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Productive Uses of Energy in African Agriculture Could Reduce Poverty

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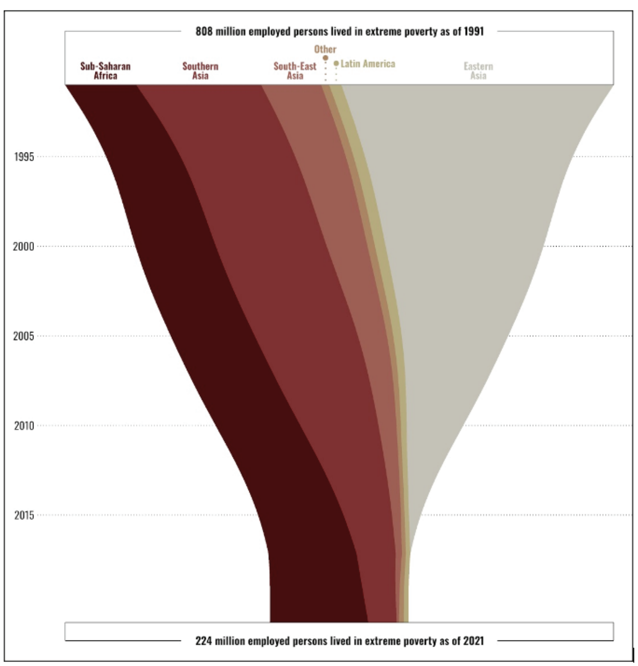
Low rates of energy access in sub-Saharan Africa (SSA) limit the adoption of productive uses of energy (PUE) throughout the economy. This is particularly true in the agricultural sector, which has even lower levels of PUE adoption because rural areas have the least energy access. In many SSA countries, the predominant form of energy is biomass, while the rate of modern fuel consumption for production is very low. This has limited agricultural productivity and value extraction in the continent's dominant employment sector, leading to extensive poverty. Much greater use of energy, particularly electricity from renewable sources for productive uses, will enhance productivity, revenue generation, and employment, doing much to reduce poverty in SSA countries. Cost reductions for critical distributed energy technologies, including solar cells and batteries, along with innovations in products, financing, and purchasing, could make this possible. This paper explores PUE for irrigation, cold storage, and grain milling, and makes suggestions to accelerate their adoption[2].

Introduction

A recent article showed a graph of the number of working poor (those making less than $1.90 per day) by region between 1991 and 2020 (see Figure 1). Where the numbers for Asia are vanishing, the numbers of working poor in sub-Saharan Africa have grown and now make up about two-thirds of the total. (Fontana, 2023) This change in circumstances is undoubtedly due to, among other factors, the different degrees of progress these regions have made toward providing energy access. While most Asian nations are approaching universal access, much of SSA is struggling.

Figure 1. In every Global South region except sub-Saharan Africa the number of working poor has declined since 1991.



For hundreds of millions in SSA, the lack of energy access has kept them in poverty by constraining their ability to improve their economic prospects. While basic energy access opportunities including lighting and clean cooking have improved the quality of life for many, these have not led to large gains in incomes and employment because the amounts of energy supplied are simply too small to generate much economic activity. And on the flip side, the small amount of energy these appliances demand does not provide the necessary incentives for energy suppliers to expand.

Since the beginning of the Industrial Revolution, energy availability has been the driving force for economic development. For millennia, people relied on their own labor and that of animals for plowing, planting, irrigation, harvesting, milling and transport. As energy was limited, so was agricultural productivity and processing, keeping economic development stagnant.

