The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa

LIGHTING GLOBAL
Catalyzing markets for modern off-grid energy

AN INNOVATION OF
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IN PARTNERSHIP WITH

ESMAP
Energy Sector Management Assistance Program

Dalberg Advisors

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Lighting Global is the World Bank Group's initiative to rapidly increase access to off-grid solar energy for the 840 million people living without grid electricity world-wide. Lighting Global – managed by IFC and the World Bank – works with manufacturers, distributors, governments, and other development partners to build and grow the modern off-grid solar energy market. Our programs are funded with support from the Energy Sector Management Assistant Program (ESMAP), The Public – Private Infrastructure Advisory Facility (PPIAF), The Netherlands' Ministry of Foreign Affairs, The Italian Ministry for the Environment, Land, and Sea (IMELS), and the IKEA Foundation.

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Our global perspectives are firmly rooted in local realities. We have 17 offices across the world and have served clients in more than 90 countries. By combining local knowledge and international experience, our strategies blend the best global ideas and innovations with the local practicalities and partnerships needed for effective implementation.

FOREWORD

For the past 10 years the World Bank Group's off-grid energy programs – now including Lighting Africa, Lighting Asia, and Lighting Global – have been at the forefront of the drive to develop sustainable markets to deliver quality off-grid solar products to those living without grid electricity. Nearly fifty-four million people worldwide are currently meeting their basic energy needs with products meeting Lighting Global Quality Standards, and the off-grid sector is now seen as crucial in closing the global electrification gap.

Rapid innovation in both technology and distribution models have helped the sector reach this point, and this same innovation continues to explore and open new frontiers in the sector. A host of products powering productive uses leveraging solar energy (PULSE) are being developed across the agricultural, industrial, commercial, and public sectors – products which can provide livelihoods and income-enhancing opportunities for off-grid households.

In this report, we explore the emerging market in Sub-Saharan Africa for small-scale solar applications of 1 kW and below. This is an interesting market segment, especially given that small scale farmers in Africa are the backbone of the agricultural sector. Off-grid energy companies have made significant inroads in reaching rural communities and farmers with solar home systems (SHS) for lighting and entertainment, this adjacent market segment in productive use represents a natural progression that could potentially leverage upon these distribution networks and rapidly scale up adoption.

The findings highlight the potential of PULSE's transformative impact and provides a compelling case for their adoption in agriculture. The vast majority of Africa's off-grid households are in rural areas and largely engaged in agricultural activities – for sustenance, or income, or both. Most are smallholder farmers, often without access to electricity to power incumbent electrical appliances, which would increase their yields.

PULSE can increase productivity and have wide-ranging impacts on these small scale farmers and rural communities, while also supporting governments' transformation agendas, including enhancing food security and creating employment opportunities. The report also looks at the challenges facing this emerging market. We hope these insights will help inform the strategy for industry, governments, and development actors going forward in order to maximize the benefits of PULSE and extend their reach and adoption. At the same time, we will continue to pursue our mandate to grow the off-grid market and lend our support to innovative solutions in this segment and in closing the affordability gap for these ground-breaking new products.

We are excited to begin work on this new frontier in the sector, and are committed to scaling up our work in PULSE as part of our ongoing off-grid electrification efforts. PULSE expands the boundaries of what has been possible through stand-alone technology to date – and thus holds the key to expanding the opportunities and transforming the lives of millions of rural households.

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EXECUTIVE **SUMMARY**

Productive use leveraging solar energy (PULSE) represents the next frontier for off-grid solar (OGS). The OGS sector has grown rapidly over the last decade and is now seen as critical to addressing the global electrification challenge.

To date, efforts have mainly focused on powering consumption-related energy needs, such as household lighting and appliances. PULSE represents the next frontier in providing livelihoods and income-enhancing opportunities for off-grid households.

The spectrum of PULSE use cases is diverse and encompasses activities that can be mechanized across agriculture, industry, and commerce. Solar energy sources can power a myriad of different "productive" activities. These include appliances for tradespeople such as sewing machines and carpentry tools, farmers such as water pumps and processing machines, and for retail outlets such as refrigerators, blenders, and hair clippers.

Given such diversity, it is difficult to narrow in on a single sector of the PULSE landscape. Still, given the importance of agriculture in regions which are predominantly off-grid, we focused in this report on agriculture and primarily irrigation, refrigeration & cooling, and processing use cases.

PULSE appliances are increasingly available in African markets, driven by early-stage firms that develop off-grid technology and the specialist solar distributors that help them reach customers. We estimate there are over 100 firms developing PULSE technology for the African market and hundreds more distributing solar products. These products increasingly fall within small-scale applications of 1 kW or below.

The most common PULSE appliances in the market are water pumps and refrigerators using DC solar power. However, sales penetration remains low. Leading firms report solar water pumps sales of fewer than 5,000 units and DC refrigerators sales of fewer than 1,000 units. Agro-processing units are still in pilot stage.

Currently, early stage firms lead the market. These firms are innovating around technologies to ensure products are off-grid appropriate and affordable. And they are adapting their business models to ensure products can reach those who need them. Large international manufacturers are starting to view the off-grid market as viable, as demonstrated by the initiatives of Lorentz (water pumps) and Embraco (refrigerators) to launch smaller-sized DC products. Solar home systems firms see the potential in PULSE appliances to drive sales and deepen customer value, however they must adapt their business models for more expensive and complex products.

Neither the PULSE technologies themselves nor the markets for these appliances are yet mature. For the most part, PULSE appliances are still at an early product development stage and performance/efficiency has not improved sufficiently for the technology to make sense in the mass market. Solar irrigation is most ready to scale given the comparative performance of solar water pumps versus alternatives and the relatively affordable

cost at small-scale. Irrigation, which requires less aggregation to be viable, also tends to make business sense for individual farmers.

However, solar refrigeration and cooling appliances are still relatively expensive and the business case for farmers is sensitive to utilization of the unit. This requires farmers to produce enough to justify the investment. Solar refrigerators are gaining the most traction for lower-volume higher-value applications, such as milk chilling and fish freezing, as opposed to the cooling of bulkier fresh fruit and vegetables.

The least mature applications are for processing activities, such as milling, threshing, and grating. These activities are more energy-intensive than pumping and cooling, and the business case is heavily dependent on utilization. In addition, the limited mobility of processors constrains farmers' ability to increase utilization by renting them out to others.

The PULSE sector faces traditional agricultural sector constraints, in addition to energy access barriers. The uptake of productive appliances in general, whether solar or alternatives, has traditionally been limited by the sub-commercial scale of most smallholder agriculture across sub-Saharan Africa. Individual farmers often do not have the resources to expand their operations or group together to reach a scale sufficient to benefit from mechanization.

They are cash-constrained and, given volatile income streams, are unable to save capital to invest in productive assets. Also, a whole set of value chain issues, which vary in severity by country and crop, prevent farmers from being able to reap the full benefits of productive appliances. If farmers are unable to access quality inputs or fair market values for their produce, they cannot realize the full income benefit from yield uplifts gained through modern irrigation. If farmers are not well-trained in agronomic best practices, then they may be vulnerable to crop disease or weather shocks.

This leads to diminished yields and keeps them from achieving the minimum utilization required to make a return on agro-processing units. Industry players as well as donors and policymakers must understand these constraints in order to grow the market.

The market potential is vast however, across all PULSE use cases, affordability significantly constrains uptake. We estimate the total "addressable" market in sub-Saharan Africa for three key PULSE appliances—irrigation pumps, cooling & refrigeration, and agro-processing—to be USD 11 billion today. When we factor in an affordability constraint (i.e., which of those farmers could afford the appliance) the "serviceable" market is reduced to USD 700 million. Leading small-scale solar water pumps or DC cooling units on the market cost anywhere from USD 600 to 2,000.

Even with asset financing, which is rarely available in many markets, monthly repayments for PULSE products can reach between USD 20 and 75—unaffordable to the majority of smallholder farmers. There are several key trends which should improve affordability in the coming years. First, as technology improves the relative cost per unit of performance should go down. Secondly, as PULSE firms increase their sales, they should benefit from economies of scale in manufacturing and distribution.

Some portion of such cost savings could be passed onto customers. And finally, rural incomes continue to rise, meaning rural households have higher disposable income. In line with these expected trends, we estimate that the serviceable market for solar water pumps in sub-Saharan Africa will increase from USD 456 million today to USD 1.63 billion by 2030.

Given the complexity involved, growing the PULSE sector requires policy action, market development, concessional financing, and greater coordination between energy and agriculture actors. Governments can do more to incorporate PULSE appliances into their electrification and agricultural transformation strategies. This could subsequently involve subsidies or, perhaps, more deliberate integration of such technologies into wider public schemes.

Tax regimes can be revised to incentivize uptake of PULSE appliances—currently, they often attract high value-added tax (VAT) and import duties, and even where exemptions for DC appliances exist, they are often applied inconsistently. Donors and impact investors can play a role in both (i) subsidizing research & development to drive the performance/efficiency gains required to make the technology more viable and (ii) providing financing to help manufacturers and distributors reach their rural markets.

This capital will need to be patient given the technology's current position along the cost curve and the myriad challenges inherent in agricultural value chains. Finally, PULSE cuts across both energy and agriculture. Donors and policymakers tend to organize in verticals that emphasize one or the other. Greater coordination between the two can ensure that PULSE technology is rolled out successfully and integrated into wider agricultural programs that provide both aggregation and market linkages.

The complete study which this report summarizes can be accessed at *https://www.lightingglobal.org/resource/pulse-market-opportunity/*.

CONTEXT

This report provides an overview of the market for productive use appliances leveraging solar energy ("PULSE") in sub-Saharan Africa. The report seeks to inform the strategy of industry, government, and development actors going forward and to catalyze the market for PULSE solutions across the region. It was produced by Lighting Global, in collaboration with Dalberg Advisors.

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For the purposes of this report, we focused on small-scale applications that can be powered by standalone solar systems of 1kW or less ("micro-PULSE"). While the precise threshold is arbitrary, this is broadly the segment within the PULSE market which overlaps with off-grid household solar, and Lighting Global's traditional field of inquiry.

We narrowed our scope to micro-PULSE in order to explore whether there is an opportunity to catalyse growth in the PULSE market and produce similar results to those achieved under the Lighting Africa and Asia programs. The micro-PULSE segment represents a natural extension for off-grid manufacturers and suppliers that have achieved great success in expanding energy access in rural areas.

We recognize that, by focusing exclusively on micro-PULSE, we leave out the part of the PULSE market focused on larger system loads. Larger PULSE applications that serve farmer groups or cooperatives are often more viable solutions given the economies of scale that can be realized through aggregation.

The market opportunity for larger applications would be a valuable focus for another study. However, for the purposes of this report, we seek to shed light on the micro-PULSE segment, which, although relatively unexplored, presents significant potential. Hereinafter, when we use the term "PULSE" we will be referring to "micro-PULSE."

WHAT DO WE MEAN BY PULSE?

