EFFICIENCY FOR ACCESS

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2021 APPLIANCE DATA TRENDS

Insights on Energy Efficiency, Performance and Pricing for Off-Grid and Weak-Grid Appropriate Appliances

JANUARY 2021

EFFICIENCY FOR ACCESS COALITION

Appliances have moved from the fringes to the forefront of the energy access conversation. The increasing availability and diversity of high-quality, affordable appliances and productive use equipment has enabled consumers living in off-grid and weak-grid conditions to gain access to information, cooling, food storage and irrigation.

The inaugural Data Trends Report published in 2018 presented the first snapshot of energy performance and market trends for televisions (TVs), fans and refrigerators in the off-grid market. Since then, the market has continued to grow and mature. Building on the 2018 Data Trends Report, the 2021 report provides updated insights on technology trends using data collected and analysed in 2020 – particularly performance and pricing – for four appliances and productive use technologies: TVs, fans, refrigerators and solar water pumps. The report also includes early technology insights for electric pressure cookers.

This report was developed by CLASP and Energy Saving Trust as part of Low Energy Inclusive Appliances, a flagship program of the Efficiency for Access is a global coalition working to promote high performing appliances that enable access to clean energy for the world's poorest people. It is a catalyst for change, accelerating the growth of off-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life and support sustainable development. Current Efficiency for Access Coalition members have programmes and initiatives spanning three continents, 44 countries, and 22 technologies.The Efficiency for Access Coalition is jointly coordinated by CLASP – an international non-for-profit organization specializing in appliances, energy efficiency and market development – and the UK's Energy Saving Trust, which specializes in energy efficiency product verification, data and insight,
advice, and research.

This report was authored by Lauren Boucher, Asif Hassan, Elisa Lai, Riley Macdonald, Michael Maina, and Michael Spiak of CLASP, as well as William Jamieson and Andrew Tod of Energy Saving Trust.

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ABBREVIATIONS

AC	Alternating Current
Ah	Amp Hour
BLDC	Brushless DC (Motors)
C	Celsius
DC	Direct Current
EEI	Energy Efficiency Index
EPC	Electric Pressure Cooker
FOB	Free on Board
kWh	Kilowatt Hour
L	Litre
MEPS	Minimum Energy Performance Standard
NPV	Net Present Value
PAYG	Pay-As-You-Go (Motors)
PM	Permanent Magnet
SDD	Solar Direct Drive
SHS	Solar Home System
SWP	Solar Water Pump
TV	Television
US$	United States Dollar
W	Watt
Wh	Watt Hour
Wp	Watt-Peak

Building on the 2018 Data Trends Report, the 2021 report provides updated insights on technology trends – particularly performance and pricing – for four appliances and productive use technologies: televisions (TVs), fans, refrigerators and solar water pumps (SWPs). This report also includes early product insights on electric pressure cookers (EPCs) using manufacturer-reported data.

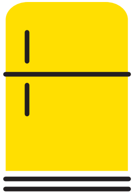
KEY FINDINGS & TRENDS:

Despite a market shift toward larger screens, the average efficiency of TVs has improved by 48% since 2016, while average pricing continues to drop.

In 2019, efficiency improved by 149% compared to the prior year, which may be due to several leading solar companies releasing highly efficient models and the off-grid TV market moving toward maturity and achieving greater scale. Although the average price of TVs decreased slightly between 2018-2019, prices have decreased by 44% since data collection efforts began in 2016. The TV market is also seeing a shift towards larger TVs, which is consistent with insights from manufacturers and distributors on consumer preference.

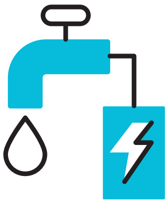
Fan efficiency improved by 49% over a one-year period, possibly due to the adoption of energy-efficient motors.

These efficiency improvements may be due to the increasing number of companies adopting brushless DC (BLDC) motors into their product design, which can be up to 39% more efficient than typical AC motors. The case for efficient fans was evidenced by our analysis of total system costs (i.e., the cost of the fan, battery and PV module) between efficient and inefficient products. Systems using efficient pedestal and table fans were on average 42% cheaper than systems using inefficient fans, and 25% cheaper for ceiling fans.



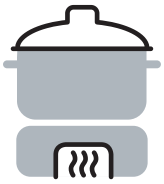
Refrigerators show promising advancements in efficiency, with average efficiency improving by 36% over a two-year period.

Refrigerators are gaining traction in the off-grid market, but high prices prevent them from reaching consumers at scale. For half of off-grid customer, the average refrigerator costs more than three times their average annual disposable income for energy.[i]



Price is a key barrier to widespread adoption of high-performing solar water pumps. For half of off-grid customers, the cost of a best-in-class SWP is five times higher than their disposable income for energy and appliances.

The average best-in-class SWP costs US$853. This is extremely expensive considering that for half of off-grid consumers, their average disposable income for energy and appliances is only US$169 per year.[ii]



The EPC market is nascent, but early insights show that most products are designed for on-grid use.

The vast majority (82.5%) of EPCs submitted for the Global LEAP Awards were marketed as AC compatible, sig-nalling that they may not be intended for use with an SHS kit. EPCs also had high power ratings (845 W on average) compared to other appliances analysed in this report, but DC EPCs showed lower power ratings (271 W on average).

BACKGROUND

Appliances have moved from the fringe to the forefront of the energy access conversation. The increasing availability and diversity of high-quality, affordable appliances and productive use equipment has enabled consumers living in off-grid and weak-grid conditions to gain access to information, cooling, clean cooking and irrigation. These services are essential to improving quality of life, enabling income generation, and building resilience in the face of he COVID-19 pandemic, climate change, and other global shocks.

The inaugural Data Trends Report published in 2018 presented the first snapshot of energy performance and market trends for TVs, fans and refrigerators in the off-grid market. Since then, the market has continued to grow and mature, and this trend is projected to continue. The number and variety of TVs, fans, and refrigerators has steadily increased alongside improvements in affordability and efficiency. At the same time, new technologies like solar water pumps and electric pressure cookers have emerged onto the market. Product sales are expected to grow rapidly; the 2019 State of the Off-Grid Appliance Market Report projects a doubling of sales for off-grid TVs, fans and refrigerators from US $12.6 billion globally at the end of 2018 to US $25.3 billion by 2030.[iii] The SWP market in Sub-Saharan Africa and India could potentially grow to US$11 billion in the same period.[iv]

Yet for many of these appliances, market penetration in off-and weak-grid communities remains low. Leading solar companies reported total global sales of approximately 1.15 million units of TVs, fans, refrigerators and 28,000 SWPs in 2019. While this figure is encouraging, a significant gap between current sales and market potential exists--just 4% rural households in Africa own a refrigerator.[v] To date, approximately 770 million people do not have access to electricity,[vi] and an additional 1 billion people live with an unreliable grid[vii], suggesting there is a market potential gap. The growth of pay-as-you-go (PAYGO) business models and increase in sales of larger solar home systems could lead to more appliance sales in the coming years.

