems or SHS, for short, here) have seen dramatic consumer adoption levels. They meet the basic needs of a home, for now, for affordability reasons. These basic needs are evening and nighttime electricity requirements to power lighting, information (for example, TV or radio) and communication (such as a mobile device, internet) appliances.

We will also see below why these systems deliver power at prices in excess of US$1/kWh. Poor households can afford only a few kWh of consumption at these prices, but for those whose electricity needs grow over time, or for those who need much larger consumption, the price point can be a severe constraint. Yet, these systems are popular because they can be put in place quickly without major scale diseconomies. Solar PV technology is "divisible" in a way no other energy source is today. Divisibility implies that, in principle, one 250-watt solar module[1] costs the same to manufacture and has the same efficiency as each of the 1 million panels that will make up the 250 MW solar power plant in Ethiopia. It is this unique feature that has already brought light to millions of homes without electricity. This option, however, does need ample storage.

Reality: Home-Scale Solar with Ample Storage

A single 250-watt solar module would generously allow one to use several LED lights, a TV, a computer, and even a small refrigerator. Certainly not an air conditioner. When one includes ample battery storage, one-time upfront retail prices, including installation, approach US$1,500. This is well beyond the means of the poor, even without counting future battery replacement costs. This high first-cost price point has discouraged the adoption of packaged systems at this scale. It remains a technological opportunity to crack in the future. Coincidentally, a conventional grid extension could also cost the utility a similar sum. (Of course, when a utility installs the identical solar module without storage at a utility-scale solar plant, the cost of installation today is from US$150 to US$200.)

1. Just in a handful of years, mass-manufactured full-size solar modules that were commonly 250 watts are now 300 to 400 watts. They are about the size of an entrance door in one's house.

The first cost limitation has meant that commercially sold solar home systems (SHS) for homes of the poor are more likely eight to ten times smaller than 250W. Thanks to divisibility, it is possible to have your own personal solar panel. Divisibility also implies that you can obtain electricity without utility wire. So, SHS have been adopted by the millions with an output of a few units of electricity per month, just enough for a few lights and enough to charge a cell phone. Even if they are larger, with the costs of batteries, electronics, and packaging, combined with unit costs of procurement, logistics, and installation, the cost of this solar power now rises to 50 cents or more per unit of electricity—that is, nearly twenty times the cost of bulk unstored solar power at utility scale. Add to this the costs of collecting payments, risk of default, and customer acquisition, and what started out as 2.5 cents/kWh of unstored solar power becomes at least US$1/kWh when retailed to a customer.

Given how important even a small basic amount of electricity is, and the lack of other options, the poor have been willing to pay a high price per kWh for solar with ample storage for single homes. Social enterprises have tried to raise capital from those keen to support a good cause. They have worked hard to add reliably sourced, high quality products, and combined them with good-quality efficient lights and appliances. A fuller description of solar home systems is included at the end of the chapter.

Combining the Divisibility of Solar, Minimizing Storage, and Ensuring Higher Utilization: Can We Come Closer to Utility-Scale Economics?

While for small household loads, the high cost of battery-backed power remains attractive, it is not so for the much larger loads that power small industry or agriculture or even household cooking. Industry or agriculture must compete in a global marketplace. Cooking must compete with free firewood and the supposedly low opportunity-cost of time, generally that of women and girls, used in collecting firewood.

The larger electrical loads could enjoy some economies of scale in ancillary hardware, as opposed to the laptop-size solar panels. Can such an approach maximize the use of solar electricity when the sun shines, by connecting multiple customers to the same supply source? Can one use smaller storage or possibly no storage?

A Practical Experience in Senegal

There is no magical technological solution. But at the scale of tens (and could be hundreds) of 250-watt panels, as opposed to one panel or a million panels, we were able to exploit a dimension of this missing middle when working with farmers in Senegal five years ago. We demonstrated the potential to achieve a retail price point of 20 cents/kWh if attractive financing terms could be reached. This price point includes the cost of capital. Note that with small US$300 to US$500 grants per household that we had access to, and which paid for distribution wire, at today's solar power costs, this would drop to 10 cents/kWh. The farmers were willing to shift their larger loads to daytime hours in order to benefit from the lower price points of daytime solar power without a utility grid connection.