Off-grid solar (OGS) has scaled rapidly over the past decade in Africa and Asia, primarily in the areas of household lighting and basic appliances. As of 2017, total sales of solar products (pico and solar home systems) exceeded USD 3.9 billion and projected market sales by 2022 are USD 8 billion.[1]

The sector is beginning to move beyond lighting appliances to televisions, fans, and radios. Governments are increasingly integrating off-grid initiatives into their electrification plans. Development financiers and commercial investors combined have invested USD 500 million into the OGS sector across Africa in the past two years.[2]

To date, the OGS sector has focused on consumptive use of energy; the industry and investors are now increasingly looking at productive use appliances. For our purposes, PULSE is defined as:

> ***any agricultural, commercial, or industrial activity that uses solar energy as a direct input to the production of goods or provision of services.***

Productive use of energy enables or enhances income generation for households and micro enterprises, often by mechanizing commercial activities that are otherwise performed manually. PULSE appliances can provide significant gains in productivity.

They also offer a multiplier effect to wealth creation, providing a platform for off-grid households to achieve increases in income and build up their capital base. In short, PULSE presents significant commercial and impact opportunities for off-grid communities.

"Productive use" is a broad category with diverse applications across agricultural, industrial, commercial, and public sectors. In agriculture, PULSE encompasses a wide range of activities including: pumping, drying, milling, and pressing.[3] Industrial and commercial applications are even more diverse. Given the range of use cases, it is difficult to have any one overarching view of the PULSE landscape.

PULSE use cases exhibit variable load requirements and energy needs, but for this report, we have focused on applications powered by standalone solar systems of 1kW or less. As set out in the Context, this is the segment of the PULSE market which overlaps with off-grid household solar, Lighting Global's traditional field of inquiry, and typically DC appliances.

Given the current capacity of prevailing solar home systems in the market (broadly between 8 and 350 watts), PULSE products requiring more than 1kW are unlikely to be supported by standalone household systems in the near or medium term.

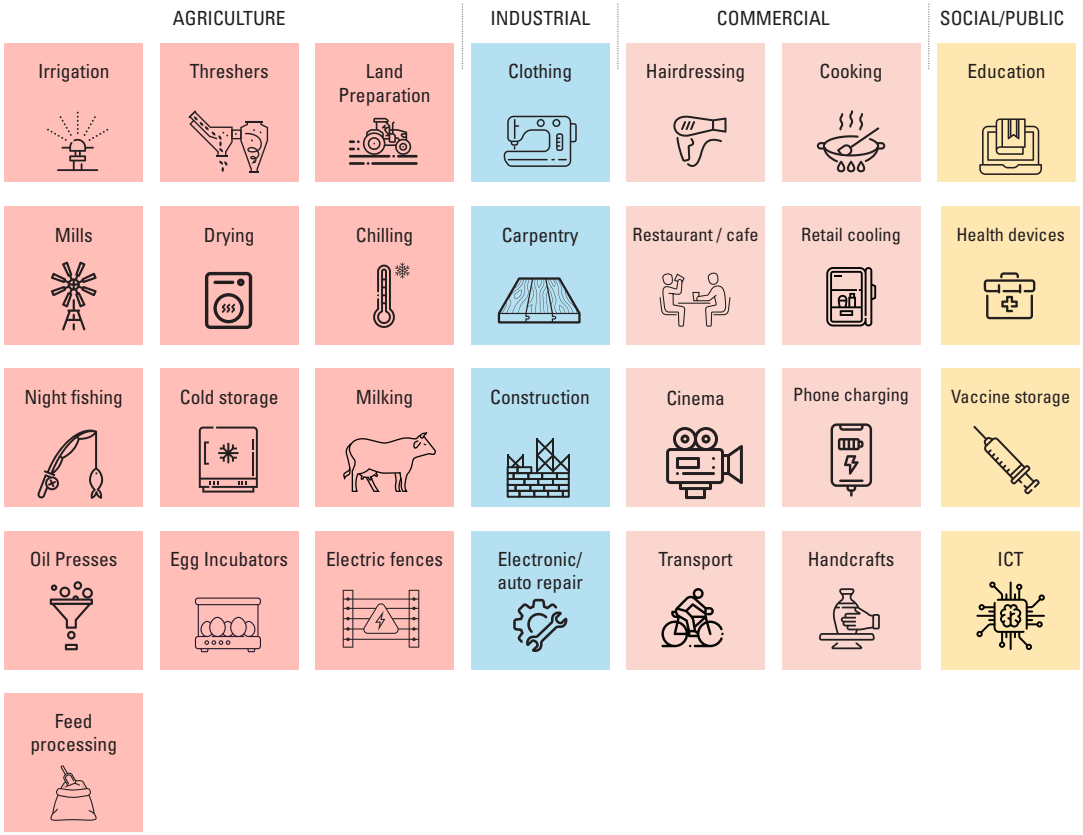
1 Lighting Global. "Off-Grid Solar Market Trends Report." 2018.

2 Ibid.

3 https://www.usaid.gov/energy/mini-grids/economics/productive-use/

Such higher-load appliances are typically AC systems more appropriately powered by larger installations (i.e., commercial & industrial) or as anchor loads for mini-grids and will be relevant only for larger businesses or collective ownership models (e.g., cooperatives). The typical users of standalone DC systems are households, sole traders, and micro enterprises.

Figure 1: Universe of productive uses relevant for off-grid markets in sub-Saharan Africa (non-exhaustive)



WHY IS PULSE MOST CRITICAL IN AGRICULTURE?

The majority of Africa's off-grid households live in rural areas and are engaged in some way or other in agriculture [4]. Many households rely on their farms for both sustenance and income. Because most smallholder farmers cannot afford electrical appliances (water pumps, mills, tractors, etc.), farming remains under-mechanized and yields sit at global lows.

Incumbent technologies have low penetration, rely on diesel fuel or grid electricity, and are mainly geared toward mid-sized and large farms. Given the importance of agriculture in predominantly off-grid regions, we have focused, in this report, on agricultural use cases including, primarily: pumping, refrigeration & cooling, and processing.

Innovation in PULSE appliances for agriculture has increased, but further research & development is required to reduce costs and appropriately tailor products for smallholder farmers. Several firms are designing PULSE appliances for the smallholder market.

For example, SunDanzer's DC refrigerator incorporates features such as bespoke sizing for milk-cans and thermal energy storage to avoid the need for batteries. SunCulture's micro-irrigation kit integrates remote monitoring and system modularity, and is bundled with "pay-as-you-grow" financing.

However, PULSE appliances generally sit at the early stages of the technology curve and more work is needed to make them accessible to a mass market. For example, solar hullers for rice processing in Cote d'Ivoire have 70% less capacity than diesel processors yet cost six times more[5].

This offers a weak commercial case for adoption. However, as costs of solar come down and performance improves, the proportion of the PULSE market most cost-effectively served by solar is getting larger.

Further innovation is needed to increase efficiency and reduce technology costs, especially for more intensive energy uses such as heating and processing, where performance of solar is still not on par with diesel.

PULSE solutions can have a wide-ranging impact on rural communities and the wider economy. Most African governments today boast ambitious agricultural transformation initiatives that aim to commercialize agriculture and significantly increase domestic output in the sector.

These agendas simply cannot be achieved without energy access for productive use. Widespread adoption of PULSE solutions can:

- **Improve food security:** 26% of the sub-Saharan African (SSA) population, aged 15 or older, suffers from food insecurity.[6] PULSE solutions can help meet the growing demand for food through increased productivity and reductions in post-harvest losses.

- **Increase farm productivity:** Most land in SSA is tilled, ploughed, and weeded by human hands (65%) or animal power (25%).[7] The use of machines could increase yields substantially by increasing efficiency up to five-fold or more.

4 Dalberg market sizing; World Bank population data

5 Dalberg research and analysis

6 European Commission. "Africa Regional Overview of Food Security and Nutrition." 2016.

7 FAO. "Mechanization for rural development: A review of patterns and progress around the world." 2013.

© *SunCulture*

- **Create employment opportunities:** Agriculture sustains the livelihoods of more than 50% of the African population. Greater productivity and output can diversify value-adding employment, while accounting for some potential net job loss from mechanization.[8]

- **Enhance resilience to shocks:** PULSE products can reduce vulnerability to multiple shocks by cushioning farmers from the impacts of climate change, fuel price variations, and fluctuations in market prices for agricultural produce.

- **Stimulate growth in the real economy:** By increasing agricultural productivity, PULSE products stimulate socio-economic development. UNEP estimates that, for every 10% increase in farm yield, there has been an estimated 7% reduction in poverty in Africa and more than 5% in Asia.[9]

8 FAO. "Mechanization for rural development: A review of patterns and progress around the world." 2013.

9 United Nations Environment Programme (UNEP). 2012.

WHAT ARE KEY PULSE USE CASES IN AGRICULTURE?

Among agricultural PULSE use cases, water pumps are most ready to scale, cooling solutions are still relatively expensive, and, agro-processing units are still at pilot stage. The market readiness of PULSE technology varies significantly depending on the use case and associated energy consumption and system requirements.

The more power-intensive the PULSE use case, the larger, bulkier and less mobile the system required can become. Larger installations of standalone solar are still prohibitively expensive for the vast majority of farmers. Solar water pumps are now relatively affordable at a micro-scale and even farmers of land as small as 0.5 acres can benefit from the yield uplift from irrigation.

Solar refrigeration remains relatively expensive and the business case for farmers is sensitive to the value density of the produce (higher for milk/fish than for vegetables) as well as utilization of the unit which is often low for smallholders.

Walk-in cold rooms typically require power of 2kW or more and are therefore out of range for all but larger commercial farmers or cooperatives. PULSE applications for processing activities such as milling, threshing, and grating are the least mature.

These activities require more energy than pumping/cooling and the business case is heavily dependent on utilization. Ample use is challenging given small average farm sizes. In addition, the limited mobility of processors constrains farmers' ability to increase utilization by renting them out to others. Solar-powered agro-processing units do not currently match diesel units in terms of performance at any scale.

There are a variety of other use cases for agriculture which can be mechanized. However, cost and performance of PULSE appliances are still not competitive with diesel or mains-based alternatives. Solutions leveraging solar energy for specialized applications, such as egg incubators, butter makers, and coffee pulpers, are emerging.

These products are increasingly competitive with traditional alternatives but have not yet found a large market due to the lack of access to consumer financing of the smallholder farmers who would most benefit from such appliances. For more energy intensive agricultural activities, such as heating, drying, and pressing, PULSE appliances do not yet match the performance and output of available alternatives.

