Power Sector

ISSUE BRIEF

BEYOND BASIC ELECTRICITY ACCESS: THE UNREALIZED PROMISE OF SOLAR POWER FOR ECONOMIC GROWTH IN AFRICA

SDSN

COUNCIL OF ENGINEERS
FOR THE ENERGY TRANSITION

An independent advisory council to the
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KEY MESSAGES

Sustainable Electrification in Sub-Saharan Africa

What makes sub-Saharan Africa so unique is that it has ample renewable energy potential but stagnant rural electricity demand. Lacking both last-mile distribution and rural growth strategies limits economic and energy system growth in concert. As a result, the region is home to the majority of the world's 760 million people without access to reliable electricity.

We know Access to Energy isn't Enough

The three main objectives of scaling solar power to support economic growth in Africa are 1) ensuring universal electricity access by 2030, 2) aligning electricity access with existing and new income generating loads and social infrastructure, and 3) creating pathways by 2035 to ensure how rural households can utilize clean cooking. It is important to recognize that affordable access benefits from demand; it is necessary to match efforts for social infrastructure and livelihoods.

Matching an Energy and Economic Transformation

Alongside energy systems development, sub-Saharan Africa must implement country-specific economic transition plans. These plans would identify key growth opportunities in food security, value addition, agronomy, water provision, transport, and manufacturing. With clear agriculture and industrial policy, engineers can develop cost-competitive energy systems that dovetail with economic development to support energy demand and growth.

Prioritize Existing Demand Clusters

Identifying existing demand clusters will create lower risk off-take opportunities for electricity. Clusters of high existing diesel or petrol use are opportunities for an early transition to clean energy, providing proven anchor load demand and lower off-take risks for investors.

Making Electricity Affordable

Utility-built distribution networks have high capital costs relative to demand; however, costs can be lowered through right sizing, incremental infrastructure growth, community-assisted distribution, programmatic deployment of decentralized renewables, and increased daytime solar power. This can jump-start affordability for an economic transition. For example, a shared irrigation system without batteries amongst a cluster of farmers is attractive, because it can ensure high utilization, sharing the cost burden and thus increasing affordability.

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EXECUTIVE SUMMARY

Key insights on energy system challenges and opportunities for productive uses:

The challenge of achieving universal energy access in rural sub-Saharan Africa is both technically complex and financially daunting. The good news is that the continent is blessed with ample energy resources. However, the lack of last-mile distribution of electricity, particularly for agriculture, processing, and businesses, and the lack of a planned rural growth strategy appears to be limiting the economy. Additionally, nearly all agencies and multilateral banks have noted a large gap between needed and actual levels of investments.

Technologically, we are at a tipping point between the use of mature centralized grids and newer decentralized approaches, which are in their relative infancy, but are already cost-effective for lower-density electricity use. An entry point for low-density end use would be policies that provide a combination of solar infrastructure and last-mile wire as public infrastructure to demand clusters — this can jump start deployment and development just like centralized grids do. Jump starting with public provision would make high capital expenditure (capex) technologies — such as solar photovoltaics — viable in settings where the cost of capital remains high. The other entry point is the combined role of decentralized energy and digitalization in creating new employment opportunities for youth, with applications in information and communication technology, education, health, environmental monitoring, payments, and early warning systems.

A core underlying premise of Sustainable Development Goal 7 (SDG 7) has been that if every household has access to electricity, then access to farms, enterprises, businesses, and markets would promptly follow. While this would be closer to the truth if household access were through electric grids, as in countries with universal access today, it is not true if an entire rural sub-region of a country relies only on off-grid solar home systems (SHS).

While an SHS provides for low-capex basic household needs, such as lighting and electronics, avoiding need for distribution wires, the architecture with a deep reliance on battery storage cannot be scaled-up to much larger electric loads, nor can it be scaled up for electric cooking. Yet, it is these larger loads that could play a catalytic role in meeting the SDGs and driving the local economy. Hence, a community reliant on SHS alone ends up limiting electrification of productive activities, which are forced to use expensive diesel power — or else those loads end up being inadequately served.

This use of diesel driven power is ubiquitous in many rural settings without grid access and limits value-addition and agro-processing. We observe smallholder food production requiring irrigation has to rely on manual power, which is not viable for growth. This suggests that labor-saving mechanization is needed for productivity, and such mechanization provides a pathway for both economic growth and for an energy transition. Small and medium-scale rural enterprises that support agriculture, or farmer groups that have already come together to purchase and move inputs or move product to market, are natural social units for creating energy demand hubs for irrigation, processing, or e-mobility.