Rural areas in sub-Saharan Africa suffer from extreme energy poverty, even in comparison to the rest of the

2 This paper is intended for agricultural practitioners and others who may be new to productive use of energy concepts.

Global South. While 71 percent of urban people in SSA have access to electricity, just 25 percent of those in rural areas do. (*Global Electrification Database (GED)* 2020) Power grids don't reach most rural areas of SSA, so the average amount of electricity consumed by residents is only enough to charge a phone and power a light bulb for a few hours a day. Even where access is available, power may not be affordable for many. With the exception of South Africa, the dominant form of energy used in SSA is biomass, mostly wood and dung—comprising about 80 percent of all energy use. (Hafner, Tagliapietra, & Strasser, 2018) The lack of access to more—and more efficient—energy cascades throughout society, notably in—and through—the agriculture sector

Agriculture is the predominant economic activity in rural Africa and the leading employer overall, at 53 percent of total employment on average and as high as 80 percent in some countries. (World Bank, 2021) These factors mean that efforts to increase productivity by improving rural energy access—and, in particular, electrification of agricultural activities—would provide large benefits for economic development and poverty alleviation in SSA. Except for biodiesel and ethanol, bioenergy is not a suitable source of energy for most agricultural processes. Mechanical (including labor), electrical, and thermal energy is required for most agricultural and food manufacturing processes. Some examples include:

- Land preparation
- Weeding
- Harvesting
- Irrigation
- Grain milling
- Oil pressing
- Drying
- Food and drink cooling
- Sawmilling
- Improved warehousing (Energy Catalyst, 2020)

Not surprisingly then, with such low levels of suitable energy to power machinery and appliances, only the most fundamental production processes take place in rural areas. In much of SSA, the mechanical energy for land preparation, weeding, and harvesting is supplied by human labor, with the energy for basic food processing such as milling provided by diesel fuel. The energy for irrigation in many places is also supplied by human labor, while the energy for cooling, and most food processing and manufacturing is largely absent, severely restricting the ability to produce perishable products.

Energy availability provides many opportunities to move up the agricultural value chain by transforming harvested crops into products and to grow crops with higher profit margins. Grain milling and pressing turn wheat into flour and oilseeds into oil. Food manufacturing goes a step further in adding value for producers and consumers, turning flour into bread, milk into cheese, and tomatoes into tomato sauce. Cold chains and transportation can then provide market connections for perishable goods such as milk, meat, fruits, and vegetables. To produce these goods and services, "productive" uses of energy (PUE) are critical at every step of agricultural value addition. PUE can be defined as "agricultural, commercial, and industrial activities that generate income and are powered by clean energy sources. These activities increase productivity, enhance diversity, and create economic value." (Energy Catalyst, 2020) Currently, most of the value addition from agricultural production happens outside rural areas because of the lack of suitable energy supplies.

How Can We Support the Expansion of agricultural PUE?

The expansion of PUE holds the promise of resolving these problems even though there are significant barriers to PUE adoption that must be addressed. Fortunately, solar PV and battery prices are moving quickly in a direction that provides the financial spur for PUE. As this fundamental trend continues and new financial models are developed and scaled, the affordability gap will narrow, and more people will seek PUE products. If the PUE market in SSA follows the development of similar markets in other parts of the world, eventually a virtuous cycle of supplier innovation, product familiarity, and buyer trust will lead to exponential growth. The pace and breadth of that growth is the key unknown, but available information suggests it's worth pursuing.

The Rocky Mountain Institute recently published a report that identified six value chain opportunities in Ethiopia with high potential for electrification and revenue generation. (Borgstein, Wade, & Mekonnen, 2020) These opportunities, all suitable for smallholder farmers, could generate over US$800 million a year in additional revenues. They include:

- Irrigating high-value fruits and vegetables, $240 million per year
- Collecting and cooling milk, $260 million
- Two types of baking, $186 million
- Coffee washing, $108 million
- Replacing diesel powered milling, $24 million.