A key barrier to more rapid growth of the off-grid appliance market is a lack of information about product performance and quality to help market actors make informed decisions. Products available in the market today vary widely in quality, performance, and durability. With a lack of third-party certification or testing available, buyers often rely on manufacturers' own technical specifications and ratings, which can be inconsistent or inaccurate. This makes it difficult to compare products and identify quality products.

The Efficiency for Access Coalition seeks to fill this gap by collaborating with independent, accredited laboratories to generate performance and quality data for appliances. Efficiency for Access then shares this data through an online product database on the VeraSol website.[viii] As of December 2020, the VeraSol Product Database shares data on over 300 off-grid appliances and 190 certified solar energy kits. This data supports the rich analysis presented in the Data Trends Report.

APPROACH

This report identifies key efficiency and price trends for TV, fan, refrigeration and solar water pump markets by:

1. Analysing the performance and price of products tested through Efficiency for Access Coalition programs;
2. Creating year-by-year baselines;
3. Comparing the performance of off-grid appliances with those sold in the conventional on-grid market; and
4. Assessing each product's retail price, as well as the cost of the solar energy system needed to power it.

This report builds and expands upon the data analysis for TVs, fans and refrigerators contained in the 2018 Data Trends Report, and provides first-time analysis on SWPs. Since there was no lab-tested data available on EPCs at the time of publication, the authors used manufacturers' self-reported technical specifications to develop preliminary product insights.

For a complete methodology, please refer to the Annex.

BACKGROUND

DEFINITIONS

Appliances and productive use equipment refers to appliances that are designed to be powered by distributed energy systems (such as standalone solar energy kits or mini- and micro-grids), or to be used in weak-grid contexts where electricity supply is unstable. This report focuses on five types of appliances and productive use equipment: TVs, fans, refrigerators, SWPs and EPCs.

"Market samples" are products selected from retail outlets in off-grid markets in Sub-Saharan Africa (Ethiopia, Kenya, Nigeria, Sierra Leone, Tanzania and Uganda) and South Asia (Bangladesh, India, Myanmar and Pakistan). Products are selected to be representative of the market based on brand popularity, size, power input and power consumption. Market sampling and testing is conducted on an ongoing basis through Efficiency for Access. This data is available for TVs, fans and refrigerators, but not yet for SWPs nor EPCs (see Table 1).

"Awards samples" are products that manufacturers and distributors have submitted to the Global LEAP Awards[1], an international competition that identifies the highest-performing off-grid appliances. As part of the testing process, product samples are randomly selected by third-party sampling agents from manufacturers' warehouse stock. Historically, this data has been available for all products. However, TVs and fans have not been included in the Global LEAP Awards since 2018, primarily because these product markets are moving beyond early-stage development. More recent data on TVs and fans is only available from market samples (see Table 1).

"Conventional on-grid market samples" are appliances typically powered by mains electricity (AC power) and are used in households with access to a stable electricity supply. These samples are typically used in urban settings and are easily accessible by consumers. In this report, the conventional on-grid market samples used for comparison are models available in European markets or Kenyan markets, and the performance data were captured from initiatives such as ComplianTV[2] and TopTen[3].

Table 1. Appliance Sample Method Based on Product Type and Year

	2016	2017	2018	2019	2020[4]
TVS	Awards samples, Market samples	Awards samples, Market samples	Market samples	Market samples	Data not included in analysis
FANS	Awards samples, Market samples	Awards samples, Market samples	Market samples	Market samples	Data not included in analysis
REFRIGERATORS	X	Awards samples, Market samples	Market samples	Awards samples, Market samples	Data not included in analysis
SWPS	X	X	X	Awards samples	Data not included in analysis
EPCS	X	X	X	X	Manufacturer rated data

KEY: AWARDS SAMPLES | MARKET SAMPLES | MANUFACTURER RATED DATA | X NO DATA

1. Global LEAP Awards
2. ComplianTV
3. TopTen
4. 2020 data for TVs, fans, refrigerators and SWPs was not included in the analysis due to a relatively small sample size from COVID-19 restrictions.

Televisions

The 2020 Off-Grid Appliance Market Survey identified, TVs as the second most desired appliance by off-grid consumers.[ix] Consumer demand for TVs is one of the primary demand drivers for solar home systems and mini-grids.[x] Therefore, scaling the global off-grid TV market goes hand-in-hand with increasing the market penetration of distributed renewable energy systems.

TVs provide information and entertainment, delivering other significant social and economic impacts. For communities in rural areas, especially women and children with less access to education, TVs are a vital source of national, regional and global information and perspectives. During the COVID-19 pandemic, TVs have provided essential public health information and increased entertainment when social interaction is limited. In 2020, Efficiency for Access interviewed 2,370 TV customers in East Africa to better understand the social impacts of TVs. The vast majority (90%) of consumers believed their TV helped them to improve their general awareness of current affairs and politics.[xi] Half stated that their TVs significantly improved their quality of life, the most common reasons being that the TV reduced stress levels and improved family connection.[xii] Many business owners and entrepreneurs use TVs for commercial purposes, like bringing customers into restaurants and cafes.[xiii] Field research indicates that the increasing availability of larger TVs can spur the development of new businesses, such as village cinemas.[xiv]

Compared to 2018, the off-grid market for TVs is more developed and its growth is projected to continue. The 2019 State of the Off-Grid Market Report estimates that the global market opportunity for TVs will grow to US$8.2 billion by 2025 and reach 9.5 billion by 2030.[xv] As the market develops, TV manufacturers are facing new challenges. As more quality products enter the market and competition increases, product manufacturers need to differentiate their brand and optimize price to remain competitive.