Development partners can assist with identifying clusters of existing energy demand opportunities. For example, irrigation presence provides strong evidence that issues of land, water, fertilizer, seeds, and market are at least partially overcome, even though all of them could perhaps also benefit from improvement. Pre-identified load clusters are also cost-effective to deliver energy services to offer lower off-take risk for investors.

Certainly, for larger industrial loads from tens to hundreds of kilowatts, captive solar power is already lowering the costs of supply. Yet proven business models for extending distribution wires, or for captive or shared power that can adequately serve these loads, remain elusive except for SHS. This is both an engineering and a financing challenge.

In this paper, we primarily focus on identifying the engineering challenges and opportunities that could make a difference for low-cost distribution, lowering the cost of decentralized solar, increasing utilization of investments, and lowering total cost of ownership of end-use equipment.

With the growing need to ensure food sovereignty and surpluses beyond subsistence, one will need to go beyond electricity provision alone. National governments will need to develop granular, longer term development plans for growth that address value addition, produce certification, market and minimum price assurances, and adaptation for climate extremes. This entails identifying place-specific value chains and activating other line ministries (roads, trade, water, agriculture, energy) to support those specific value chains. The green revolution in India is a prime example of such a mission-driven approach to food security where energy played a key role.

Development professionals have time and again pointed out that investing in women and health is crucial, and yet, clean cooking remains perhaps the most difficult challenge of all. In this paper, we also address how to move the needle on this issue, especially when no electric grids are present.

Key insights on energy system solutions for productive uses:

- Many productive loads, such as agro-processing and irrigation, small and medium operating enterprises, and electricity for e-mobility, are loads that can be daytime centric. It is particularly cost-effective to utilize solar photovoltaic (PV) technology for these loads, especially if they are backed-up by diesel, which in most cases already exists. While solar PV is by no means the only clean technology, it is mature and divisible (it can be utilized at household as SHS, or country scale as utility solar) and it has supply-chains and financing that are potentially scalable.

- An immediately viable short to medium term path is rural options that include mid-scale solar PV systems. These could be in the form of captive or shared SME, agro-processing, and irrigation clusters. One can also leverage clustering, in abstraction a form of special economic zones, but at a micro-rural scale, one can combine the same loads with those for markets and households that are in proximity. These systems would be sized to ensure that wire requirements are not excessive and that solar capacity is not oversized, to ensure economic viability and battery capacity in relation to solar capacity is kept small. A decentralized renewable energy (DRE) rural backbone of such clusters (interconnected within but not across the clusters immediately), coupled with back-up (infrequent use) power where diesel operated machines/gensets already exist, can dramatically lower cost of battery storage.

- A unique feature of solar PV is that if one utilizes the generated electricity directly without first storing it in batteries or feeding the electricity or any surplus into the grid, then the cost of power is an order of magnitude lower than when it is first stored in batteries. As is the case with an SHS. Secondly, engineering solutions for “grid forming,” with decentralized solar for weak grids, are emerging, and hence a pathway for integration of DRE into the grid will most certainly be handy before battery storage is an order of magnitude lower in cost.

- Significant fractions of populations already live close to the grid. Extending wires to both productive uses and households makes economic sense. Such connections are also an immediate opportunity to promote electric cooking. Many countries already have surplus electricity supply available that is ready for off-take, and if they do not, then adding additional renewable capacity to the grid is a cost-effective thing to do.

- In Senegal, we observed a very rapid uptake of power when such power was provided for productive uses. The power had to be competitively priced, and for this to occur, it had to be shared amongst a half-dozen or so farmers to ensure high utilization. Sharing comes with some behavior adaptation, but poorer people are resourceful in leveraging social capital, especially when it comes to producing food and income. It is critical to mention that the success was predicated on concessional-term development finance, which was used to spread interest-free capex over four years and nearly 30% in grants for administrative and loan default risks.

A complementary energy access pathway (in addition to household SHS), should consider:

- Identifying and prioritizing access to existing productive use loads that are operationally expensive to serve otherwise (using diesel, gasoline, manual means) due to the high cost of fossil fuels, are indirectly expensive (manual power), or where the opportunity cost of not serving a load is high. In this demand-driven approach, both development and energy transition imperatives coalesce, so long as concessional finance and administrative distribution mechanisms are in place.