To achieve these gains, we will need to:

Conduct outreach. Many farmers are unaware of the existence of PUE appliances and their benefits and are not familiar with PUE vendors. This leads to a lack of trust and slow uptake of equipment that could reduce costs and increase revenues. Before a solar water pumping campaign in Kenya, just 1 percent of farmers surveyed were using one. After the campaign, 96 percent said they would consider buying a SWP but still did not understand how they could afford it. (World Bank, 2022) **Outreach programs that promote revenue-enhancing appliances, coupled with information on affordability and access to finance, could be transformative.** These programs could be implemented in partnership with renewable energy associations.

Develop high-performing machinery. To convince farmers to spend their money on electric-powered PUE appliances, they must outperform diesel on cost and output in rural settings. Current manufacturers have not shown willingness to invest the R&D required to make electric agricultural machinery competitive with diesel. This inertia may be due to a misconception about the true size of the opportunity. **R&D funding could enable the sector to provide the data, analysis, and information to manufacturers to design and modify mills and other agricultural income-generating machines** that work in rural Africa, catalyzing large-scale production by the private sector. Governments and development partners can accelerate this process by working with manufacturers and retailers to design and implement incentives for achieving specific performance metrics. In addition, quality assurance standards will provide greater trust among buyers that appliances will perform as promised.

Create effective supply chains. Achieving scale of PUE appliances requires end-to-end services along the value chain, including procurement and warehousing, marketing, and distribution, and after-sales services (maintenance and warranty fulfillment) at the last mile. PUE appliances need to get from international to local markets, and from urban distribution centers to rural sites. **Linkages that introduce international and regional suppliers to existing local supply chains could unlock access to communities cost-effectively, increasing penetration of PUE in these areas.** This could be done through local distributors of diesel-powered agricultural machinery, local machinery manufacturers and suppliers, fast-moving consumer goods players, and third-party logistics providers.

Provide flexible financing for appliances. Rural mini-grid customers cannot afford to buy income-generating machinery outright, which hinders uptake. Additionally, mini-grid developers do not have the expertise to structure financing facilities in-house, and it is not their core business. Microfinance institutions (MFIs), non-banking institutions, and Savings and Credit Cooperative Organizations are natural partners to offer financing facilities for rural customers at scale. Leveraging these institutions to provide end-user financing enables developers to focus on their core business. However, MFI terms can be restrictive due to higher interest rates and shorter tenures, and credit assessments can be challenging and resource-intensive, limiting the appetite of financiers to service these customers. **Flexible financing with appropriate payment modalities for PUE appliances is needed.** Governments and development partners could provide guarantees to further increase loan affordability. They could also minimize credit assessment risk by supporting MFIs to utilize more credible data sources and verifiable proxies e.g., national duration of customer relationship with utility providers, employment status, billing history etc.

Establish renewable energy and carbon credit (REC) markets. RECs and carbon offset credits can provide an additional source of revenue for PUE developers and investors, helping to de-risk investments. RECs are intended to support renewable energy development rather than offset direct emissions and do not require a 1 for 1 reduction in carbon dioxide emissions or an additionality test as carbon offsets do (for example, by demonstrating that a diesel generator or water pump was replaced with a solar one). In both cases, the market infrastructure has not been set up in SSA and trades are ad hoc. Only a few countries, including Nigeria and the DRC, have policies in place that explicitly allow trading. To take advantage of the growth of these markets, **it would be helpful if regional market infrastructure plans were developed, standard regulations that each country can adopt were drafted, advice and technical resources were supplied** to relevant government ministries to support implementation of trading regulations, and tools developed and made available to developers to certify and sell their credits.

Encourage gender inclusion. Women make up almost half of the agricultural labor force but have lower productivity and are much less likely than men to be commercial farmers. The gap in micro-, small-, and medium- enterprise financing between men and women in SSA is measured in the tens of billions of dollars and certainly is an impediment to the adoption of agricultural PUE among women. The recent focus on gender-lens investing and initiatives such as the 2X Challenge have helped channel more investments toward efforts that improve gender outcomes, but demand still exceeds supply, so more remains to be done. For example, it would be helpful to **develop targeted outreach and financing programs for women.**

Map potential applications of PUE. Sellers and financiers of agricultural PUE may not have good information about where potential markets exist, leading to inefficiencies and high costs of discovery. **It could be helpful to market development if the densities of potential customers were mapped and made publicly available.** Factors used to create the maps could include crops produced, farm size, availability of surface or groundwater, presence of the grid or mini-grids, distance to populations centers, and incomes.