Although TVs are becoming more affordable, consumer financing is still critical to reaching new customers. This is evidenced by the fact that 94% of TV sales reported to GOGLA in the first half of 2020 were sold using pay-as-you-go (PAYGO) financing.[xvi] In India only 5% of customers living in off-grid and weak-grid areas can afford a TV on a cash basis; that number jumps to 75% when financing is available.[xvii] Finding the appropriate balance between cost, efficiency and quality is key to realizing the potential of this market.

EFFICIENCY TRENDS

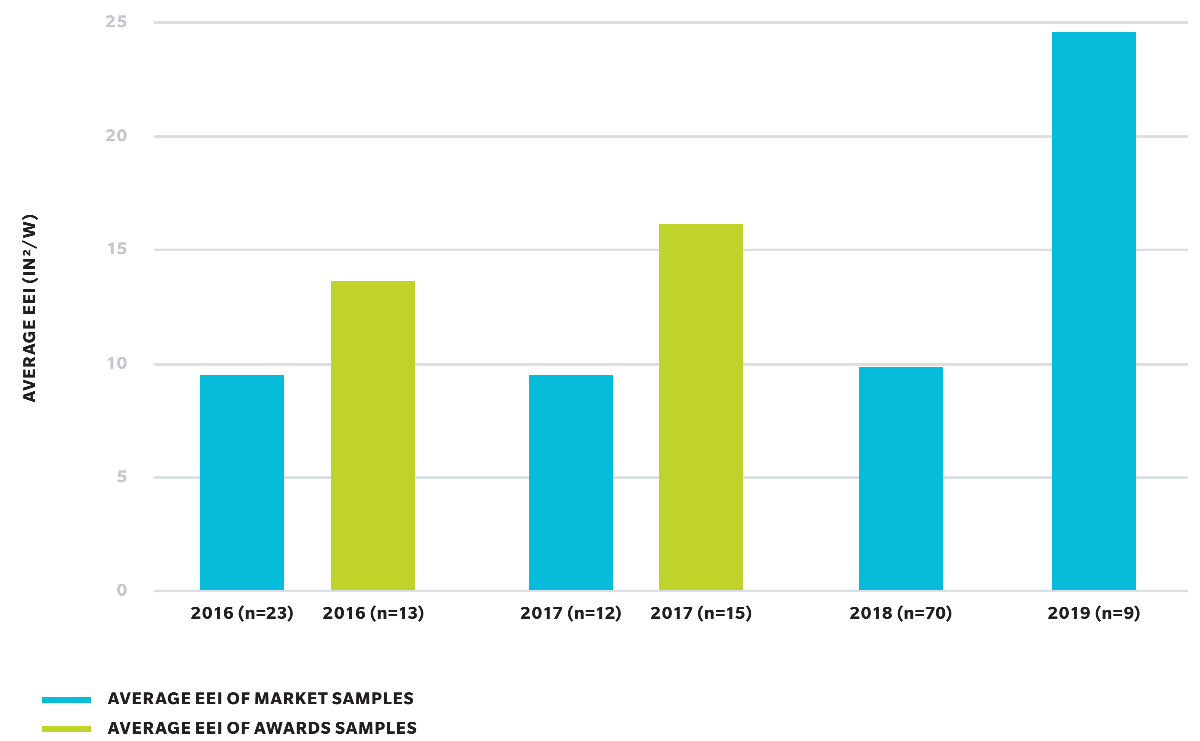
Overall, TV energy efficiency is improving, with significant energy efficiency gains recorded over the last year. The average efficiency of Global LEAP Awards products improved by 18% between 2016 and 2017 and market sample products showed modest but steady improvements in efficiency during the same period. In 2019, a market sample of nine TVs showed drastic improvements in efficiency. These TVs were 149% more efficient than those sampled in 2018 and 52% more efficient than samples tested in 2017 (Figure 1). This may be due to the fact that several highly-efficient TV models were brought to the market by leading solar energy companies in 2019, as well as the smaller sample size in 2019 compared to previous years.

DEFINITION

TV ENERGY EFFICIENCY INDEX

For the purposes of this study, the TV Energy Efficiency Index (EEI) is defined as the screen size in square inches per watt of input power, or in^2/W. The higher the EEI, the more efficient the TV.

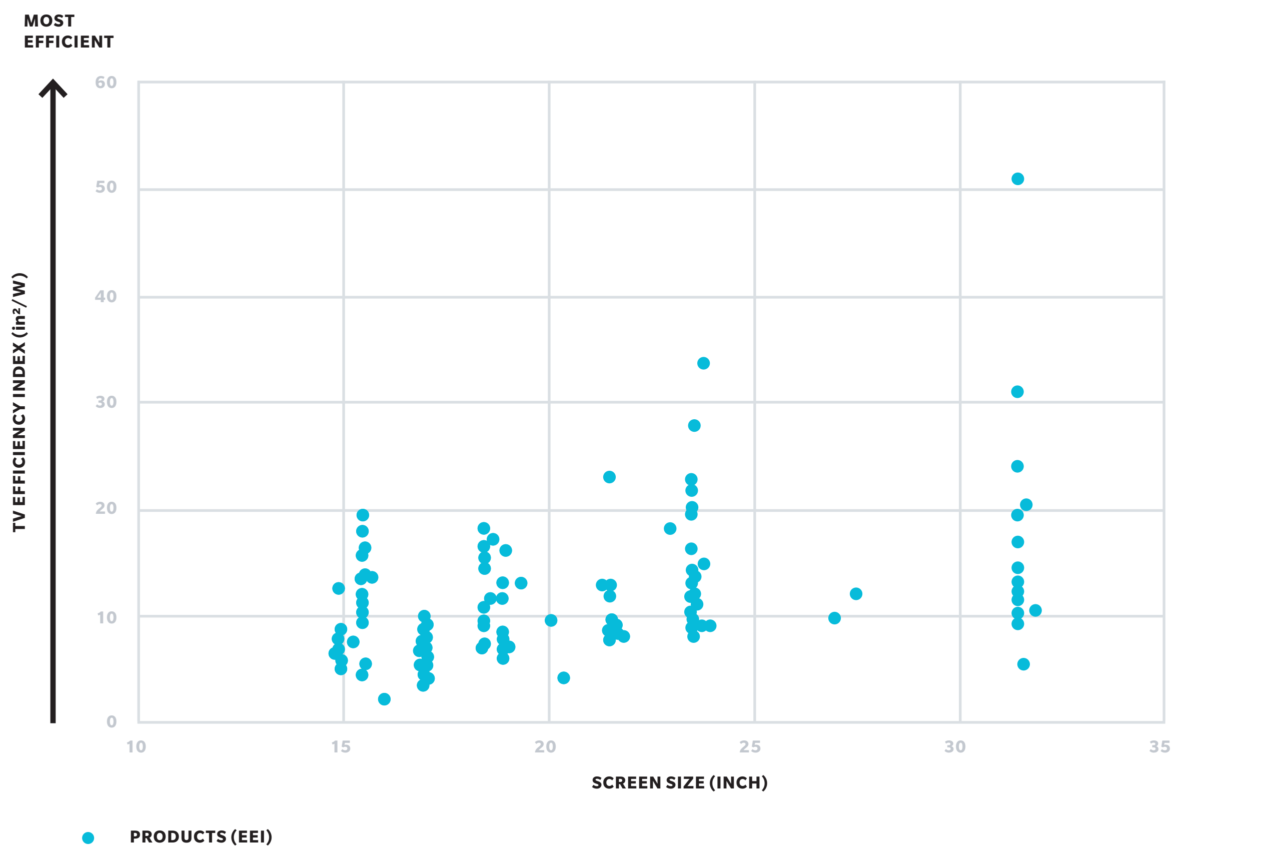
Figure 1. Average Efficiency of Off-Grid TVs from 2016 to 2019[5]