- With support from national agricultural and rural growth policies, initiating a process where these productive use sites start to have knock-on benefits for the communities they are located within, eventually becoming vibrant hubs of economic activities. As diversity of electric loads emerges at these load clusters, they ensure higher utilization across the year, and hence lower delivery costs. Electrification of rural mobility, specifically of 2 and 3 wheelers (for goods transport to market centers) with portable battery packs for shops and households, are both particularly well-suited complementary loads.

- Development of demand hubs to provide low-cost daytime electricity for emerging productive loads, social loads, and in particular daytime household electric cooking, which initiates a path for at least some meals to be cooked in a clean and convenient way. This pathway leads to higher electricity use in the entire community both for businesses and households both seamless growth choices with the same flexibility that the rest of the world has.

- Lowering cost of technologies, both the hardware and deployment. This continues to be essential for greater impact. There is now also consensus around the need for efficient and robust appliances procured at scale, since supply chains are otherwise thin. We discuss some system architectures in the full paper that leverage the low cost of solar PV without being limited by the high upfront and replacement costs of battery storage.

HOW TO LOCALIZE AND PRIORITIZE ENERGY INVESTMENTS

Numerically, there may be far fewer productive loads. For example, on average, one hectare of land irrigated in two seasons with a 40 meter head can end up using the annual electricity equivalent of 3000 kWh, equivalent to 50 times the household electricity use in poor rural settings.[1] A rural maize grinding mill serving the needs of a small rural community (from 50 to 100 tons of grain processed annually) would utilize the equivalent of 1000 to 2000 kWh of electricity, 20 to 40 times the consumption of a single household.[2] Transport estimates are more difficult since a combination of walking, bicycles, motorcycles, and trucks might be involved. Agriculture and food experts suggest increases in both irrigation and value addition, and, hence, associated access to market, are imminent in sub-Saharan Africa.

There is a need to identify clusters of existing energy demand opportunities to leverage their two valuable characteristics. First, load clusters indicate that other constraints to productivity have been addressed by the users. For example, irrigation by petrol, diesel, or manual means provides strong

1. Sowby and Dictaldo, "The Energy Footprint of U.S. Irrigation: A First Estimate from Open Data," 1; Moss et al., *The Modern Energy Minimum: The Case for a New Global Electricity Consumption Threshold*, 3.

2. Galitsky, Worrell, and Ruth, "Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry," 14.

evidence that issues of land, water, fertilizer, seeds, and market are at least partially overcome even though all of them could perhaps also benefit from improvement. Second, known load clusters are cost-effective to provision because they bring higher and proven demand density with lower off-take risk.

In many settings, due to historical, political, or agro ecological reasons, some populations, either because they are pastoral, dependent on low-rainfall drylands, live in difficult terrain, or have livelihoods that are increasingly at risk due to climate change, mining, deforestation, or displacement due to war, have remained without energy infrastructure and new livelihood opportunities. Urgent basic access to energy for these populations is essential, as least-cost planning will not reach them. Moreover, in some of these settings, woody biomass scarcity is acute. Yet, these populations are sometimes nucleated in settlements, either by tradition or as a result of displacement. Solar power provides a unique opportunity to power these communities where daytime power for water pumping or for cooking can jump start a transition led by energy.

Given time urgency, it is necessary to leverage what is technologically possible now. Populations cannot wait for new technological advances. For energy access to aid in growing incomes and for people to fully benefit from energy consumption, rural economies will need to be supported by industrial and agricultural policies that ensure other non-energy constraints are addressed in parallel. In the absence of such policies, we observe that household electricity consumption stagnates at low levels and does not grow.

ENERGY TRANSITION: FOR THE POOREST — ONE ELEMENT OF OTHER TRANSFORMATIONS

The energy transition is one element of other ongoing transitions, and we need to appreciate which other transitions will precede or follow. Noting that the details are very country specific, below is a simplified summary:

An economic transition that lifts people out of a condition of extreme poverty will also be needed. This condition is loosely thought of as the nearly 860 million people that go hungry each night as per a recent IMF study (ref 1). Note that amongst the 48 countries in the list, nearly all are in sub-Saharan Africa. These countries will most certainly consider food security as the most urgent transition. Their planning will need to consider intentional and purposeful policies, interventions, and investments that address extreme poverty, in addition to co-investments in energy that support that goal.