Figure 2: Commercial readiness of PULSE use cases by product size

	Irrigation pumps	Cooling & refrigeration	Agro-processing
	> 5 Ha	**>10,000 L**	**> 10 MT/day**
Large	While technologies exists there are limited large scale applications in practice	Typically applied as walk-in cooling, technologies are available at an aggregated scale, but uptake remains low	The main examples that exist are mini-grid applications as like-for-like replacement of grid processing
	2 – 5 Ha	**2000 – 10000 L**	**2 – 10 MT/day**
Medium	The majority of supplier distributors are targeting this scale and uptake is reasonable depending on the geography	Fewer technologies in this category as providers are either looking at large aggregated systems or smaller individual systems	The main examples that exist are mini-grid applications as like-for-like replacement of grid processing
	< 2Ha	**200 – 2000 L**	**1 – 2 MT/day**
Small	Technologies are well developed and available but affordability and market development are barriers	Productive uses typical adapt refrigeration intended for small retail enterprise use, uptake is low	Incumbent technologies exist but the system size is prohibitive for standalone applications
	<1 Ha	**<200 L**	**< 1 MT/day**
Very Small	Recent product development has increased affordability, precedents are emerging in some markets and are starting to scale	Productive uses typical adapt refrigeration intended for household use and uptake is low	There are limited standalone technology choices and use cases are unproven

Commercial readiness: ***High*** ***Mid*** ***Low***

Figure 3: Spectrum of PULSE products by system capacity

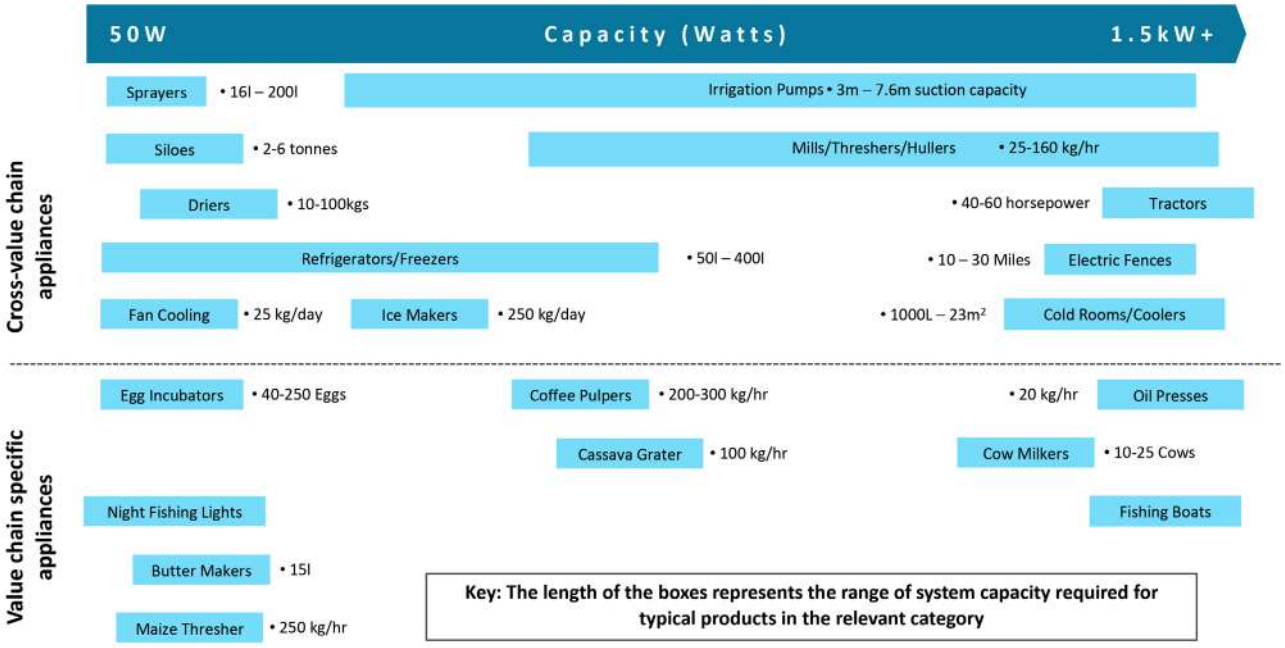


Figure 4: Illustrative range of product specifications of typical PULSE appliances

Irrigation Pumps

Surface water pumps
- Wattage: 75w – 1.5kW
- Head: 6-75m

Submersible pumps
- Wattage: 0.45-22kW
- Head: 4-310m

Other - Livestock

Poultry incubators
- Wattage: 75w – 100W
- Capacity: 48-1000 eggs

Milk machines
- Wattage: 1,1kW
- Head: 20 cows/day

Cooling/Drying

Chilling systems
- Wattage: 40-200W
- Capacity: Up to 45l of milk/day

Refrigeration
- Wattage: 40-400W
- Capacity: 50-400l

Freezing/ice making
- Wattage: 95W
- Capacity: 1.2kg/day

Walk-in cooling units
- Wattage: 2kW+
- Capacity: 9 tonnes+

Fan cooling/drying
- Wattage: <50W
- Capacity: 25-100kg

Agro-processing

Flour Milling
- Wattage: 500-750W
- Capacity: 25 -160kg/hr

Husking/Threshing/Hulling
- Wattage: 100-375W
- Rice Capacity: 35 -70kg/hr
- Maize Capacity: 250kg/hr

Grating
- Wattage: 250W
- Capacity: 100kg/hr

Oil & nut presses
- Wattage: 1.5kW
- Capacity: 20kg/h

WHAT IS THE SIZE OF THE OPPORTUNITY IN AFRICA?

The potential addressable market for PULSE in sub-Saharan African (SSA) is large and growing, but the serviceable market remains limited by affordability constraints. We sized the market for three PULSE use cases in agriculture: (i) irrigation, (ii) cooling & refrigeration, and (iii) agro-processing.

These three uses cases represent some of the most in-demand and mature PULSE use cases in agriculture across the region. We first looked at the total addressable market of all farming households that would need one of these products, accounting for the necessary conditions for households to benefit from PULSE products e.g. access to water for pumps.

Then, we looked at the total serviceable market, factoring in the proportion of those households who could potentially afford one of these products based on current retail prices, disposable income and associated access to finance. To benchmark the appliances, we looked at the leading products on the market and focused on applications of 1kW and below.

Based on our analysis, we estimate the total addressable market for these three PULSE products to be USD 11.3 billion.[10] However, when ability to pay is factored in, we estimate the total serviceable market to be considerably lower at USD 734 million.[11]

This serviceable market might be discounted further if we were to take into account the relative affordability of solar products versus traditional alternatives, especially for agro-processing where solar technology is still early stage. Further primary data would be needed by market to fully incorporate this aspect.

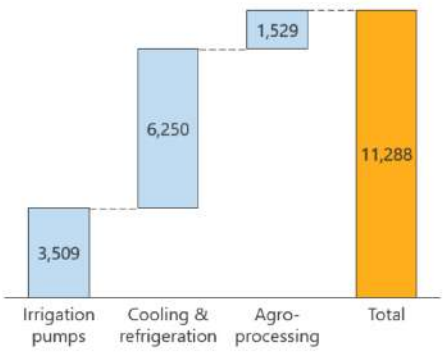
10 Dalberg analysis.

11 The market sizing methodology is based on: (i) assessing the number of smallholder farmers or production volumes to indicate total potential demand and (ii) discounting the potential demand (total addressable market) by market structure/physical constraints, grid access, and affordability to determine the serviceable market. The serviceable market is then multiplied by the average unit price of industry-leading products to calculate market size.

Figure 5: Total market size for PULSE use cases in sub-Saharan Africa

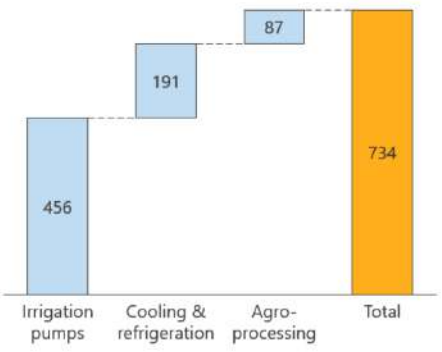
Total SSA addressable market (2018)

Market value, millions (USD)



Market value, millions (USD)

Total SSA serviceable market (2018)



For solar-powered water pumps, the total addressable market (without factoring in affordability) is comprised of 5.4 million farmers, whereas the total serviceable market (taking affordability into account) contains 701,000 farmers. We based our sizing in relation to the average cost of leading products on the market— USD 650 for a 220-watt pump. To estimate the total serviceable market, we performed the following steps:

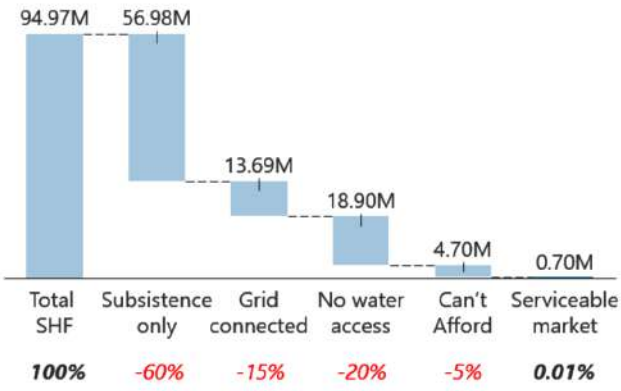
- First, we estimated the number of rural smallholder farmer households – 95 million
- Next, we deducted:
    i. Famers who only grow produce for subsistence use – 57 million,
    ii. Famers who have grid access – 13.7 million,
    iii. Famers who don't have a water source—18.9 million, and
    iv. Farmers who can't currently afford solar pumps— 4.7 million.

This estimates the total serviceable market to be 701,000 farmers today, amounting to USD 456 million (compared to the total addressable market of USD 3.509 billion).

Figure 6: Total market size for solar-powered irrigation pumps in sub-Saharan Africa

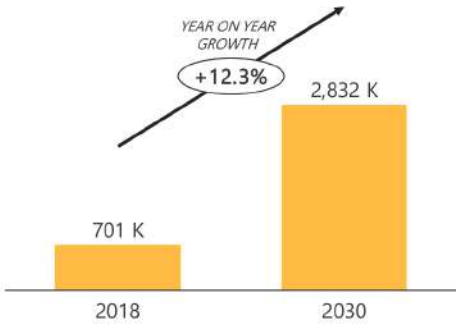
Total SSA serviceable market calculation breakdown (2018)

Number of smallholder farmer households



SSA serviceable market projected growth (2018-2030)