As agriculture is the dominant economic activity in SSA, activities that enhance productivity and value additions in the sector are likely to have a significant impact on economic development. Those increases though, are not going to happen without a broad infusion of energy for applications such as irrigation, milling, cold storage, and others. As Asia shows, energy access is an essential ingredient to lift people out of poverty and, under the right conditions, near universal access can happen in a relatively short period of time. Of course, the challenges in SSA are in some ways different than Asia. In particular, population densities are much lower, so there will have to be much less dependence on grid expansion to reach people, which is part of the reason solar-powered appliances are appealing. Energy produced from solar panels, where available, have already gone below the cost of energy from the main off-grid competition, diesel. As technology and supply chains continue to improve, and with appropriate policy and financing support, the cost of agricultural PUE will drop further, helping to reverse the growing trend in the numbers of working poor.

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Case Studies: PUE Applications in Agriculture

Water pumping for irrigation | Refrigeration | Grain milling

WATER PUMPING FOR IRRIGATION. Green Scene Energy is an Ethiopian firm that offers solar water pumping (SWP) systems for irrigation[3]. Their cost-benefit analysis shows an 81-percent reduction in the cost of solar-powered irrigation[3] compared to a similar diesel-powered system, due to the high annual cost of diesel fuel. Table 1 shows Green Scene's summary calculations. While the upfront cost of a solar system is more than a diesel system, the savings on fuel more than make up the difference.

Table 1. Solar water pumping for irrigation in Ethiopia costs much less than diesel pumping.

WATER PUMPING SYSTEM	ANNUALIZED CAPITAL COST OF SYSTEM ($US/Y)	ANNUAL MAINTENANCE COST ($US/Y)	FUEL COST ($US/Y)	TOTAL ANNUALIZED COST ($US/Y)	COST OF PUMPING ($US/M3)	ANNUAL SAVINGS OF SOLAR SYSTEM (%)
Solar	1,726	0	0	**1,726**	0.10	**81**
Diesel	1,407	193	7,626	**9,227**	0.51	

Source: (Tufa, 2022).

A similar study in Kenya identified challenges to the adoption of solar irrigation systems, including lack of information for farmers, high initial cost, higher loan rates for solar, lack of technical assistance, and lack of suitably sized solar systems for these farms. However, the study also found that, while the capital cost of solar systems is about three times more than diesel pumping units, avoiding the high cost of fuel produces a net savings for the solar systems by the third season. (SNV, 2022)

In Ethiopia, the recently launched Distributed Renewable Energy-Agriculture Modalities (DREAM) project provides mini-grids to supply power for year-round "large-scale cluster" farm solar irrigation. By supporting household farmer-based Agricultural Commercial Clusters, DREAM is expected to increase farm productivity by 91 percent, production by 86 percent, and farm income by 80 percent compared to diesel-based irrigation. (Odyssey Solutions, 2022)

The World Bank estimates 5.2 million small holder farmers in SSA without grid access grow cash crops for export and have access to water for irrigation. Because of affordability constraints, only about 640,000 of them can access SWP systems. If they did, they could generate an additional $684 in revenue. (World Bank, 2022)
One solution to affordability is to use pay-as-you-go, or "PAYGO" financing. SunCulture offers two options for its Rainmaker 2c Kubwa (See figure 2). One is to make a lump sum payment of US$654, and another is to pay US$34 per month for 24 months (SunCulture, 2023).

Figure 2: Rainmaker 2c Kubwa, a solar irrigation system.