- In this situation, planning for rural growth linked to food is needed, either through improved agronomy, water provision and irrigation, transport, trade, or markets. When linked to this overall planning, energy provision will have immediate benefits.

- There are no-regret measures one can take, even in the absence of such planning, such as identifying existing reliance on diesel, petrol, or manual power and taking advantage of the low costs of renewables (if done right) to replace that use. This increases incomes and reduces reliance on imports.

An energy transition beyond household level SHS that will progressively enable the following transitions:

- From manual or diesel/petrol based productive uses and a diesel-backed industrial sector to cleaner power — captive or otherwise.

- From high total-cost-of-ownership internal combustion engines to electric vehicles, with dramatic increases in both public and private passenger/freight movements.

- Increasing adoption through fuel stacking of cleaner-burning fuels and electricity for cooking in rural areas as is already underway in urban settings.

If we succeed in these transitions, then a desirable outcome will be a significant growth in primary energy use, leveraging efficient end-use where cost effective, and a pace of growth in electricity consumption that is not otherwise seen in developed economies. The good news is that sub-Saharan Africa has the energy and materials supply to provide for itself and perhaps others.

A demographic transition. Over the next several decades, it is inevitable that only a minority of the population will live in rural settings, producing food through mechanization in a labor-efficient manner. With increasing incomes, education, and a younger demographic, a shift to urban areas will hopefully also be fueled by job opportunities in services and manufacturing. However, this transition can take decades, and currently, many countries in sub-Saharan Africa do not observe a rapid decline in rural populations. In fact, it is quite the opposite in some countries. Hence, the timing of a reversal is difficult to predict, and for now one must address the challenge of both energy access and increasing energy supply to provide for economic growth.

HOW CAN TECHNOLOGY AND ENGINEERS SUPPORT THE CHALLENGE?

In this section, we will discuss technologies and their immediate availability, in addition to engineering processes supported by appropriate policy and financing tools to meet the challenges outlined earlier. Note that there are multiple linked measures, both with context specificity and legacy infrastructure to build upon, designed to accomplish goals articulated earlier.

Objective 1: Ensure basic electricity access to all households by 2030.

An estimated 91% of the global 2.1 billion households already have access to electricity[3], with about 2% globally now accessing electricity using off-grid SHS.[4] About 180 million households, or about 8.5% globally, remain without electricity access.[5] The majority of those homes are in sub-Saharan Africa.[6] From an engineering perspective, as many as half of these 180 million households could be cost-effectively reached by grids and mini grids in the coming dozen years. Since financing for such approaches has progressed slower than expected, it would be prudent to ensure basic access for all by 2030. Basic access is ensuring electricity access for lighting, charging mobile, and other electronic ICT devices, and for possible use of small-scale cooling. Much of this gap could be met through off-grid systems. It is worth clarifying that this is a no-regrets stop-gap approach given the urgency, and that a significant fraction of the 8.5% would have an even higher level of access through grids and mini grids. The miraculous divisibility of solar photovoltaic power and advances in low-power consuming electronics for both managing and using the electricity efficiently (e.g., LED) has led to an increase in the benefit to costs of SHS. The same divisibility that allows access to solar energy at smaller scales anywhere also implies reliance on battery storage. Despite progress, the largest contributor to electricity costs (higher than $1/kWh at small sizes prevalent) remains battery storage. With very efficient end-use, especially for the basic uses that are built with solid-state electronics (LED lighting, mobiles, radio, TV) that SHS cater to the most, the services they deliver easily outcompete kerosene and disposable cells.

3. Reliable and safe power connections could be an issue for at least those who live in informal settlements, which in urban metropolitan cities can be as high as 50% of population. While poorly measured, a variety of reasons contribute. These are a poor unsafe quality of a connection due to mud/straw/tin wall materials, tenancy linked issues in informal settlements, reliability of supply and frequent outages due to a host of reasons linked to utility investments, incentives, operations and deferred maintenance.
4. IEA "Tracking SDG7: The Energy Progress Report," 3.
5. Tracking SDG7: The Energy Progress Report, 12.
6. Tracking SDG7: The Energy Progress Report, 13.

The engineering challenges and opportunities are:

- Developing robust packaged systems with long component lifetimes and ensuring appropriate branding, standards, certifications, and built-in fault diagnostics. Additionally, standardizing battery replacement and recycling protocol with indicators of remaining capacity and life.