Number of smallholder farmers



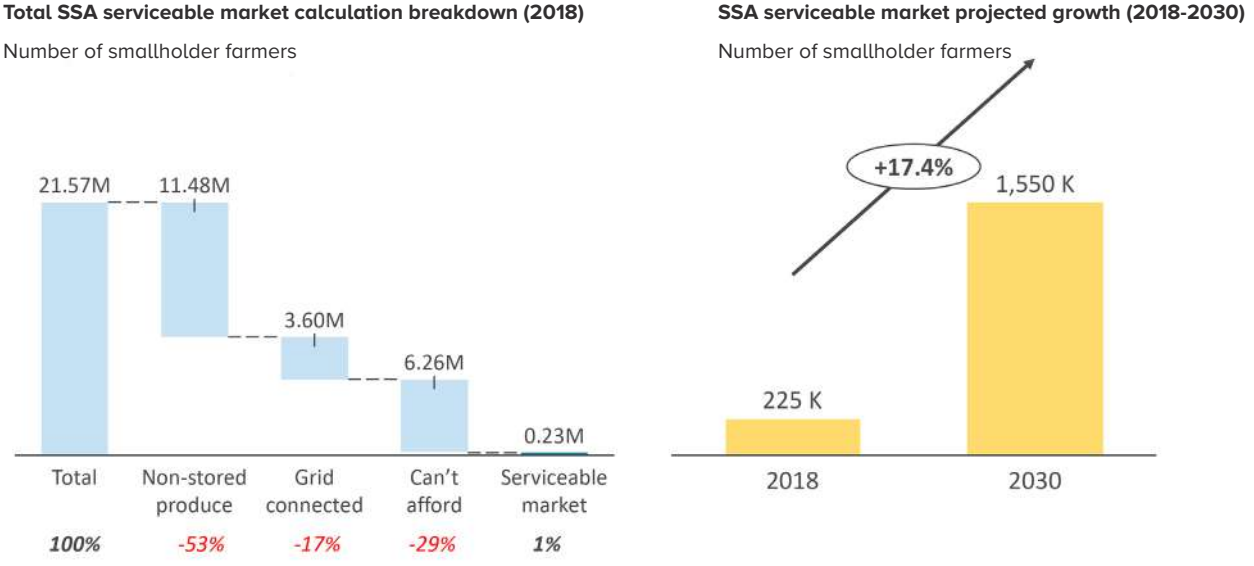
Based on our projections, we estimate that the total serviceable market will grow by 12.3% year-on-year from 701,000 farmers in 2018 to 2.83 million farmers in 2030. This will be driven by the combined effects of rising income levels, growing rural population, electrification rates, and an estimated reduction in end prices of between 10% and 15%.[12] This will represent a total serviceable market value of USD 1.633 billion in 2030.

For cooling and refrigeration, the total addressable market (without factoring in affordability) comprises 6.5 million farmers, whereas the total serviceable market (taking affordability into account) is 225,000 farmers. We based our sizing on an of average of leading products in the market— USD 825 for a 100-litre refrigerator. We performed the following steps:

- First, we estimated the number of smallholder farmers in dairy, aquaculture, and horticulture—21.57 million.
- Next, we deducted from this number the:
  i. Farmers who work with produce that does not require cooling—11.48 million,
  ii. Farmers who are grid-connected—3.6 million, and
  iii. Farmers who cannot afford cooling products—6.26 million.
- This estimates the total serviceable market to be 225,000 smallholder farmers today, amounting to USD 191 million (compared to the total addressable market of USD 6.25 billion).

12 There has already been considerable effort to reduce product prices therefore a conservative 10% reduction in product cost has been assumed based on industry interviews.

Figure 7: Total market size for solar-powered cooling and refrigeration in sub-Saharan Africa



Based on our projections, we estimate that the total serviceable market will grow by 17.4% year-on-year from 225,000 farmers in 2018 to 1.55 million farmers in 2030. This will represent a market value of USD 1.32 billion in 2030. The cooling and refrigeration market will continue to be driven by small refrigerators for commercial use rather than walk-in cold rooms, due to prohibitive costs for cooling a whole store room.

For agro-processing, the total addressable market (without factoring in affordability) is approximately 937,000 units, whereas the total serviceable market (taking affordability into account) is 54,000 units today. We based our sizing on an of average specifications of pilot products in the market across different types of processors (threshers, graters, mills, etc.). Giving a product costs of USD 1,625 for a 150 to 350-watt system being roughly able to process 200 kilograms of produce per hour; this rate is sensitive to the type of crop and processing activity being undertaken. We then performed the following steps:

- First, we calculated the proportion of crop output for cereals, pulses, roots, and tubers, that is produced by smallholder farmers—120.45 million metric tons (MT).
- Next, we deducted from this number the:
    i. Crop output processed by large processors—50.59 million MT,
    ii. Crop output of farmers who are grid-connected—18.32 million MT, and
    iii. Crop output of farmers who cannot afford PULSE products—48.6 million MT.
- This leaves a remaining total crop output of 2.95 million MT that can be processed by PULSE.
- We then assumed that 55MT of crop output is processed per processor unit, leading to a total serviceable market of 54,000 processor units amounting to USD 90 million, compared to the total addressable market of USD 1.53 billion.
- The total serviceable market could be expanded significantly if we factor in group ownership and shared use, which emphasizes the important role which value chain aggregation can play in expanding the market for PULSE appliances.

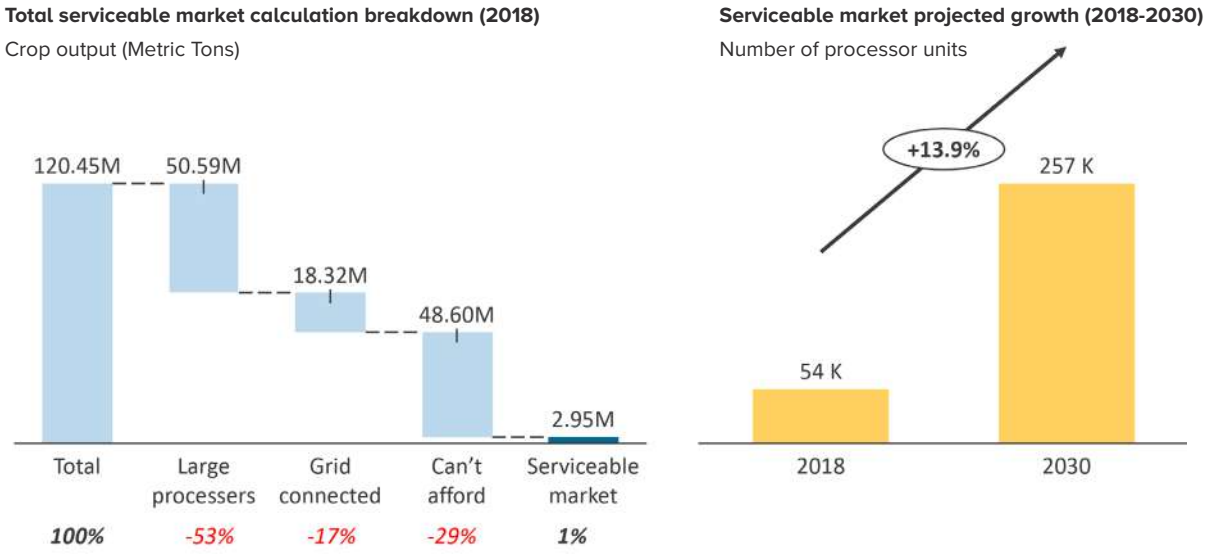
Based on our projections, we estimate that the total serviceable market will grow by 13.9% year-on-year from 54,000 units in 2018 to 257,000 units in 2030. This will represent a market value of USD 417 million in 2030. The main driver of a relatively low serviceable market today is the high price of USD 1,625 per processor unit.

This is significantly higher than our benchmark cooling and pumping appliances. Prices of solar-powered agro-processing equipment are likely to come down in the next five to ten years. For our projections, we assume a reduction in end prices of 35% by 2030. Even with such decrease in cost, the products will remain outside the affordable price range for most smallholder farmers.

Affordability significantly constrains the uptake of PULSE products, and, though asset financing models are expanding (through Pay-As-You-Go (PAYGO) financing, leasing, MFI, and asset finance), access to finance remains limited. In most markets, only the most affluent farmers can afford to pay for PULSE products in cash up-front.

If we factor in cash sales only, the serviceable market for PULSE appliances is significantly lower. Consumer financing increases the number of consumers capable of purchasing products and the serviceable market thereby expands. For our

Figure 8: Total market size for solar-powered agro-processing in sub-Saharan Africa



sizing, we assumed that all potential customers have access to asset loans at a standard set of terms (for our purposes, 15% annual interest rates and a 36-month tenor), and that they could spend up to three months of saved income on an upfront deposit and 15% of household income on monthly instalments.

At present, consumer financing is not widely available in African markets. PAYGO players, who have expanded access to household systems and lighting for off-grid households, are piloting similar PAYGO models for productive use appliances. But this is still nascent and faces challenges because PULSE appliances are higher value (requiring larger loan sizes), more complex (less plug-and-play and needing more customer touchpoints), and bulkier (harder to market and distribute in rural areas).

We are also starting to see other models expand access to financing for PULSE appliances, such as asset leasing, guarantor loan structures (e.g. through off-takers), and specialist agricultural credit facilities. While it does not reflect current reality, the assumption of full access to finance allows us to estimate how large the serviceable market could be if these asset financing models become more prevalent.

There are several key trends which should make PULSE appliances increasingly accessible in the coming years. First, as technology improves, the relative cost per unit of performance should go down. We have seen substantial cost savings in off-grid solar systems over the past five years driven by declining panel costs and improvements in efficiency of LED lighting.

Across a range of PULSE appliances, the industry expects to see a reduction in manufacturing costs, for example through technology advances in new brushless DC motors and more appropriate compressors for DC refrigeration units. Solar irrigation pumps are already further along this cost curve and firms such as SunCulture, FuturePump, and Jain Irrigation are now taking to market entry-level DC pumps for retail prices as low as USD 600.

This trend will be supported by increased research & development focused on designing PULSE appliances to be appropriate for small-scale farmers (e.g. plug-and-play, mobile, and modular). Secondly, as PULSE firms increase their sales, they will benefit from economies of scale in manufacturing and distribution.

Today, low order volumes and component sourcing for manufacturers is sub-optimal, and distributors face high costs per unit for transport and freight. With greater economies of scale, some portion of cost savings will be passed onto customers.

And finally, rural incomes are continuing to rise, meaning households will have higher disposable income. In line with these expected trends, we estimate that the serviceable market for solar water pumps in sub-Saharan Africa will increase from USD 456 million today to USD 1.63 billion by 2030.

For more detail on the market sizing, please refer to slides 47 to 63 in the full study.

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HOW DOES THE PULSE OPPORTUNITY VARY ACROSS AFRICAN MARKETS?

To explore this question, we assessed PULSE use cases in three countries: Kenya, Cote d'Ivoire and Zimbabwe. The countries were chosen to have both regional variety and differing levels of OGS sector maturity. Additionally, for each country focus agricultural value chains were chosen based on their contribution to total agricultural production, level of small-scale production/processing and to have a range of PULSE technologies to compare between contexts.

The PULSE opportunity in a given African market varies significantly according to: (i) the maturity of the OGS sector, (ii) the composition of the agricultural sector and (iii) the strength of incumbent products. Kenya is a global leader in the adoption of OGS with approximately 4.7 million pico and solar home system products sold in the last ten years. Cote d'Ivoire and Zimbabwe are more nascent markets, with up to approximately 100,000 solar home systems installed in each market.[13]

In a market like Kenya, prospective customers of PULSE products are more aware of solar and its benefits, there is a more extensive network of solar distributors and retailers, and there is greater access to asset financing and PAYGO models for solar products. More mature sectors also have established practices for after-sales support.

As an input into agricultural produce, the performance of a PULSE technology is critical to farmer income; this raises the bar further for after sales support. For less mature markets, those selling PULSE products find fewer distribution partners in the value chain and need to work harder to drive sales.