5. A higher EEI indicates better efficiency.

Larger TVs are more efficient on average, with some 32" models consuming less than 10 W. More large size TVs were found in the market in 2019 and there are now a growing number of TVs that are bigger than 30 inches, with the largest measuring 38.6 inches. Larger TVs are also becoming more efficient, and the difference in power consumption between large TVs and small- to medium-sized TVs is minimal (Figure 2). The most efficient model in the dataset is a 32-inch TV that consumes only 8 W—significantly less than most small- and medium-sized TVs. Many similar-sized TVs sampled from African markets consume 20 to 40 W, which is 2.5 to 5 times more power than the most efficient model. This efficiency makes it possible for consumers to upgrade to larger TVs with their existing SHS kit without needing to upgrade their PV panel and battery. For commercial users, larger TVs could also be a good investment since they provide a better viewing experience for their customers with similar energy requirements.

Figure 2. Correlation between Off-Grid TV Energy Efficiency Index (in^2/W) and screen size (inches)



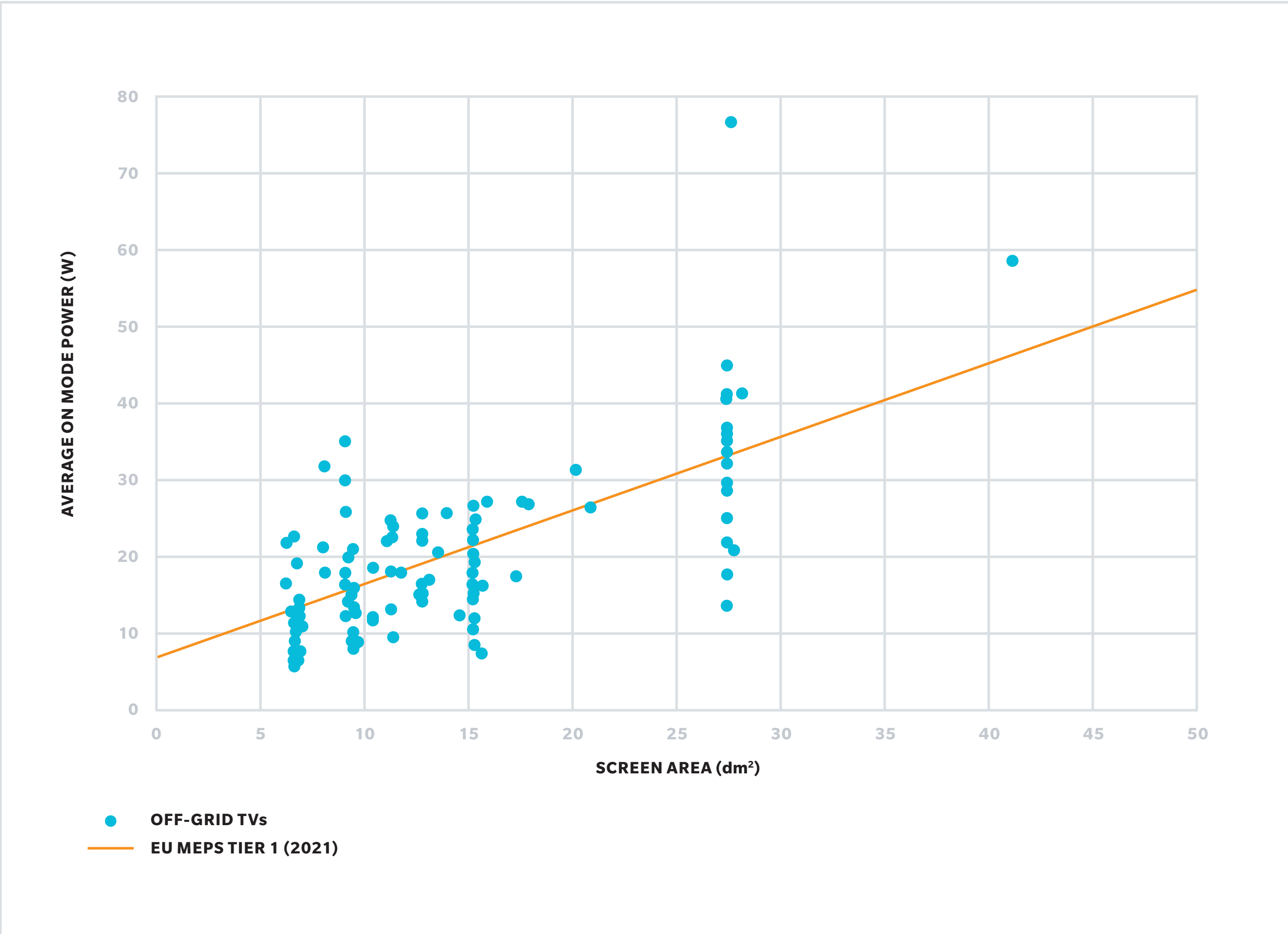
Efficiency comparison with TVs in the conventional market

Comparing TVs designed for use in off-grid contexts with conventional TVs widely available in the developed markets is helpful in assessing the potential for efficiency improvements (Table 2). The data suggests that, on average, the efficiency of off-grid TVs is equivalent to similarly sized on-grid TVs (15" to 39") sold in European markets. In fact, the most efficient off-grid TVs tested – those in the 90th percentile – exhibit a 15% better energy efficiency than the most efficient on-grid TVs in Europe.[6] When benchmarking off-grid TVs against new European regulations, 58% of the models tested met Tier 1 of the minimum energy performance standard (MEPS) that will be introduced in 2021, with a few larger TVs far exceeding them (Figure 3).