- Given reliability of grid power, early adopters have been those with grid access, therefore priming the market, and allowing for SHS sizes/capacities to be upgraded to provide additional functionality. However, servicing systems is adding additional high cost to an otherwise low-cost system in trying to reach remote populations.

- It should be possible technologically to *both provide and maintain* a basic electricity service package through an SHS with affordable incentives, subsidies where appropriate, and training programs to those who can afford less than $10/year in spending on electricity. The public component of such a program should be a similar sum of $10/household per year.

- Private sector innovations, payment systems, and packaging of efficient bulk procured end-use have helped. There is also a role for the government now to support adoption to the poorest communities. This can be done through the private sector, directly through local governments' distribution channels, or civil society. Schools or rural productive hubs could be natural aggregation or maintenance locations.

Objective 2: Ensure electricity for existing productive loads (irrigation, agro-processing, markets, SME) and social infrastructure (health, education, drinking water facilities) by 2030.

The impact of productive uses and social service infrastructure is beyond simply a clean energy transition from a diesel/petrol load — it is additionally about leveraging technology to lower the operating costs of such facilities and in turn creating societal value. From the perspective of a service provider, whether a public utility, a mini grid operator, or a seller of captive power systems, the viability gaps to serve larger loads are smaller when compared to the much smaller household loads. The good news is that these are likely to be the most reliable off-takers of electricity. For productive loads, there is already a willingness to pay, and the importance of electricity to health systems is also recognized.

From an engineering perspective there are unique opportunities stemming from these challenges. We first discuss these opportunities in the context of central electric grids with energy transition opportunities for those central grids:

Opportunities for grid systems:

- Productive uses, pumps, refrigeration loads, and motor loads can be seasonal, can need three-phase connections, and can draw larger surge currents at start-up. The electric grid is well suited for such loads. Since annual energy demands for productive uses are much higher than household demands, serving these productive uses in conjunction with household and other market loads in the vicinity is a win-win for the utility, the load operator, and the households. Consequently, it becomes worthwhile for the state to finance the utility which in turn could finance the load operator for the conversion.

- On the utility electricity supply-side, it is worth noting that with increasing interconnections and legacy hydropower, one can utilize hydropower in tandem while increasing solar supply on the grid, which can in turn enhance the value of solar by lowering the need for grid-scale battery storage. This is particularly true if co-located near the hydropower resource.

- It is important to note that whether wire extensions are carried for grids or mini grids, there are opportunities to lower their unit costs by involving local labor and adopting locally appropriate standards, which can be suitable to low initial consumption levels. The examples in Figure 1 show both a professionally built grid and two grids that are for safe, low voltage reticulation built using local labor.

- There are also technical and business models around the edge-of-the grid or service franchisee that may purchase bulk power from the grid. While traditional utilities remain in the sole business of selling electricity, off-grid and mini-grid models have demonstrated the value proposition of sourcing proven, tested, and energy-efficient end-use equipment in bulk at attractive price points, thus protecting the consumers from the uncertainties of a thin last mile end-use equipment supply chain. Mini grid operators are better equipped to diagnose local community constraints and opportunities, localize the sourcing and value addition opportunities, and in turn, source end-use productive use equipment and ensure better utilization of the distribution of grid assets. An edge of the grid model allows you to combine the ability of a utility to deliver low-cost power with the agility of the mini grid to localize distribution and grow demand, thus ensuring that the benefits of the electricity supply are realized.

If the distances from existing grid infrastructure are high, then one seeks alternative approaches. At distances larger than about one kilometer, one starts to also need medium-voltage wire extension in addition to last mile low voltage wire and service drops. There are ways to lower the upfront costs by using mini-grids or the use of captive power. An ecosystem of private EPC contractors and mini grid operators have emerged that are specifically leveraging solar PV technology.

Opportunities for mini grid systems:

- Mini grids save on medium voltage wires and transmission lines, but can become just as high-cost as grids if the added costs of battery replacement and maintenance are high.

- When the power provision requirements are tied to specific tasks that can be scheduled or shifted in time, productive loads can provide significant additional flexibility to reduce upfront sizing costs. This is particularly true if an operator maintains an existing diesel operated standalone supply as a back-up.