The PULSE opportunity is largely shaped by agriculture. This relates to both the sector profile (which crops and livestock are dominant) and the value chain structure (the number, financial profile, and market-access of smallholder farmers).

Value chain characteristics—and challenges—of dominant crops in a country shape the demand for PULSE products and can determine which PULSE products may be most applicable. If the most produced or highest value crops exhibit a high need for irrigation, then the PULSE market for solar pumps would be larger.

Similarly, if the key agricultural outputs depend heavily on cooling to avoid spoilage, the PULSE market for refrigeration may benefit. For example, Cote D'Ivoire's vibrant fisheries that employ over 70,000 people represent a large potential market for PULSE refrigeration. Similarly, we estimate that up to 250,000 Kenyan dairy farmers could be users of solar-powered milk chillers.

By comparison, in Zimbabwe, smallholder milk offtake is less structured but higher quality chilled milk can attract a price premium. Careful value chain selection is needed to expand PULSE product sales, for each value chain.

Key considerations include: the level of commercialization, the prevalence of farming co-operatives, the strength of offtake arrangements, any political economy of crops, the spatial distribution of production, and the strength of domestic/export markets. We look at the effects of some of these factors in test use cases later in this report.

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Finally, another key factor influencing the PULSE opportunity and uptake across markets is the relative attractiveness of incumbent technologies. Depending on the value chain structure, some PULSE products compete with incumbent technologies (e.g., diesel, grid electricity).

However, in other situations there is no incumbent technology in use and a PULSE product could actually enable a value-adding activity, for example mechanized, small-scale, off grid milling. The introduction of a new technology, for example, offering small scale milk chilling as a service where milk is not typically chilled, requires soft behavior change, training, and potentially the 're-wiring' of existing transactions in the value chain.

The degree to which a PULSE product must compete with existing technologies varies by country. In Kenya, the market for diesel powered pumps is strong for both individual and shared use, but in Cote d'Ivoire agricultural practices and the climatic conditions mean that uptake of diesel pumps is lower. If alternative grid, diesel, and/or manual alternatives are present, the affordability of PULSE products, and their overall competitiveness against these options is a key determinant of the market opportunity.

Generally, market actors are more likely to use PULSE products if they perform better in some key regard than other options. In Cote D'Ivoire, despite significant agro-processing needs for staple crops, we estimate a challenge with PULSE competitiveness because solar mills have 70% lower processing capacity and cost up to 6 times more than diesel mills[14].

Incumbent technology costs differ by geography, with product prices influenced by: strength and scale of existing distribution, fuel prices, grid tariffs, and the duties/incentives placed on agricultural inputs. This variability plays out in the relative uptake of solar product types, as summarized in the figure below.

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Figure 9: Level of current uptake of PULSE appliances by country

	 KENYA	 ZIMBABWE	 COTE D' IVORE
Irrigation 	**Uptake is growing rapidly;** specialist providers/ distributors and (now) larger manufacturers are starting to enter segment using Kenya as entry point.	**Solar pumps are available but uptake is limited;** there are several distributors targeting smallholders, but affordability is a major constraint.	Penetration remains very low to date; climate patterns and market structure makes **water pumps difficult to market** other than for horticulture.
Cold Storage 	**Nascent but growing market;** to date suppliers have intentionally targeted aggregators in high value crops.	Opportunity for cold storage is limited, **post-harvest losses are largely driven by poor handling** and a lack of market access.	**Limited to no uptake;** highest potential in higher value exotic fruit for export, and more difficult for domestically consumed vegetables.
Milling/ threshing 	**Pilot activity only;** current actors are exploring segments where **distance to existing processors** is prohibitive but **technologies are untested**	**No activity;** there is potential to displace incumbent micro-scale milling, but services are ussually **compensated in a % of produce not money**	**No activity;** GoZ wants more local processing, especially rice, cocoa, and cashew; for rice there is a quality concern at smaller scales
Milk chilling 	**Pilot activity only;** potential for farmers in both formal and informal channels but prices need to come down to reach individual SHF	**Pilot activity only;** there is an opportunity to help boost smallholder incentives to utilize the government's milk collection centers	**No activity;** local milk production is limited and mostly informal. Powdered milk imports are a barrier to domestic sector development
Drying 	There is some talent demand across several value chains, but no incumbent commercial equipment is currently being utilized	Farmers voiced some need for maize drying technologies, **buy returns are low** and no incumbent technologies exist	Could reduce losses and time spent in cassava and rice processing but additional margins are limited, and there is **limited incumbency**
Other		The **reliabilty of electricity supply in cities** creates demand for PULSE solar products from vendors/ reatilers mainly for task lighting	Inland fisheries appear to offer better **incentives to preserve fish through cooling** than coastal, targeting traders not fishermen

WHO ARE THE KEY PLAYERS DRIVING PRODUCT AND DISTRIBUTION INNOVATION IN PULSE?

There are diverse types of actors bringing PULSE appliances to market. We estimate there are approximately 100 firms developing PULSE technology for the African market and hundreds more firms distributing solar products. These products increasingly fall within small-scale applications of 1 kW or below. The most common PULSE appliances in the market are water pumps and refrigerators for (DC) solar power. However, sales penetration remains low. Leading firms report solar water pumps sales of fewer than 5,000 units and DC refrigerators sales of fewer than 1,000 units. Agro-processing units are still in pilot stage.

The PULSE landscape is being shaped by the following types of actors:

- **Early-stage innovators,** start-ups focused exclusively on segments of the PULSE market, are developing products specifically tailored for small-scale and off-grid use. These firms are leading innovation in PULSE technology. Many of these firms still require R&D and pilot support, and several are set to scale. They face significant challenges in manufacturing at small volumes and building out distribution networks and partnerships.

- **Large appliance manufacturers** are starting to take interest in the market opportunity and are adapting conventional appliances for the small-scale, off-grid market. Manufacturers such as Lorentz have been active in solar pumps for years but are only now starting to look at small-scale applications within an affordable range for smallholder farmers. These manufacturers have large balance sheets and can exploit economies of scale to reduce the cost of production, manufacturing, and distribution. Their entry could significantly drive down product costs given these firms' scale economies, however concerns around customers' ability pay and the high level of difficulty in reaching the target market means that large manufacturers will struggle to justify the opportunity cost of focusing on this market. Partnership and competition between early stage innovators and thee larger international manufacturers will be crucial to driving the sector forward and unlocking technology advances.

- **SHS/PAYGO firms** have successfully included household appliances (e.g., televisions, fans) into customer bundles and are now looking at PULSE appliances as the next line of products to roll-out. They are interested in PULSE appliances also as a way to enhance rural household income streams and therefore drive higher repayment rates. They are well-positioned to leverage their customer profile and credit repayment data to target PULSE customers who are high potential with PAYGO financing. However, they will need to adapt their business models to account for longer-term and higher-volume financing, bulkier and harder to distribute products, and more complicated technologies which require higher touchpoints at point of sale and after-sales servicing.

- **Portfolio distributors** are distribution companies with established networks in one or more markets for productive use appliances (irrigation solutions, other farming machinery & equipment) or solar equipment more broadly (panel arrays, lighting, etc.). These firms have networks

of outlets into rural areas either through owned-stores or retail partners, and they often sell a range of technologies including diesel and grid-based alternatives. They rarely offer financing to customers and therefore rely on cash sales. Many of them are looking to expand their product ranges by adding PULSE appliances. Often quality and warranties are a concern, with many distributors hesitant to add new-to-market solar products to their product lines. Master distributors, such as African Energy, are working through networks of local distributors to expand reach into multiple markets. Working capital is a major constraint to growth as thee master distributors are not able to offer flexible payment terms to distributors who are cash constrained but need to hold stock.

- **Mini-grid developers** are now starting to actively promote use of appliances at their sites to drive energy consumption and recognize the important role which PULSE appliances can play in making mini-grid economics viable. Larger PULSE applications can even serve as an anchor load for the mini-grid. These developers are looking to partner with appliance manufacturers and distributors to target sales to their mini-grid customers. But these partnerships, and the financing models required to facilitate uptake, remain at an early stage. One constraint is that many of the mini-grids being developed in SSA install connections which run on AC power and therefore customers would require inverters to power DC appliances.

- **Leasing firms, MFIs, and other non-bank financial institutions** are also increasingly looking to PULSE appliances, partly driven by the demand from their existing customer base. Leasing models in particular have a strong parallel for larger farming machinery & equipment which can potentially be adapted for small-scale products. PULSE appliances tend to be above the higher end of MFI range of credit products, however the income-enhancing nature of PULSE appliances means that proper use could increase their capacity to service larger loans.

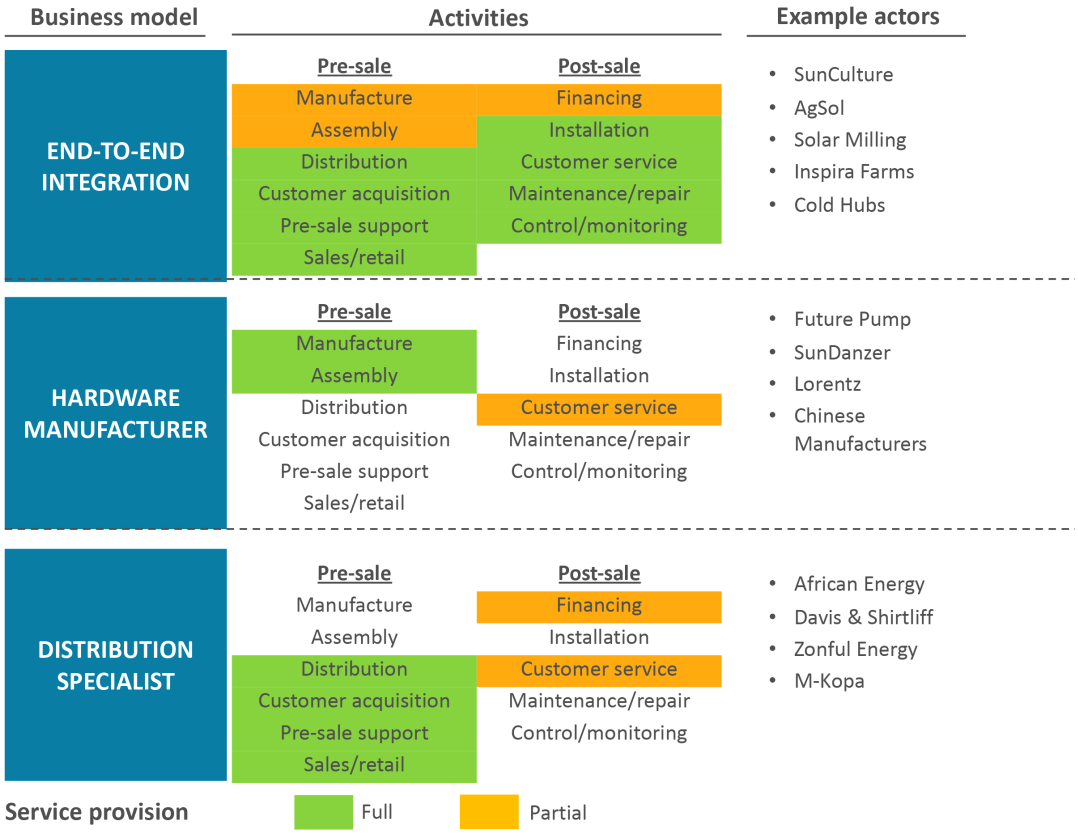
Figure 10: Illustrative actors bringing PULSE appliances to market in sub-Saharan Africa

These actors are adopting business models with varying degrees of vertical integration; early stage firms tend to control operations end-to-end whereas larger manufacturers are more used to working through distribution partners. The benefits of vertical integration for firms at an early stage are that they can hold close the relationship with their customers and have quick feedback loops to inform ongoing iteration of product technology and sales and marketing.