An agronomist colleague of mine had introduced me to onion farmers that were otherwise hand-irrigating their small patches of land, mostly lifting buckets of water from small, shallow wells. A handful of enterprising farmers were using gasoline-powered pumps at a cost equivalent of US$1/kWh, not an attractive proposition for poor farmers. I was told by the farmers that they could make significantly more money by putting a greater fraction of their small land holdings to onions, getting better yields, and doing two crops of onions per year rather than one, if lower-cost power was available. Listening to farmers was key to truly understanding their operational and financial constraints. They were willing to make their own investments in seeds, fertilizer, and drip lines that would save water and energy. The price points of battery-backed solar were not attractive to them, and alternative price points had to be lower than those from diesel and gasoline.

There was the option of requiring a large immediate investment from either the farmer or the utility or the government to extend utility wire to their farms. Utilities have not fully appreciated these farmer energy demands and lack the directives that would encourage them to run such wire. They do not see a strong likelihood of recouping capital costs, so view rural power provision as a losing proposition rather than a great investment in development. Regardless, the grid extension option was not immediately available to the Senegalese farmers I met. Their preference, if they had a choice, was to irrigate fields in the early morning or late evening. There might have been agronomic reasons for this, and a few also did side jobs in the daytime so could only work on their fields in the morning or evening. But they were willing to adapt and make some trade-offs if lower-cost power could be had.

One option we considered was to imagine every farmer having their own private solar panel(s) and pump. Individual systems have tremendous benefits accruing from personal stake and control. Such systems have flourished in some settings. But the main challenge with individual systems in the absence of batteries has been poor utilization. Unused power leads to higher cost. We also learned that it was not easy for individual farmers to prove their creditworthiness to a bank, so they could not finance a personal system. Individual systems that are mobile and low cost sometimes have even greater value for farmers whose power needs are sporadic or at multiple locations. One should not discount the value of a small liquid fuel (at present gasoline or diesel) engine powered pump that can be purchased for a low capital cost. Such a solution would be ideally suited if the power needs are for a single four-month season, or if power is only needed for a couple of times a week, or if one needs to move the system for multiple farm plots. So while a liquid fuel engine is inefficient and expensive to operate, one would not want to close the door on such choices just because solar could be attractive in the settings described here.

Through farmer dialogue, the approach we took for the specific Senegal setting was to work closely with farmer groups. They were already collaborating among themselves for marketing and sourcing of seeds and other agriculture inputs. The group would, in effect, become the owner-operator of a shared system, ensuring financing, maintenance, and payments for the power utilized. They certainly needed a way to ensure accountability of individual farmer electricity use and payments—who used how much and what they owed. They opted for a shared system that would minimize the need for storage and ensure high utilization. Buried wire from the shared solar installation ran to each individual pump, and the longest wire-run was no more than three hundred meters (a thousand feet) to allow use of a wire diameter that kept costs low. Farmers were willing to internally schedule loads in order to match the solar supply curve, thereby minimizing unused power. This is an extreme version of flexibility and demand response that a smart grid of the future is supposed to enable. The Senegal farm group approach may not be applicable everywhere, but the experience provided some lessons from this lean infrastructure and low resource setting that are summarized below.

Some Lessons Learned

First, for income generating electricity loads such as smallholder irrigation, farmers are willing to adapt their demand to timing of solar radiation and solar electric supply.

Second, the price point of supply was critical to farmers, and a battery-storage based system would have priced them out. They were willing to trade the benefits of lower price points for the inconvenience that came with timing their use with the sun and with the constraints of sharing and scheduling power off-take with others.

Third, they wanted to leverage the low cost of submersible AC pumps as opposed to far more expensive DC pumps, even though DC pumps are more efficient. This meant higher electrical power draw when the pump operates, but using three phase AC power reduced wire sizes and made it easier for pumps to start even with partial sunshine.

Fourth, while utilization was high during cropping periods, the fact is that there was no immediate use for power for three months of the year, so an annualized utilization rate of higher than 50 percent was difficult to achieve, based on irrigation loads alone. Note that this could be different with a diversity of daytime loads beyond irrigation, the key being willingness to schedule loads.

Fifth, allowing farmer groups to make payments for pump-hours they utilized, on the day they used the pump, allowed mimicking the payment schedule for petrol or diesel fuel with which they were familiar. A shared system also allowed large anchor farmers to initiate a system, while permitting much smaller farmers to also join.