Table 2: Energy Efficiency Index (in²/W) Comparison: TVs Sold in Off-Grid Markets vs. TVs Sold in the On-Grid European Market[7]

ENERGY EFFICIENCY	INDEX OFF-GRID TVS	ON-GRID TVS DIFFERENCE	DIFFERENCE
EEI (mean)	11.76	11.90	-1%
EEI (90th percentile)	18.27	15.71	16%

Figure 3. Mapping TVs Sold in Off-Grid Markets Against European TV Regulations



6. Off-grid test data was compared with manufacturers' declared energy consumption data from 172 randomly selected, similarly-sized on-grid TVs from the ComplianTV database.
7. A higher EEI indicates better efficiency.

PERFORMANCE TRENDS

There are no clear trends in TV brightness, and the average brightness varies significantly across regions. TV luminance, in units of candelas per square meter (Cd/m²), is a key performance metric for TVs. While some manufacturers and distributors indicate off-grid consumers would prefer brighter TVs, others believe that when used in a dim environment, TVs do not necessarily need to be bright in order to provide a satisfactory viewing experience. This lack of market consensus is reflected in the data, with TV luminance values varying widely both within and across regions. Figure 4 shows the minimum, average and maximum luminance values of products sampled in three different regions: South Asia (India, Bangladesh, and Myanmar), East Africa (Kenya, Uganda, Tanzania and Ethiopia), and West Africa (Nigeria and Sierra Leone).

Figure 4: Average Off-Grid TV Luminance (Cd/m²) by Region

Off-grid appropriate TVs must balance brightness and efficiency. Luminance settings impact how much power a TV consumes, with higher luminance typically resulting in higher power consumption. The display efficiency metric looks at TV's luminance per watt. Market samples are typically brighter than Global LEAP Awards products, but the data indicates that Awards TVs achieve a better balance of brightness and efficiency (Table 3). This suggests that even though they may be brighter, there is an opportunity for market sample products to boost their display efficiency to the same level as that of Awards products.

Table 3. Comparison of Average TV Luminance between Market Samples and Awards TVs

SAMPLE SOURCE	AVERAGE LUMINANCE (CD/M²)	AVERAGE DISPLAY EFFICIENCY (CD/M²/W)
Market Samples in South Asia	165	8.4
Market Samples in East Africa	177	9.2
Market Samples in West Africa	208	8.4
Awards Samples (2016-2017)	136	11.5

PRICING TRENDS

The price of TVs continues to drop as products become more widely available. Figure 5s shows both the average retail price and price index of TVs tested between 2016 and 2019. The data indicates that, although the average retail price shows no clear trend, TV Price Index – defined as retail price (US$) per square inch of screen size – is decreasing over time.

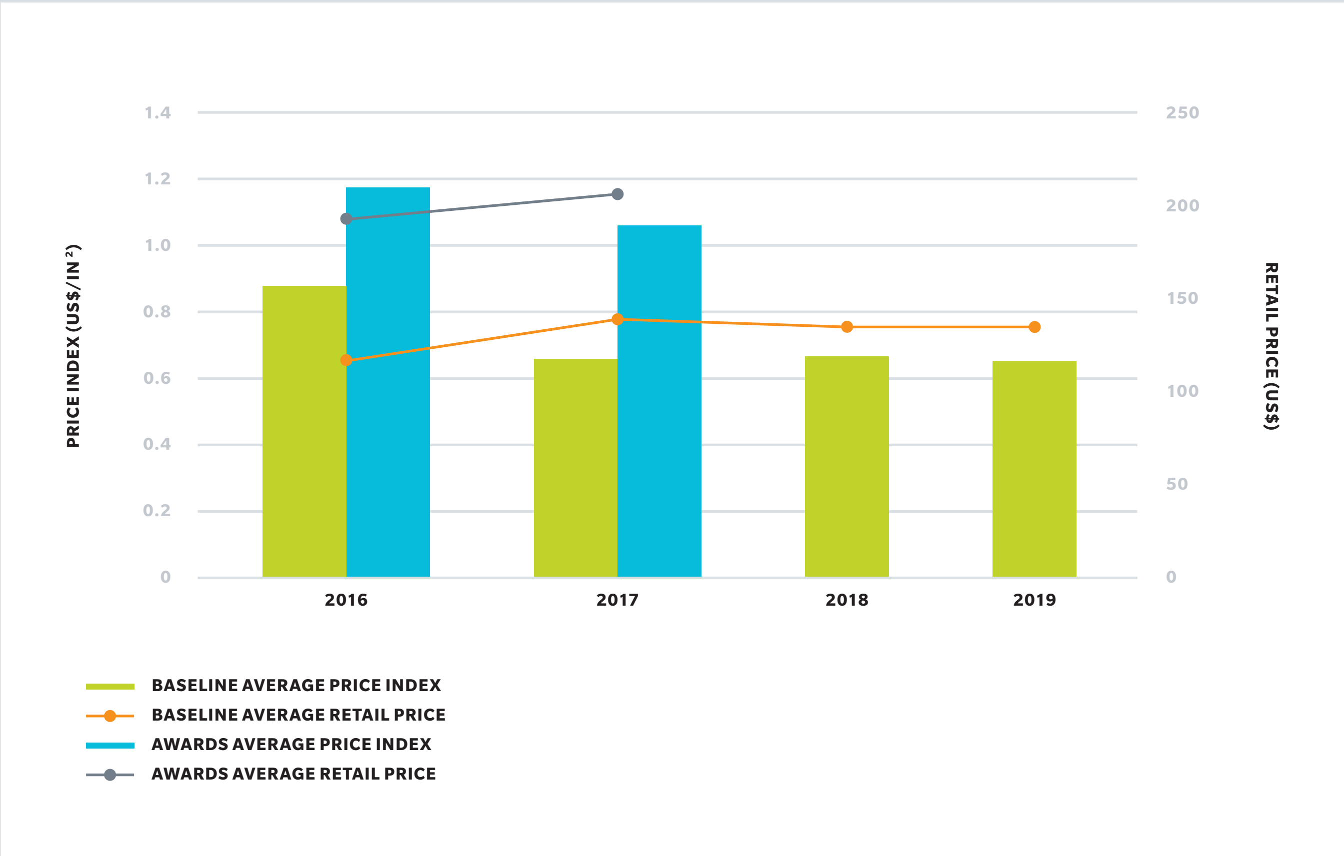
This could be due to higher sales volumes, increasing availability of TV brands and models driving competition, and lowering manufacturing costs as the TV market matures. Solar companies are also delivering more value to customers by selling larger TVs at the same price as smaller, now discontinued, models. These factors suggest that the TV market in off-grid areas is reaching commercialization. However, 2016 and 2017 Global LEAP Awards TVs remain more expensive than market samples (Figure 5). This price disparity will likely shrink in line with market trends, but it difficult to draw concrete conclusions because TVs have not been included in the Global LEAP Awards since 2017.