Also, given they are launching new products into the market, they can keep better control of brand and customer experience through a tightly-managed sales process and after-sales services. On the downside, vertically integrated models are expensive and difficult to scale quickly.

They also require these early stage firms to build out capabilities in distribution and logistics, which can take years. If these firms are also providing financing for their customers, it means they need to raise significant capital from investors to do so and develop internal credit management policies and functions to manage risk prudently.

Figure 11: Different business models for PULSE players and where they operate along the value chain



Alternatively, various firms are looking to partnership models to reach a larger market. Larger manufacturers and several early stage firms are looking to channel their products through established distribution players in key markets. This has the benefit of tapping into existing distribution channels which sell adjacent or competing products.

By doing so, manufacturers do release an element of control over how their product is marketed and how it is positioned alongside other products. Much depends on finding the right distribution partners. In his respect, some manufacturers have decided to partner with specialist solar distributors (e.g. SimuSolar) who understand the nuances of marketing, transporting, and installing solar products.

Other partnerships involve the manufacturer deploying their own field staff, or shared staff with the distribution partner, to provide technical product support at the point of sale and for after-sales servicing. These models increase the unit costs however they ensure quality of customer experience and drive sales via word of mouth.

While vertically integrated models are helpful to incubate new technology, as the PULSE market matures we expect to see unbundling and greater specialization along the value chain. While the technology is still nascent, vertically integrated models will be important to ensure that PULSE appliances find their market.

Over time, as the industry matures, the industry will benefit from having firms who focus on distribution, as the demands of distributing PULSE appliances at scale across many markets are significant. The presence of specialist distributors, especially those who can extend customer financing terms, will also be an incentive for new entrants on the branded manufacturing side as these firms will see viable channels to take their product to market.

For more detail on the supply side landscape, as well as case studies on SunDanzer, African Energy, and SunCulture, please refer to slides 26 to 45 in the full study.

WHAT IS THE PULSE BUSINESS CASE FOR FARMERS?

The business case for farmers to invest in different PULSE appliances is variable and highly sensitive to farm / market dynamics and the ability of the owner to utilize the asset. For this report, we tested the viability of different use cases within specific value chains across our three focus countries.

We assessed both return on investment and performance of solar versus alternative technologies (grid / diesel). We found that the business case is not clear-cut and viability varies depending on farm / market dynamics and asset utilization, the conditions for which vary a lot across the different countries.

On farm / market dynamics, viability depends on crop / livestock selection (and associated productivity uplift), market prices for agricultural output, seasonality of crop cycles, and the cost of alternatives (notably, diesel fuel).

On asset utilization, viability depends on the size of the PULSE appliance and the extent to which the owner can utilize it, which itself depends on production volumes and mobility of the appliance itself (for example, to rent it out to others). For solar-powered irrigation, the business case for farmers to invest in a solar water pump is most often positive, even at small farm sizes.

For solar-powered cooling, the business case makes sense when the asset can be sufficiently utilized, which is still challenging for most individual farmers in our focus countries. For solar-powered agro-processing, the technology is still nascent and product costs need to come down to be competitive versus alternatives. Even then, it only makes sense at higher volumes which requires some level of aggregation.

Testing the horticulture irrigation use case

Smallholder farmers in Africa are increasingly seeing the benefits of solar irrigation for horticulture. Product innovation and declining prices have made small-scale DC pumps more viable, but product lines have not yet reached commercial scale.

Across all countries covered by this study, the business case for customers to invest in solar water pumps are strengthening but the level of viability differs from one country to the other. It is important to remember also that the ability to derive full benefits from irrigation depends on a farmer's access to markets for their produce.

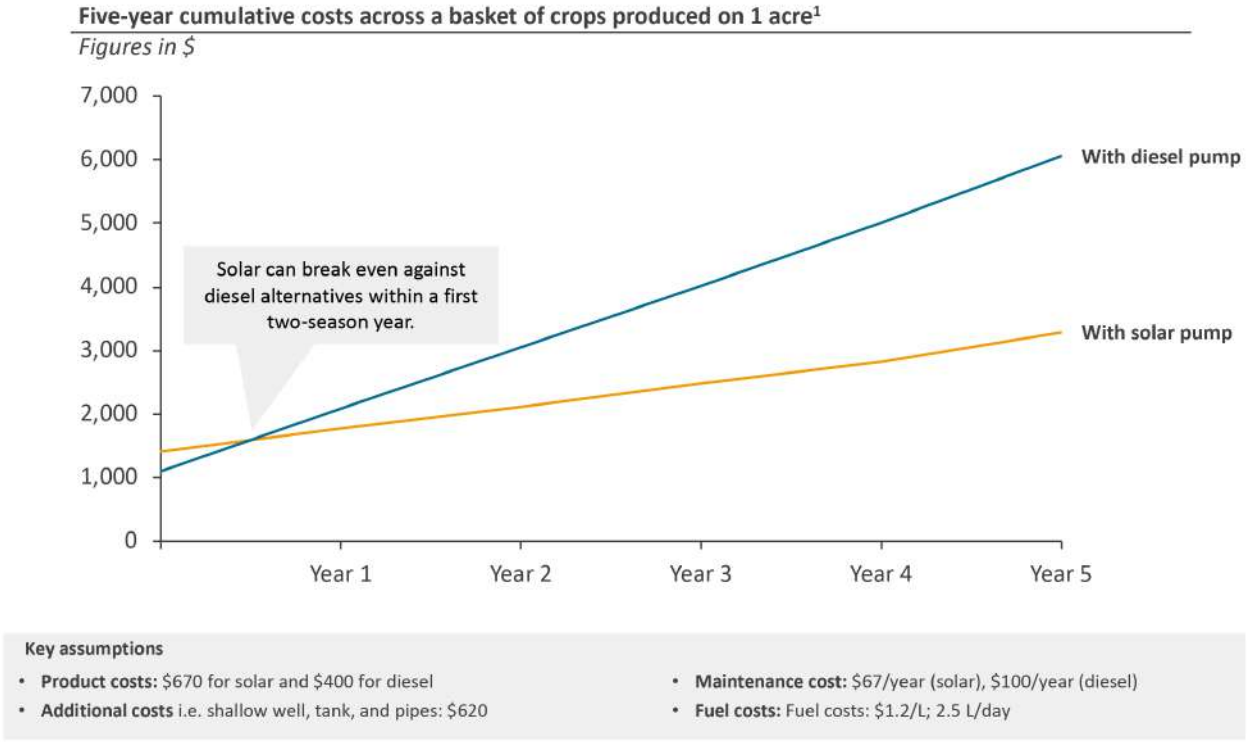
In Kenya, solar irrigation shows a high return on investment for horticultural crops. Solar pump expenditures can break even against diesel alternatives within the first year, despite their higher upfront costs (up to 60% higher). Solar outpaces diesel for higher value crops, but for lower value crops, it takes longer to see a return on investment.

If a farmer already owns a diesel pump, the payback period for switching from diesel to solar extends from three to four years. This longer payback period indicates a more limited value proposition for farmers who already own a diesel pump. Where farmers have a renewable source of water, a solar pump can allow a farmer to diversify the crops they grow and be more resilient to periods of low rainfall.

Figure 12: Overview of value chain characteristics for PULSE use cases in three focus countries

	IRRIGATION	COOLING & REFRIGERATION	AGRO-PROCESSING
	**Horticulture** • Value chains (VCs) are relatively well commercialized • **Strong aggregation of smallholders,** especially in export crops such as horticulture • Uptake of irrigation by smallholders is generally low, including for horticulture	**Dairy** • **Domestic demand for milk is strong,** however spoilage rates are high, and can reach up to 50% in informal markets. This creates an opportunity for cooling • No incentives for quality milk, which cooling enables, as in some other markets	**Maize** • **Smallholder agro-processing is highest for maize,** with 67% of overall milling done at small-scale • Many suppliers provide processing products for maize because it involves 98% of Kenya's smallholders
	**Horticulture** • Land reforms left much of existing irrigation systems under-utilized • **Smallholder farming is still being developed** after land reforms • Smallholders are mostly not using modern irrigation solutions	**Dairy** • Uptake of **cooling products in dairy is restricted to large farmers** • Chillers can support dairy farmers with better utilizing milk collection centers	**Maize** • **Agro-processing is well-developed for cereals (including maize)** but over 50% of rural farmer processing is manual • Exisiting products for processing maize offer mobility to reach remote customers
	**Horticulture** • **Abundant rainfall reduces general demand for irrigation,** but there is still irrigation potential for horticulture and fruits • Only 15% of irrigable land is under irrigation	**Fish** • Cooling could reduce high post harvest losses in fisheries • Fish traders have strong incentives to reduce spoilage by investing in cooling	**Cassava and Rice** • High agro-processing activity across staple and cash crops, including cassava and rice • **Cassava is primarily processed by smallholders,** while 95% of farmers travel 2-7km to take rice to a mill for processing

Figure 13: Illustrative payback period of solar water pump versus diesel pump in Kenya



Note: A basket of crops includes maize, kale, tomatoes and capsicum, and assumes 0.25 acres for each crop.

In Zimbabwe, solar pumps can provide significant yield uplifts and higher income. Such yield uplifts can be demonstrated using two crops, cabbages and tomatoes, which have increases of up to 2.5-fold and 3.2-fold respectively when using irrigation. Using conservative estimates for yield uplifts, irrigation still boosts income enough to recoup the cost of the solar pump in one year.

However, it could take several seasons for farmers to learn to adjust to the technology and adopt best practices. The full benefits from solar irrigation will only be realized if the technology is properly used and maintained. This can be significantly aided by upfront training at the point of sale and after-sales service touchpoints with the farmer.

The business case for irrigation in Cote d'Ivoire is still attractive but less favorable than in Kenya and Zimbabwe. Due to fairly constant rainfall (1,300mm annually), the imperative for farmers to adopt irrigation is relatively low and almost all cultivation (97%) is rain-fed only.

Sales penetration remains low, especially for small-scale irrigation, as over 65% of all irrigation systems are implemented on larger commercial farms. Climate patterns and market structures make water pumps difficult to scale, but demand is increasing.