Credit: www.sunculture.io

3 These systems do not require batteries.

Applications of solar energy have become increasingly competitive with other energy sources. The global average price per watt of solar power fell by 84 percent between 2009 and 2019, from US$2.39 to $0.38. (Our World in Data, 2022) Additional declines are expected going forward; the U.S. Department of Energy's goal for 2030 is a 60 percent drop in the cost of residential scale solar energy, to just $0.15-0.17 per watt. (U.S. Department of Energy, 2021) Meanwhile, in the last 10 years, the global average price of oil has swung from a low of $14 a barrel during the COVID lockdown to $116 afterwards, (Trading Economics, 2022) and is very unlikely to see a long-term price decline for technological reasons.

As solar pumping gains a financial advantage over diesel, it is more affordable for more farmers. This is welcome news, as enhanced water availability for crops and livestock will be a key adaptation strategy in the face of climate change. As in much of the world, temperatures are expected to continue to increase in SSA over the coming decades. USAID climate risk profiles for East and West Africa suggest that temperatures in the region will continue the warming trend that began in the 1960s, leading to more crop stress from higher evapotranspiration. (USAID, 2020) In some areas crop production may decline by 11 percent. Precipitation is expected to fall in fewer, larger events, with more runoff and less infiltration. The net impact of the changes is likely a move toward the extremes, with more rain in the wet periods, less in the dry, and more extended droughts and heat waves.

REFRIGERATION. Equipment to develop and enhance cold chains offers opportunities for growing revenues, reducing food loss, and supporting resilience in the face of climate change. Unlike in Europe and North America, very little food is wasted by consumers in SSA. Most food losses there come during post-harvest handling and storage, processing, and distribution, which can amount to 25–30 percent for animal products and 40–50 percent for roots, tubers, fruits, and vegetables. (Gustavsson, Cederberg, & Sonesson, 2011) Some of these losses are attributable to high temperatures and high humidity, problems that will worsen in the future.

For reasons including the high cost of equipment, lack of reliable power and limited energy access, adoption rates for cold storage across Africa are low. In developed countries, cold storage capacity averages 200 liters per person, but in SSA, cold storage capacity is a fraction of that: 2 liters per person in urban areas of Ethiopia and Tanzania and 15 in South Africa. (Drame, Njie, Meignien, & Coulomb, 2016) There is almost no cold storage in rural areas.

Despite great potential for cold storage applications in SSA agriculture, roadblocks remain, the principal one being the affordability gap. An estimated 7.4 million small holder farmers engaged in horticulture, dairy, and aquaculture could make use of cold storage, yet perhaps only 890,000 can afford it. If these farmers did adopt cold storage, they could generate approximately $296 million in additional revenues. (World Bank, 2022)

To improve affordability, new financial models are being evaluated with farmers who produce perishable goods, including Cooling-as-a-Service (CaaS) and lease models. In the CaaS model, a company collects perishables from smallholders, stores them until they can be sold, and then pays the farmers for their product minus the storage and marketing fees. In the lease (or B2B) model, buyers of perishables rent space and manage product purchases there. Results from a pilot in Kenya showed that the availability of cold storage cut post-harvest losses from 30 percent to 4 percent. Due to higher-quality products, farmers were able to get a 20-percent price premium for their goods, which netted a 53-percent increase in farm income (Powering Renewable Energy Opportunities, 2021), showing how PUE can help farmers capture value.

These benefits can only accrue, however, if the cold chain is secure and effectively managed. Extended power outages can damage the quality of stored perishables leading retailers to reject them or offer lower prices. When cold storage warehouses are attached to the grid, battery backups could be cost-effective. Other crucial aspects to cold chain integrity include inventory management; packaging and handling; suitability of operational models; farmer, retailer, and consumer behaviors; skills development; and access to financing. (Peters & Sayin, 2022)

To improve access to cooling for African farmers, retailers, and consumers, in 2020 the Government of Rwanda launched a new African Centre of Excellence for Sustainable Cooling and Cold-chain (ACES) in partnership with the governments of Rwanda and the United Kingdom (UK), the United Nations Environment Programme and the UK's Centre for Sustainable Cooling leading a consortium of UK universities and the University of Rwanda. The mission of ACES is to address the question of "how to provide access to cold-chains to small and marginal farmers in an efficient, affordable, equitable and sustainable manner that builds resilience and achieves the Sustainable Development Goals (SDGs)."