Sixth, such high-return irrigation opportunities for horticulture do not arise everywhere in the farming landscape. So early and rapidly assessed field data is of great value. We have the possibility today to combine infrastructure, agriculture, and water sector data to leverage opportunities, but also avoid the environmental disasters that groundwater pumping can lead to if done without attention to sustainable water extraction.

Seventh, shared systems at scale need coordination and local organization structure, and require direct lending either to user groups or to private sector that, in turn, provides a service. So, it is important to tailor the specific institutional details to each context. Indeed, individual systems would also play a major role. Specifically, individual systems that could move among locations would also provide value. Solar systems are, however, least suitable for this purpose.

In the case of the onion farmers (there were other horticulture crops as well) we worked with, a 7-kW system shared by seven farmers proved to be a good combination, even though subsequent use suggested sharing among three or four farmers could be viable as well. This system added US$300 to US$500 per farmer in costs for wire extension, but this was offset by an ability to reduce the installed solar capacity by half, to just 1 kW per farmer, compared to the 2 kW per farmer system that sole ownership would have required. The shared system allowed farmers to leverage a single large low-cost variable frequency drive (VFD) that enabled pump operation at part load, justified the higher cost of mechanical devices that allow the solar panel to track the sun, and let farmers spread the cost of managing a prepaid payment system and maintenance over multiple farmers. It turned out that, in the setting we worked in, a cluster of no more than seven farmers was about the right scale to balance the increased cost of wire with the savings from higher utilization. These tradeoffs will depend upon many factors. Certainly, the cost of wire and diversity/nature of loads is a big factor. Utilization and sizing will depend upon crop-specific water requirements, how many crops per year, seasonality of demand, proximity of farmers to each other, well depths, and sustainable water yields.

My observation was that initial adopters were those with the potential to expand high-revenue horticulture crops, local water access, and an assured market for the produce, with transport services available when needed. The farmers continue to use the systems. Over the last five years, they progressively added a larger fraction of land to higher value crops.

The Senegal experience has some broader lessons for the need to combine energy and agricultural expertise in delivering rural power. There is a need to identify viable locations where farmer clusters could leverage existing or future water access and market access and produce higher value crops. This identification could be done by regional agriculture units but strengthened with tools and support at the national level to provide advice on appropriate seeds, soil fertility management techniques, and inputs in addition to energy.

Farmers also need to be assured that energy solutions are now available at much lower price points than petrol or diesel power. Energy providers need to communicate the fact that price points of 10 to 20 cents per kWh are possible if power demands are tens of kWh per month per farmer, even for as few as seven months of the year. If the demand is higher, the unit price of power could potentially be even lower. Farmers should be prepared to adapt their practices to the time when energy supply is most available, and, in turn, the optimal energy infrastructure must adapt to realities of land parcels, well locations, and water constraints.

Many agriculture or agriculture-related applications do not lend themselves to high utilization of solar power when installed at a single fixed location. Indeed, in these situations the use of proven low-capital cost engines that burn liquid hydrocarbons, such as petrol and diesel, to operate pumps should not be discounted as an option even at high operating cost. They are much easier to move around and are well adapted to periodic use. They are seen already in use by individual enterprising farmer (or several who share among themselves) that is willing to use high-cost fuel for a higher reward from horticulture or other cash crops. Such farmers played an essential role in allowing us to identify the enterprising ones who created the anchor or nucleus of larger shared solar systems in Senegal.

Power that Is Too Cheap to Meter

The nature of solar supply is such that one might want to explore the costs and benefits to society of a provocative but as yet untested proposition: If we provide a daily allotment of scheduled power between, say, eleven a.m. and two p.m., at zero cost, for the first five years of operation, to promote safe daytime electric cooking, then the development outcomes of that free power could exceed the costs. The big question is whether such free daytime power would completely flip the equation of how electricity is first used. Currently, cooking is probably the lowest rung on the household electricity ladder—after lighting, television, and electronics. It could be the last because it is expensive, it is not adapted to local practices, lacks appropriate appliances, or scheduled daytime power is simply not convenient for cooking. Would it alleviate the drudgery of cooking for at least one meal, perhaps not every day of the year but at least on days when the sun is shining? We do not know, but this should not be terribly difficult to determine. The poor are resourceful, women particularly so. Women have shown the ability to adapt to seasonally varying biomass availability and incomes. When it allows, they already juggle limited budgets to switch fuels between cooking tasks.