Testing the dairy milk chilling use case

Overall, a market is beginning to form for specialized applications of solar refrigeration and cooling units such as milk chilling, fish cooling, and walk-in cold storage for higher value food crops. However, the business case is currently more attractive for larger farmers or small farmer groups. There could be a compelling case for providing aggregated cold storage alongside solar irrigation pumps to drive up yields while minimizing post-harvest losses.

In Kenya, the business case for milk chilling is currently more attractive for large farmers in formal value chains. This reflects the challenges of single ownership models for smallholder farmers. Milk chillers demonstrate high potential to improve farmer incomes by reducing milk spoilage. Revenue increases from selling chilled milk rely on both the ability to reduce spoilage and to find higher prices for quality milk in different markets. In Kenya, as there is rarely a premium provided for chilled/quality milk, the value from milk cooling solutions arises from their ability to boost the total volume of marketable milk.

Farmers selling to the informal market would realize higher revenues due to better prices offered by cooperatives, USD 0.5/liters (L) rather than USD 0.3/liters, however the informal market presents a less secure channel for farmers.

At current prices, solar milk chillers are not viable for the majority of smallholders for individual use. However, they become more viable when farmers aggregate together to increase utilization. Our analysis finds that, at current prices, positive returns on investment for solar milk chillers are only achieved at relatively high levels of production (15L/day), whereas the majority of farmers in Kenya (87%) produce between one and four liters per day.

At current prices, it would take a farmer selling five liters per day approximately six years to pay back the asset.[15] Aggregating milk amongst a small group of five to ten farmers would bring down payback periods significantly by achieving higher utilization. However, such aggregation requires value chain coordination which is often lacking.

We evaluated the business case if prices were to reduce by 20% and 40% respectively, using as a benchmark the similar price reductions seen in off-grid solar and LED lighting over the past decade. Several firms are innovating around compressor technologies, system size, and mobility. If prices were to drop by 40%, payback periods would reduce to under four years for a farmer selling five liters per day and under two years for a farmer selling ten liters per day. This shows that a potential reduction in end-prices could significantly increase viability for smallholder farmers.

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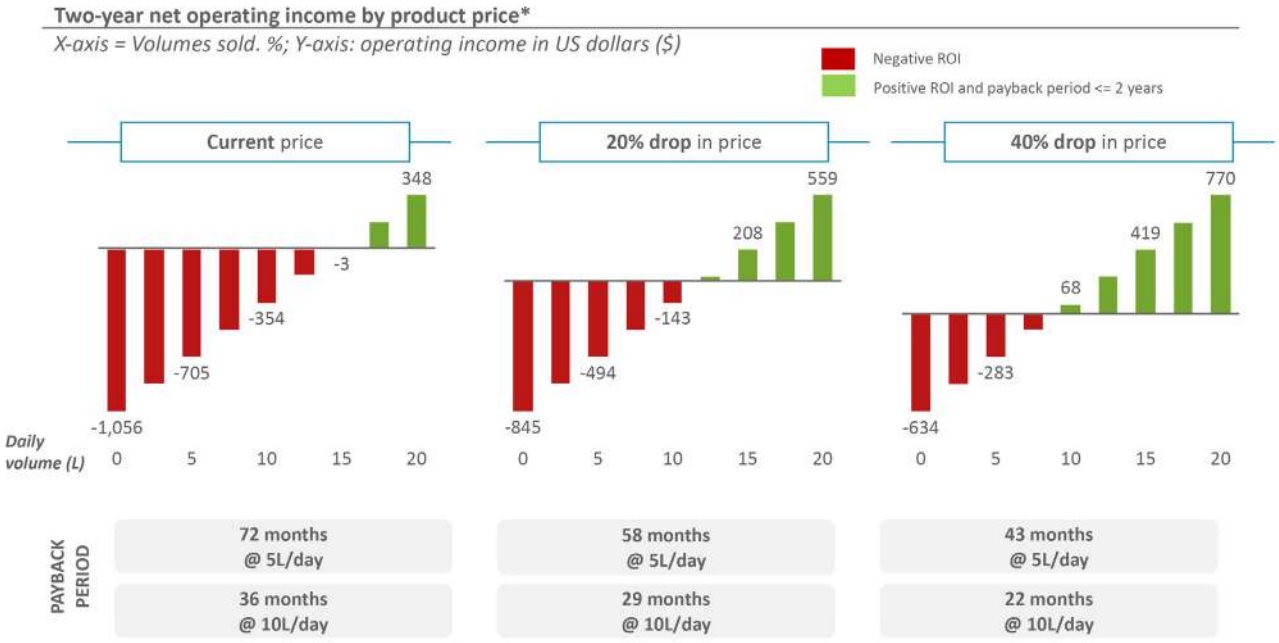
Figure 14: Analysis of farmer payback period for solar milk chillers in Kenya



** Product = 50 liter refrigerator unit. Product price without financing = USD 804. Financing costs are 18% compound interest over 24 months.*

Note: the economic analysis assumes 25% sales to a co-operative and 75% sales to the informal market.

In Zimbabwe, dairy chilling solutions have medium viability and are highly dependent on increased productivity and access to both formal and informal markets. Cold storage and refrigeration applications target more commercialized and large-scale farmers, highlighting a gap in the market for smallholder use.

Our analysis finds that by chilling their milk, farmers can increase their annual revenue by up to 60% due to increased sales volumes and premium pricing, with $0.1/liter higher earnings due to lower milk bacteria content. However, solar products on the market today only begin to make business sense for farmers who own more dairy cattle with relatively high productivity per head.

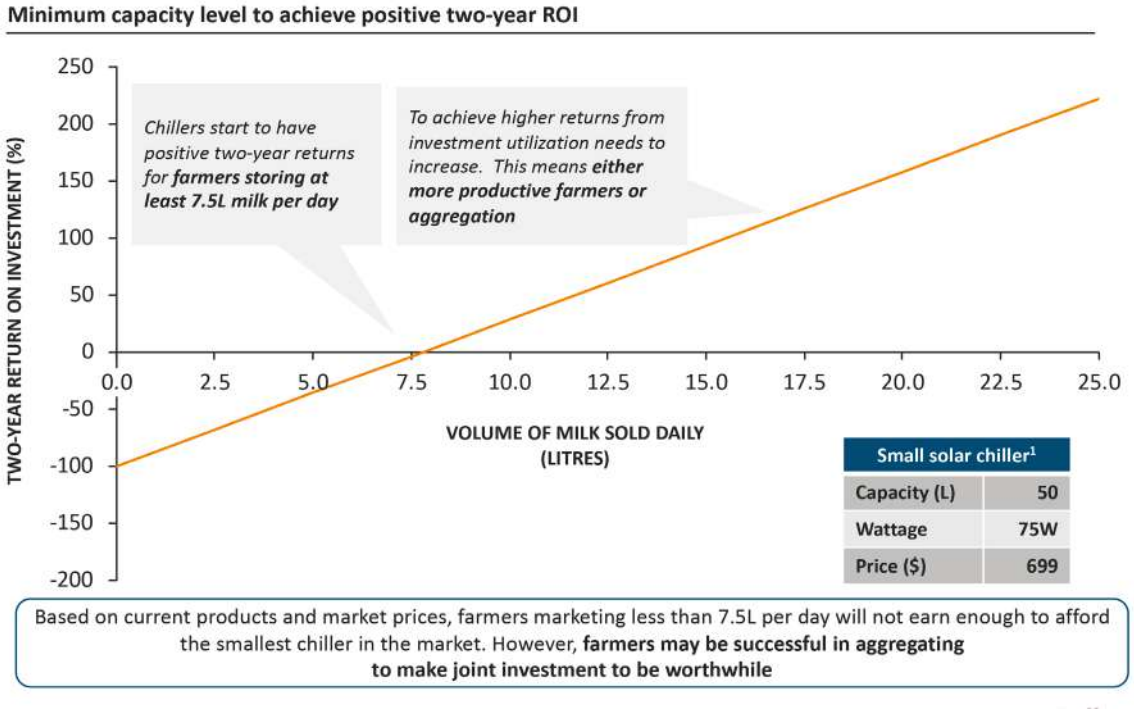
The roll out of solar chillers could be combined with mobile milking equipment to enable better aggregation through otherwise dormant milk collection centers.

Payback is typically 26 months for farmers producing 5L per day. Chillers start to produce positive two-year returns once farmers produce at least 7.5 L of milk per day. To achieve higher returns on investment, utilization rates would need to be higher.

This could be achieved by targeted the smaller groups of farmers that have higher individual production, either in cow numbers and productivity or by encouraging the aggregation of milk through small farmer groups.

Both could require additional sales and marketing effort for product distributors, either in customer aquisition or in promoting aggregation.

Figure 15: Analysis of minimum capacity level for solar milk chillers to achieve positive two-year ROI



Testing the agro-processing use case (grain milling/threshing)

The use case for agro-processing varies across value chain activities. Applications for milling, threshing, grating, pressing, and drying are more nascent and the business case for these activities is yet to be proven. Current solutions are challenged by high upfront costs and constraints to achieving necessary utilization rates in more remote rural areas, where population densities are low.

Unless users can wait two or more years to see returns, investments will rarely make sense at a small scale—solar or otherwise. Viability of solar-powered milling systems can be increased by improving the mobility of the products to achieve adequate utilization rates and by ensuring that the technology's power unit be applicable across multiple agro-processing activities to optimize system use.

In Kenya, PULSE solutions for maize milling are still at pilot stages but early results indicate that there could be viable return on investment in the longer-term. Solar products provide an opportunity for milling entrepreneurs to address a large market, while providing time and cost savings to customers.

Even though solar mills cost approximately twice as much as diesel mills, low operating costs mean they can break even with diesel mills after two years. Because operators no longer need to travel to collect fuel, they also enjoy time-saving costs. This dynamic can make solar maize milling solutions especially attractive for more remote communities.

However, our analysis finds that to reach 85% utilization (94MT/year) a solar mill needs to serve 104 households and therefore, to be viable, can't be located too remotely where population densities are lower. By comparison, in Zimbabwe, there is

only a limited opportunity to displace incumbent maize milling which is mainly performed by larger commercial mills. Incumbent small-scale milling also exists, but compensation for such services is usually paid with a proportion of the maize that has been milled rather than through a monetary transaction.

The biggest suppliers of maize threshing products in Zimbabwe only provide grid and diesel-powered solutions, and interest in solar is limited. Smallholder farmers either thresh their maize using large-scale combined harvesters (35%), mid-scale diesel-powered threshers (15%), or manual farm labor (50%). Solar threshers could be cheaper solutions than diesel incumbents and open-up more efficient threshing services to remote producers. On a cost-benefit basis, a solar-powered product breaks even with a diesel-powered product after about 14 months. This, however, requires an agro-processing entrepreneur to reach a broad enough client base to achieve viable utilization levels. At production levels ranging from 120MT up to 240MT (maximum capacity) the solar thresher assessed exhibited lower total costs than diesel.