DEFINITION

TV PRICE INDEX

The TV Price Index is defined as the retail price in US$ per square inch of screen size, or US$/in^2. The lower the price index, the more affordable the TV.

Figure 5. Price Index and Average Retail Price of TVs from 2016 to 2019



System Cost Analysis

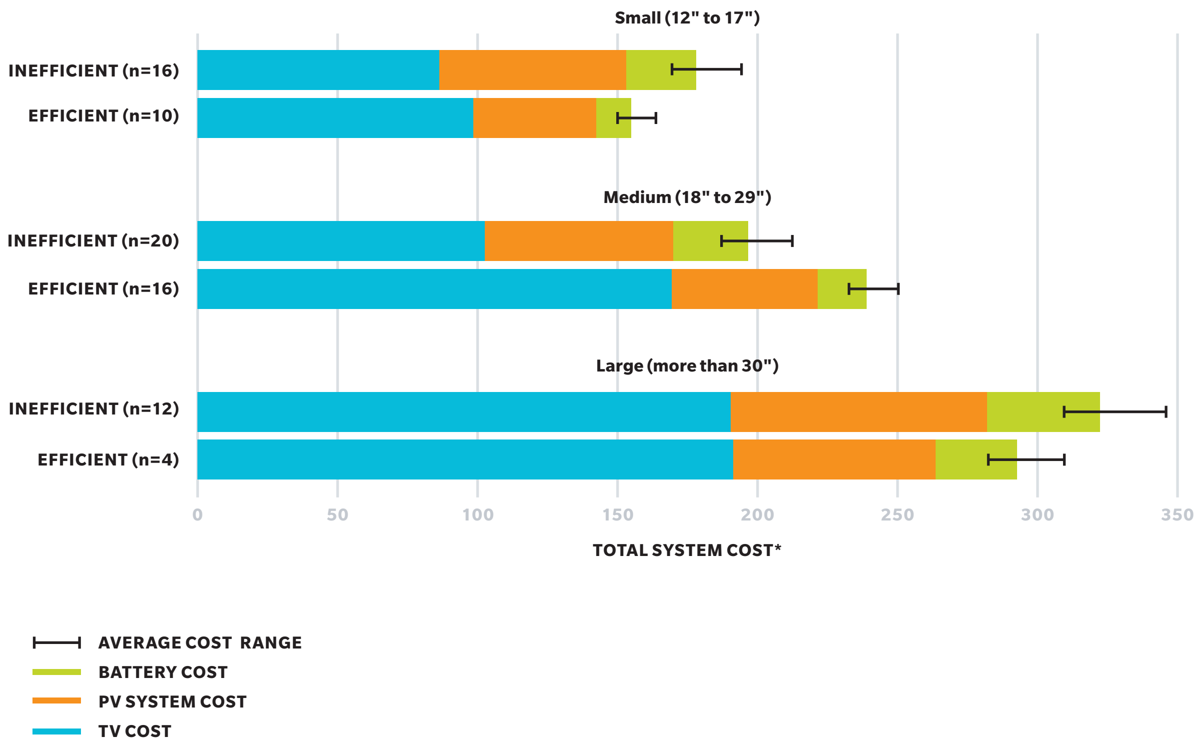
Along with examining product retail pricing, a complete analysis must take into account the solar energy system itself in order to fully understand the upfront purchase costs of off-grid appliances. This includes the estimated cost of a solar energy system, including a PV module, batteries, charge controllers and other elements (such as wires). Here, a solar energy system's capacity is estimated assuming an average of five hours of active TV viewing time in the evening.

Figure 6 compares the average cost of systems using efficient versus inefficient TVs. Given the absence of standards for off-grid TVs, the European MEPS Tier 1 was used as a proxy to differentiate efficient and inefficient models. Products that meet the EU MEPS Tier 1 are defined as efficient.

The system costs are broken down into components, and the error bars indicate the average cost range depending on levels of solar irradiance. In most cases, systems with efficient TVs are 11% to 18% cheaper than systems with inefficient TVs. Despite the decreasing costs of PV modules and batteries, solar system components still account for roughly 35% to 50% of the system cost, depending on the efficiency of the TV.

However, in the medium TV category, an anomaly is observed– systems with inefficient TVs are 22% cheaper than those with efficient TVs. The pricing of medium TVs varies widely (from US$139 to US$280), with inefficient TVs averaging US$102 and efficient TVs averaging US$167. While the average medium efficient TV consumes 49% less energy than an inefficient model, the costs saved by using a smaller solar energy system are not significant enough to make up for the higher price of the TV itself.

Figure 6. Cost of System: Efficient vs. Inefficient TVs



*This is not a lifetime cost as operational and end of life associated costs are not included.

Fans

High up-front costs and energy requirements keep air conditioners out of reach for most rural households and communities. Access to affordable cooling solutions, like fans, could be lifesaving, especially for women, children, and the elderly living and working in sweltering conditions.