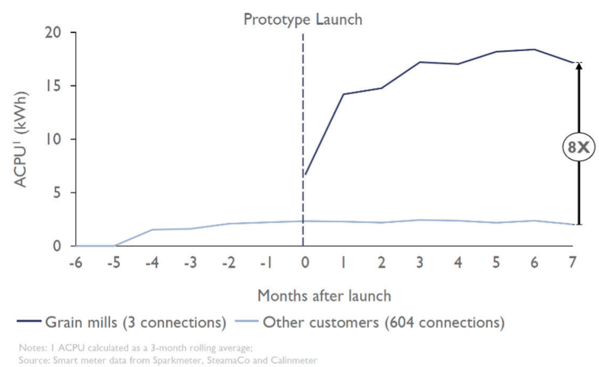
GRAIN MILLING. SSA consumes about 21 percent of global maize production, the main food source for over 300 million people. (McConville, 2020) Because grain milling is so ubiquitous, it is one of the most important agricultural activities for rural Africans, primarily carried out by women and girls.

Diesel mills currently dominate the rural off-grid market due to advantages of familiarity, low upfront capital costs, and established O&M supply chains. However, they have high fuel costs, are less reliable than electric mills, and generate soot and noise. Replacing diesel mills and accelerating the uptake of electric mills could have several key benefits, such as lower energy costs for millers and reduced greenhouse gas and air emissions. They also can serve as anchor clients for mini-grids, improving financial performance for developers and improving affordability for other users.

As noted above, the costs of solar technology are plummeting, and electrical grain mills are more efficient, leading to cost savings for this PUE application. One study found the cost per kWh for diesel versus electric grain mills was about the same, but electric mills were more efficient (0.04 kW/kg for solar mills versus 0.14kW/kg for diesel mills) and so offered a lower cost per unit of grain milled. Despite these benefits, solar mills with the same throughput as diesel mills were not available in the study area, limiting farmers' interest in them. Designs with larger throughput and the availability of installment payments for the systems would make them commercially viable. (Efficiency for Access, CLASP, & Energy4Impact, 2020)

CrossBoundary Labs evaluates new business model innovations for minigrids. One of their tests converted diesel grain mills to electric mills powered by mini-grids. Data from multiple developers showed that grain millers used eight times more energy than median customers (Figure 3). Replacing one diesel mill with an electric mill powered by the mini-grid would increase mini-grid profitability by 11 percent.

Figure 3: Average consumption per user of grain mill vs. median consumption for selected sites.



However, existing operators have sunk capital into diesel mills and are reluctant to purchase electric mills even as the business case for switching improves. To convince these operators, the Lab has launched a study across three communities in Kenya and Nigeria to determine the impact of converting diesel mills to electric on mini-grid economics as well as on mills' profitability and performance.

The presence of a grain mill on a mini-grid could r educe the cost for all users and lead to greater expansion of mini-grids. The Nigeria Integrated Energy Plan (SEforAll, 2021)—developed by Sustainable Energy for All (SEforALL), in collaboration with the Federal Government of Nigeria—explored the impacts of PUE in agriculture. The plan concluded that including maize and rice milling would reduce the cost of power for all users by 9 percent and lead to 200,000 new connections.

Considerable effort to expand energy access in rural areas has focused on residential energy use, particularly lighting and clean cooking, which has had many benefits. The next step for rural economic development is to promote uses of energy that increase employment and incomes by boosting productivity and local value additions.

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