- When small-holder irrigation is a load that needs to be served, a particularly low-cost approach is the use of solar power without battery storage. Given high power demands of water lift, a shared system amongst a cluster of farmers is attractive since such an approach can also ensure high utilization. Poorer people are willing to deal with the logistics of sharing a resource amongst themselves if they have the tools to ensure transparency of transactions. They prefer the low cost of scheduled power when compared to the high cost of on-demand power. In Senegal, we observed that farmers using expensive petrol or diesel power provided the ground evidence that energy was a key input and if lower cost power was provided, uptake and therefore incomes could grow. Several systems were deployed using this concept where each

Figure 1: Photographs from Myanmar and Uganda. Source: From the author.

of the anchor farmers led to another half-dozen farmers nearby wishing to leverage electricity provisions. This has led to the growth of a business model where a common solar installation, without storage, is shared amongst a group ensuring high utilization.

- Operators of existing diesel-powered assets are uniquely talented entrepreneurs providing a service in the most difficult of settings serving erratic demands with high-cost fuel. These individuals and the fuel they use have an important role in the engineering of the energy transition: they provide maintenance and reliable cost-effective back up and they have the ability to learn and operate new technologies.

- Productive and social loads are frequently also located at natural demographic and transport aggregation nodes, allowing for dovetailing with emerging electric mobility needs.

Objective 3: Create a pathway by 2035 so that even rural households can utilize electric cooking if they choose to do so. Note that electricity will not be the only option, but one of the options, as part of a fuel stacking strategy by households.

- With solar power, where noon-time surpluses may be present, consumers can be incentivized to cook at least one meal during those hours. While this is not a full transition from biomass to electric, we are already observing that poorer households are strategically willing to shift part of the cooking to electric when it makes financial sense to do so. For example, in informal urban settlements, we are observing that boiling water for tea or even subsequent cooking for porridge is sometimes done with an electric kettle to eliminate the comparative costly part of the cooking with biomass.

- Another technical option is to deploy captive power as an initial option. If loads can ensure at least 50% utilization, then the savings in the grid can be large enough to ensure viability. This has lower transaction costs and avoids any wire between consumers altogether. If one is converting from diesel power, then captive solar power can be lowered if the diesel system back-up is retained.

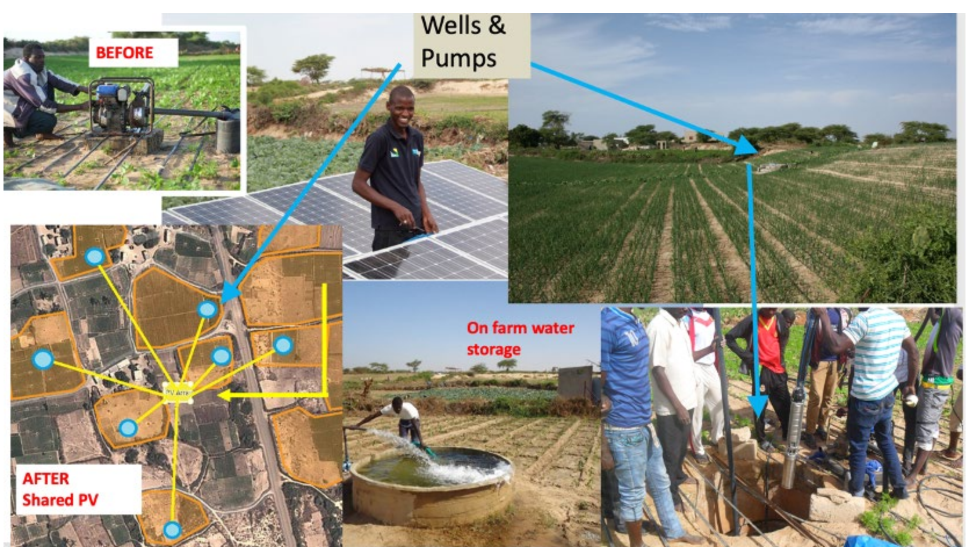

Figure 2: Photographs from Senegal. Source: From the author. Clockwise from top left: Using petrol/gasoline fueled pumps for irrigation; Using solar panels for a shared system; Wells and pumps; Small on farm storage; Farmers sharing a single solar system

SOME OVERARCHING CONSIDERATIONS

- **Where cost effective and immediate, grid or mini grid access has some inherent advantages.** Grid or grid-like mini grid access at the household level is possible, at a modest premium to SHS. We have outlined the means to reduce this premium. Where lack of grid reliability is impeding progress, measures to add solar and storage at grid-scale, and to minimize outages and voltage drops, might be the first no-regret policy.