This is vital considering that extreme high-temperature events have been occurring more frequently, lasting longer, and impacting more regions, making off-grid communities even more vulnerable than before. Between 2000 and 2016, the number of people exposed to heatwaves increased by around 125 million.[xviii]

Fans also improve users' quality of life and boost productivity. In a survey of 1,600 off-grid consumers, 81% believed that their lives had improved because of their fans. Households reported that their fans extended their productive time by an average of 2 hours 20 minutes per day.[xix]

While off-grid consumers' overall demand for fans is strong and growing, it varies widely by geography. In 2019, GOGLA affiliates reported selling 670,000 fans globally, with the majority sold in Pakistan, Bangladesh, and India. Pockets of high demand also exist in West Africa where the climate is hot and humid, but in East Africa, which is cooler and less humid, fan sales are nearly non-existent.

GOGLA sales data represents a small segment of the global fan market, where 73.3 million units of fans, designed for both on-grid and off-grid use, were sold in South Asia and Sub-Saharan Africa in 2019.[xx] The 2019 State of the Off-Grid Solar Appliance Market Report predicts that the off-grid fan market has the potential to grow significantly, reaching US$1.4 billion by 2030.[xxi]

DEFINITIONS

FAN ENERGY EFFICIENCY INDEX

For the purposes of this study, the fan Energy Efficiency Index (EEI) is defined as the volume of air delivered, in meters-cubed per minute, per watt of input power (m^3/min/W). The higher the EEI, the more efficient the fan.

TABLE FANS

A smaller-diameter propeller-bladed fan with two or more blades, intended for use with free inlet and outlet of air.

PEDESTAL FANS

A propeller-bladed fan with two or more blades, mounted on a pedestal or fixed at a variable height and intended for use with free inlet and outlet of air.

CEILING FANS

A propeller-bladed fan with two or more blades, provided with a device for suspension from the ceiling of a room so the blades can rotate on a horizontal plane.

EFFICIENCY TRENDS

Average fan efficiency improved significantly in 2019 and is nearly on par with the most efficient fans of 2017. In 2016 and 2017, the efficiency gap between Global LEAP Awards samples and market samples was quite significant (Figure 7). Awards products were 57% more efficient than market samples in 2016, and 39% more efficient in 2017. But the average efficiency of fans increased tremendously in 2019 and was almost on par with Awards products from 2017.

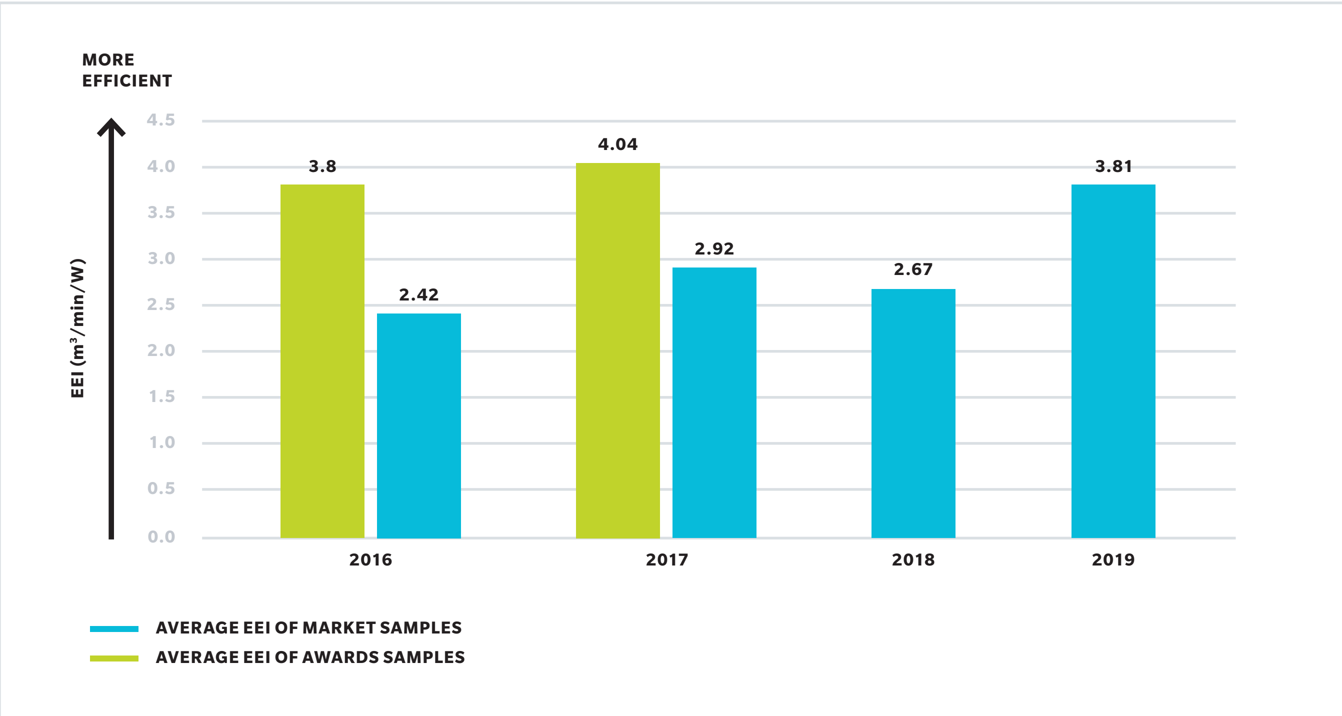
Fans that use DC motors demonstrated higher efficiency on average. A fan's motor is the most significant driver of energy consumption. A fan using an efficient motor, such as a brushless DC (BLDC) motor, could be 39% more efficient than one using a typical AC motor.[xxii] An assessment of the efficiency of fans using DC versus AC motors indicates that DC pedestal fans are approximately twice as efficient as their AC equivalents (Table 4). But for ceiling fans, whose average efficiency tends to be very high because of their larger size, the difference between AC and DC motors is minimal. Several fan models sold in India, Pakistan and Tanzania were labeled as "AC/DC compatible", indicating they could be powered by either AC or DC electricity. These could be a practical solution for weak-grid consumers who use a solar energy kit as backup during power outages.

While these fans can help address interoperability challenges, in a few cases examined, AC/DC compatible fans were less efficient than purely AC or DC fans. However, more data are needed to understand AC/DC compatible fans and their performance.