The hypothesis is that the poor will be willing to utilize the nearly free or free electricity when the sun shines, at a much higher level of consumption and with a much higher overall system utilization. We would need to carry out significant educational outreach to allow the shift from deeply rooted cultural traditions regarding when and how to cook.

Perhaps daytime productive uses of power could be provided at slight margins above cost recovery terms. This would still be attractive, compared to other options the poor have. Households would have the ability to invest in their own backup battery to accommodate evening power, whose use could grow organically as limited household budgets allow investments in storage and appliances. Batteries for lighting use alone would not be a huge burden for a poor household, due to advances in LEDs, but perhaps other appliance use at night would require added household investments.

If one can leverage the creditworthiness and the social capital of the poor, ensure the same de-risked financing for intermediate-scale systems, annual energy sales of 15,000 units of electricity could be obtained from a 10-kW system deployed at a raw cost of 10 to 20 cents per unit of power by combining household demands with the demand for productive uses. Certainly more attractive than US$1/kWh of solar with ample storage. Not always cheaper than the grid, but then also not dependent upon large early investments that the grid needs. Such systems could feed into larger grids when they are built out and could equally leverage emerging lower-priced battery storage.

This chapter proposes some engineering approaches to improve the well-being of farmers and poor rural households in a cost-effective way. Shared solar systems can permit small farmers to raise crop productivity, diversify into horticulture, and add value with the mechanization of manual lifting of water. For poor households, I postulate that eliminating or dramatically lowering the cost of electricity during daytime hours would enable a shift toward cleaner, convenient, and time-saving cooking practices. This could reduce the burden of collecting fuelwood enough to support better health, education, and environmental outcomes. We cannot tell exactly how cheap solar energy would change the lives of the poor—we would need carefully constructed field work, or perhaps to ask the poor themselves—but we can imagine a world in the not too distant future, where people who are currently without power or faced with exorbitant costs of power suddenly have access to very cheap solar power. We can be confident this would change their lives.

Appendix: Solar Home Systems

The commercial success of solar lanterns and solar home systems (here we generically refer to them as SHS) is due to the following features:

1. They can be used without any grid, small or large, hence they are called off-grid systems. They can be sold as a product you can own/rent or lease.
2. They primarily meet evening home use applications, such as lighting and, increasingly, a television set as well. The energy services they provide revolve around evening home use, hence a solar panel is packaged with battery storage. Given that these are individual products of a fixed capacity, it is difficult to size the systems for activities that occasionally draw larger power. Moreover, the usual challenges associated with batteries' lifetime, degradation, and replacement costs remain.
3. These systems achieved affordability by essentially leveraging the fact that an LED light, a cell phone or a smart phone, or a television today are all built around solid-state electronics technology that is extremely energy-efficient. Electricity consumption per month remains pitifully low and is generally no more than 2 to 3 kWh/month.

One should never look down on the commercial success that provides value to the poor, and SHS has been a value proposition for millions. Compared to a kerosene wick lamp, otherwise a near-universal staple of rural homes just a decade ago, a small but clean and efficient LED light cannot be beat. Charging your phone should not be a chore, either, with the most expensive electricity per kWh produced using petrol generator, which would waste ten to fifty times the electricity it would need to charge even ten cell phones at once. Yet the combined packaging of a SHS is such that the effective cost per unit of electricity from this packaged home system is an order of magnitude higher than the cost of grid supply.

To some degree, this higher cost of an off-grid supply is mitigated through the use of energy-efficient appliances—leveraging proven product assurances and overcoming otherwise thin supply chains for such appliances. There has been a legacy of CFL lightbulbs that did not live up to their promise because of unpredictable quality, of inefficient television sets, which product packaging has overcome. The dramatic scale-up of solid-state electronics also helped. Mobile-money and other prepayment modalities helped address the first cost barriers.

The transaction costs of collecting small payments for low-cost systems remains a challenge, and so does the issue of product longevity, especially the batteries. There are also lots of poorer-quality products on the market that the poor are compelled to buy in the hope that the seller's assurances are credible. That such small-scale solar home systems have succeeded is just as much about the lack of other alternatives for the poor.