- **Direct use of solar for daytime loads has very attractive price points.** Battery lifetimes and storage costs continue to decrease and yet remain a significant challenge for twenty-four/seven decentralized power. Where storage is absent, as in most MW-scale utility solar plants, electricity is 5 cents/kWh. Now imagine 10 to 100 kW scale power using the same basic building block, solar modules. They need a fraction of an acre as opposed to hundreds of acres of land. Such installations do cost more, but one can achieve 10 cents/kWh. Even if half the potential generation is utilized, such power can be delivered at 20 cents/kWh. This is a fraction of the cost of diesel power.

- **Maintenance.** It is not uncommon to see a large 10 to 20 hp fossil fuel machine for every 300 households in a rural setting. The operators of these petrol or diesel-powered loads are familiar with the maintenance of these machines. Even if their anchor loads can be largely replaced with solar power, the operator of a fossil fuel machine could provide low-cost O&M for a diesel back-up system given that they are well versed in the maintenance practices.

- **Bring relevant ministries and agencies together to identify any existing industrial and agriculture policy or well-identified value chains that are already in play. This can also help identify large existing clusters of adopters to learn from.** For example, Ethiopia identified horticulture clusters within the country that could benefit from reliable irrigation. The Agriculture Transformation Initiative worked closely with the ministries responsible for energy and irrigation, to demonstrate how the combination of agronomic service support, the creation of water and energy service providers, and both agricultural and household loads could be helpful to the entire ecosystem. At an operational level, one needs to identify clusters of potential electricity demands that can initiate an ecosystem of service providers.

- **Lower costs of technology, logistics, and end-use equipment.** Grid extension standards for the last mile connection to the customer could be load appropriate and could make greater use of local labor during construction. Through standardization and bulk procurement appliances for productive uses and electric cooking and could be efficient and lower in cost.

- **Build on existing social networks to scale and increase utilization to lower costs.** We found consumers willing to share infrastructure. Community-centric initiatives, whether implemented by co-operatives, through farmer groups, market associations, or small edge-of-the-grid private sector concessions can help scale. We lowered distribution costs by using devices that ensured locally installed three-phase AC power lines, which could reach as far as 300 meters from where the solar system was installed. We used insulated waterproof buried cables installed with local labor (which can cost a fraction of pole-mounted utility-grade distribution wire).

- **Financing decentralized renewables at national scale.** It is crucial to recognize that at domestic commercial interest rates, which could exceed 15% for five years, it is virtually impossible to finance renewables except, perhaps, for SHS. Hence, nearly all investments in renewables end up being for utility scale power simply because multilateral banks find it more suitable to offer financing for large single transactions. For example, investments at the scale of a few dozen $200,000/mini grids, solar and battery powered, each financed with an eight-year 15% interest loan, would imply an electricity tariff of $1/kWh. While recurrent costs and fuel costs are virtually zero, upfront costs of solar generation, associated distribution, and end-use equipment cannot easily be paid back at commercial interest rates.

- **Start small and grow infrastructure at the pace of demand.** The modular nature of solar technology makes it easier and more cost-effective to start small and expand the system as demand grows, rather than trying to model latent demand that may never materialize. As more farmer groups expressed interest, we deployed more systems, which reduced both the need for costly pre-assessments and the risk of oversizing the systems. Program support and consistency can create a cumulative pathway.

- **Upgrade regulations**. To enable the long-term success and sustainability of this approach, governments should update codes and regulations to enable interconnection with the main grid, addressing a common disincentive for investment in distributed solar.

- **Innovation Labs.** There is a need to create innovation labs to foster greater private capital inflow and nurture the entrepreneurship ecosystem, thereby developing bankable, commercially profitable, and innovative business models.

- **Accelerate bilateral knowledge exchange between countries to scale success stories.** Thanks to advancements in Asia and Latin America, the number of people without access to clean cooking has been decreasing. However, in sub-Saharan Africa, this number has continued to rise unabatedly. The progress achieved in countries like China, India, Indonesia, Vietnam, and South Africa can offer valuable insights that can be utilized to accelerate progress in addressing challenges in sub-Saharan Africa.

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CEET SUBJECT MATTER EXPERT

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