In Côte d'Ivoire, the commercial viability for solar cassava grinders is low because incumbent technologies are well established for both small and micro-scale applications of cassava grinding. In rural areas, mobile, diesel-run grinders are common.

They process approximately 2.5 tons per week (T/week) and use approximately 1L of diesel (USD 1.1) for between approximately 150 and 500 kilograms (kg) of cassava. The upfront cost of solar is twice that of diesel, but solar becomes slightly cheaper than diesel within approximately 3 years. Compared with diesel, solar grinders have lower capacity and associated revenue potential. Utilization rates are key for returns.

At 50% utilization, the cost of a solar grinder would need to drop about 40% to achieve two-year payback. Even at a maximum utilization of 118MT/year, payback would take 19 months due to high initial costs and the low charge rates of competitive, incumbent activities. Should mobile grinders be used, the level of output (and utilization) is further constrained by battery run time.

There is high demand for rice milling services in Côte d'Ivoire, however solar-powered hullers are not competitive today versus incumbent. 95% of farmers travel between two and seven kilometers to a mill to process their rice.

Entrepreneurs in remote, off-grid areas can acquire small-scale mills and generate revenue by offering processing services closer to home. The market rate for such milling services is approximately USD 53/MT. But despite the need for PULSE solutions in remote areas, solar hullers are not commercially viable when compared to incumbents.

Solar hullers provide lower revenue potential than diesel hullers due to lower processing capacity. Based on current systems, solar hullers are only operational 6h/day during 188 days of the year, whereas diesel hullers can operate 8h/day for 243 days of the year.

Even at a maximum capacity of 68MT/year (serving 75 farmers), solar hullers require an 11-month payback period. A solar huller would need to increase annual processing capacity from 68MT to 140MT to match the returns of diesel alternatives over five years. Uptake of solar hullers is also likely to be challenging due to their slow processing time which impacts customer waiting time. PULSE products also need to match or improve on the quality of rice achieved by small-scale diesel or grid-based processors.

Figure 16: Analysis of minimum capacity level of a solar-powered grinder to achieve positive two-year ROI

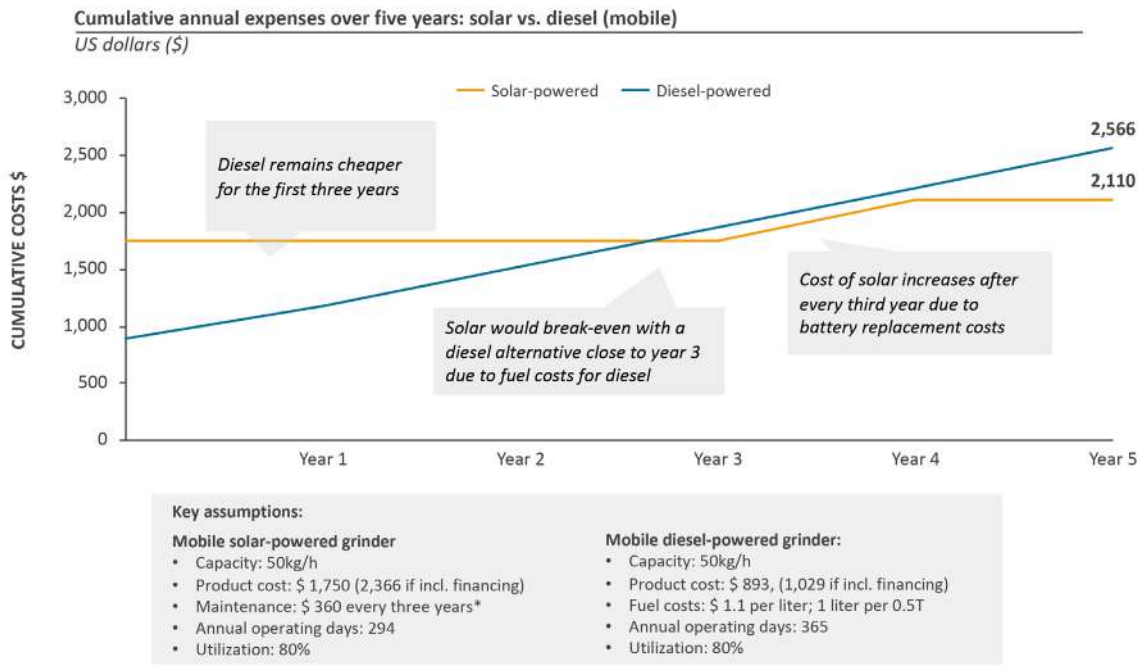


Figure 17: Commercial viability for solar agro-processing use cases

Use case	Direct incumbent	Processing capacity	Competitive vs incumbent	Two-year Typical ROI	Full payback period
KENYA Maize milling	Diesel		Year 2	15%	21 months[2]
ZIMBABWE Maize threshing	Diesel	0.25MT/h	Year 2	29%	14 months
COTE D'IVOIRE Cassava grating	Diesel	50kg/h	Year 3	-34%	37 months
COTE D'IVOIRE Rice hulling	Diesel	60kg/h	Year 5	16%	21 months

Key	Viability	Competitive vs incumbent	Two-year Typical ROI	Typical payback
	High	< Year 1	>100%	< 1 Year
	Medium	N/A or Year 2	<50%	< 2 Years
	Low	> Year 2	<0%	> 2 Years

The above use cases highlight the diversity of considerations needed to fully define each business case and understand where a PULSE technology might be viable. These considerations differ depending on the product technology, target crop/livestock, country and even sub-region.

Analyzing use cases at this level can help: investors to explore where PULSE products might have viable markets; distributors to understand which customers to prioritize; and product designers to understand how to best meet end-user needs.

A range of tools can be used to assess such use cases, which could potentially be further standardized and expanded across markets. For example, using a value chain approach with an energy-use lens can help to identify critical user groups, market sizes and the potential for value addition through PULSE product use.

This can also highlight constraints that might be faced in terms of market access, potential utilization rates and service pricing. Interviews and focus groups with potential end-users are important to reveal specific product requirements especially where there is limited incumbent technology use. Finally, there are several components to any commercial analysis. In addition to the defining the utilization rates and revenue uplifts that determine the return on investment for users, practitioners need to evaluate performance relative to incumbent technologies and consider any spillover benefits such as time-saving.

For more detail on the use case analyses, please refer to slides 65 to103 (Kenya), 105 to 144 (Zimbabwe), and 146 to 183 (Cote d'Ivoire) in the full study.

WHAT NEEDS TO HAPPEN TO GROW THE PULSE SECTOR MOVING FORWARD?

Given the complexity involved, growing the PULSE sector requires policy action, market development, innovative partnerships, and greater coordination between energy and agriculture actors.

Governments can do more to promote PULSE appliances and incorporate them into their electrification and agricultural transformation strategies, with the support of development actors. Currently, productive use appliances are often not included in national strategies, despite their importance to rural productivity.

By emphasizing their importance in policy, governments can signal to industry that there is a market opportunity and promote new entrants to the market. The promotion of PULSE appliances can be integrated into broader public schemes, such as irrigation programs and agricultural value chain development initiatives. Further support could come in the form of subsidies, credit guarantee facilities, results based financing, and other initiatives.

For example, the Government of Kenya through its KOSAP program with support of the World Bank, is launching results-based financing facility to incentivize OGS players to expand into more remote, rural regions. Such facilities could be utilized to nudge the market into PULSE appliances. Finally, tax regimes can be reviewed to identify opportunities to incentivize uptake of PULSE appliances—currently, they often attract high value-added tax (VAT) and import duties, and even where exemptions for DC appliances exist, they are often applied inconsistently.

Industry actors can explore new types of partnerships across value chains, leveraging existing capabilities of players involved in aggregation, rural finance, and distribution of adjacent products. Unlike with household energy use, to reach scale, PULSE in agriculture will require coordination between value chain actors—for example, between those with products, those with capital, and those who maintain touchpoints with farmers. Large manufacturers distribute PULSE appliances through networks of distributors.

These distributors are often situated in capitals / second cities and do not have extensive rural networks of sales agents because of historical low demand / affordability. They also do not have much experience in consumer credit models, which as discussed above are critical to expanding the serviceable market.

Early stage innovators are now having to build out their own distribution networks which is costly, requires operational expertise, and heavy footprint (boots on ground). SHS/PAYGO leaders have existing touchpoints with rural customers and they are also becoming specialist in providing consumer financing for assets, however they do not have PULSE appliances or technical expertise.

Aggregators, such as off-takers or cooperatives, have access to pools of smallholder farmers which often have agro-vets and hardware stores attached to them. In the case off-takers, their relationship as a buyer can de-risk farmers and make them bankable for commercial banks, MFIs, or leasing companies. Partnerships between these players across the value chain will be critical to unlocking the market for PULSE appliances.

Concessional financing and patient capital will be required to grow the PULSE sector, given the myriad challenges involved in agricultural value chains as well as energy access for rural communities. Donors and impact investors can play a role in both (i) subsidizing research & development to drive the performance/efficiency gains required to make the technology more viable and (ii) provide financing to help manufacturers and distributors reach their rural markets. This capital will need to be patient given the technology's current position along the cost curve and the challenges involved in agriculture.

This capital can also support innovation in consumer financing models, such as PAYGO and equipment leasing, which is needed especially for larger PULSE appliances. In particular, the seasonality of income flows for farmers is not suited to monthly repayment obligations. And, credit providers need to develop models which can reliably factor in the effect of income uplift through mechanization and how it impacts farmers' ability to service larger loans.

More broadly, development and government actors can help catalyze the PULSE sector through a range of interventions. These interventions are like those which Lighting Global and others have undertaken in the past decade to help build the OGS sector. For PULSE, addressing the requirements of the agricultural customer base offers a unique challenge.

There is a need for integrated energy access and agricultural transformation initiatives. One such set of interventions can be described as "demand generation and aggregation" wherein, for example, donors and government programs help pool farmers for individual or collective use of PULSE appliances. Firms can then plug into these programs and market their products. This can reduce the sale and servicing costs for PULSE firms, while subsidies, training, guarantees, and other mechanisms can de-risks their credit profiles.

Figure 18: Areas of intervention for development sector and government actors to support PULSE

Finally, two success factors will be crucial for the future of PULSE interventions in Africa:

(i) Energy access and agricultural actors must continue to step out of their silos and develop an integrated approach. Constraints to scaling PULSE arise in both the supply-side energy sector and the demand-side agricultural sector. Agricultural value chain issues intertwine with energy access issues. To unlock market opportunities, agriculture and energy practitioners need to work together to break down these constraints.

(ii) PULSE technology viability needs to be viewed as a spectrum across scales, which results in significantly different business case viability for end-users. Use cases highlight that PULSE product maturity, uptake, and operational requirements vary at different scales. Utilization is a key consideration. System sizing needs to carefully match the aggregation dynamics of a given agricultural value chain. Therefore, micro-PULSE is a promising solution for a significant proportion of smallholder farmers, but for many value chains and end-uses larger scale solutions might be more commercially viable. While micro-PULSE for small-scale use has been the focus of this report, such solutions need to be considered alongside the broader set of larger-scale applications.

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