Table 4. Average Efficiency across Different Fan Types [8]

FAN TYPE	SAMPLE SIZE (N=)	AVERAGE EEI (M^3/MIN/W)
Ceiling Fans	**24**	**5.77**
DC	16	5.72
AC	6	6.31
AC/DC	2	4.57
Pedestal Fans	**48**	**2.19**
DC	28	2.76
AC	19	1.39
AC/DC	1	1.56
Table Fans	**45**	**2.31**
DC	37	2.36
AC	6	1.72
AC/DC	2	3.26

Figure 7. Average Fan Efficiency from 2016 to 2019



8. A higher EEI indicates better efficiency.

Moving the efficiency dial for locally manufactured fans in Pakistan

In Pakistan, where over six million people live through sweltering summers without access to energy, the demand for efficient, affordable off-grid fans is huge. To help meet this demand, several development programs plan to finance the installation of more than 350,000 SHS kits bundled with fans and other appliances.

Limited performance data on fans sold in Pakistan exists. To address these data gaps, Efficiency for Access tested fans commonly found in local markets to help development program managers find high-quality models for financing. Although the selected models were considered high quality, they did not perform as expected. The five pedestal fans tested consumed14 to 34 W, using 16% to 68% more energy than the average pedestal fan tested by Efficiency for Access.

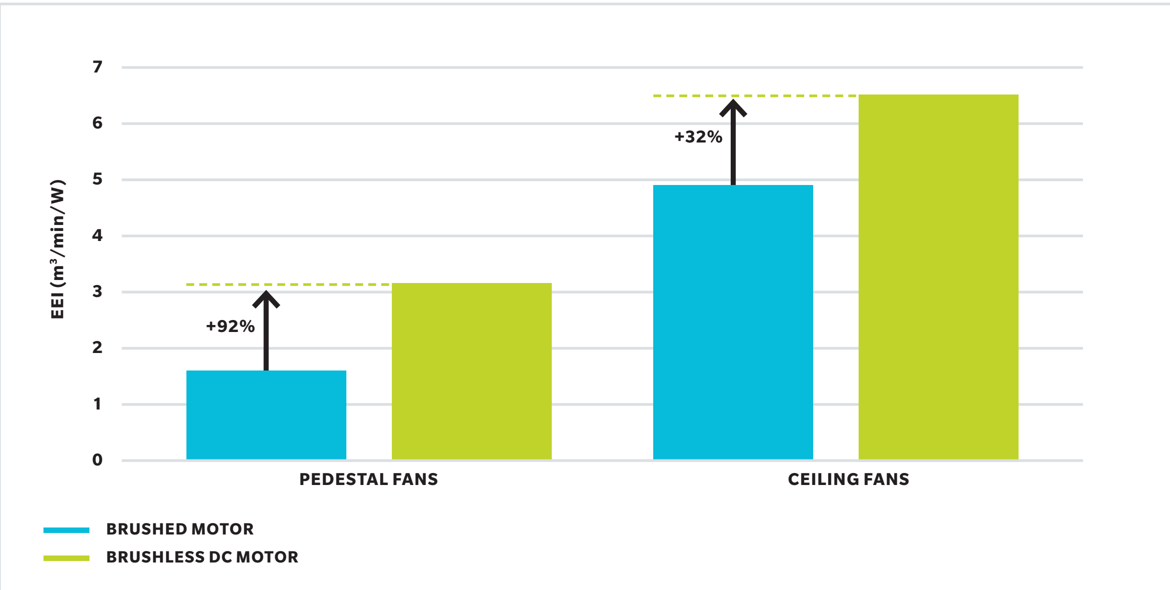
Efficiency for Access test results prompted local fan manufacturers to improve efficiency, particularly through improving their motors. They upgraded fan designs by integrating BLDC motors, and two companies even began importing machinery to manufacture BLDC motors locally to reduce import costs. With close proximity to major local manufacturers of both motors and fans, and transformational investments and subsidies, Pakistan's local context was also highly favorable to fan design improvements.

Pedestal and ceiling fans with BLDC motors are substantially more efficient; the average EEI value of pedestal fans has improved by 92%, and ceiling fans by 32% (Figure 8). For one of the models tested, efficiency improved by over 200% after the upgrades. Additionally, with better-quality fans, manufacturers are now able to offer a warranty of one or two years.

It is generally expected that the adoption of BLDC motors could lead to higher fan prices. The data suggests that the increase in price depends on fan type. The change in average retail price relative to size (price per inch) after adding the BLDC motors increased by 51% for pedestal fans and decreased by 12% for ceiling fans. Although there is a significant price jump for pedestal fans, when looking at the ratio of price to EEI, BLDC-motor pedestal fans are 46% more cost-effective.

This case study highlights how one small intervention and highly receptive local conditions can trigger a larger transformation of the market. In this case, actionable data enabled manufacturers to target product efficiency improvements, resulting in a more competitive domestic fan market, better products and stronger consumer protections for off-grid and weak-grid consumers in Pakistan.

Figure 8. Average EEI (m^3/min/W) by Fan Type and Motor Type



Efficiency comparison with fans available in the conventional market

Comparing the energy performance of fans sold in off-grid markets with those in conventional on-grid markets is helpful in assessing the relative maturity of fans sold in off-grid regions. Based on test data from off-grid models and manufacturer-rated specifications for on-grid table and pedestal fans in the European market,[9] the off-grid fans appear to be roughly two to three times more efficient. In India, local distributors indicated that the main reason consumers purchased DC fans was not to use them with SHS kits, but because consumers thought DC fans used less energy.[xxiii] This demonstrates the perceived value of efficiency for grid-connected customers.

Table 5. Energy Efficiency Index (m3/min/W) of Fans Sold in Off-Grid Markets vs. Fans from the On-Grid European Market[10]

TABLE FANS	OFF-GRID PRODUCTS (N=45)	ON-GRID PRODUCTS (N=32)	DIFFERENCE
EEI (mean)	2.31	1.04	122%
EEI (90th percentile)	3.88	1.29	201%
PEDESTAL FANS	**OFF-GRID PRODUCTS (N=48)**	**ON-GRID PRODUCTS (N=34)**	**DIFFERENCE**
EEI (mean)	2.19	1.27	72%
EEI (90th percentile)	3.40	1.59	114%

9. Data from 32 table fans and 34 pedestal fans featured on Topten Switzerland
10. A higher EEI indicates better efficiency.

PRICING TRENDS

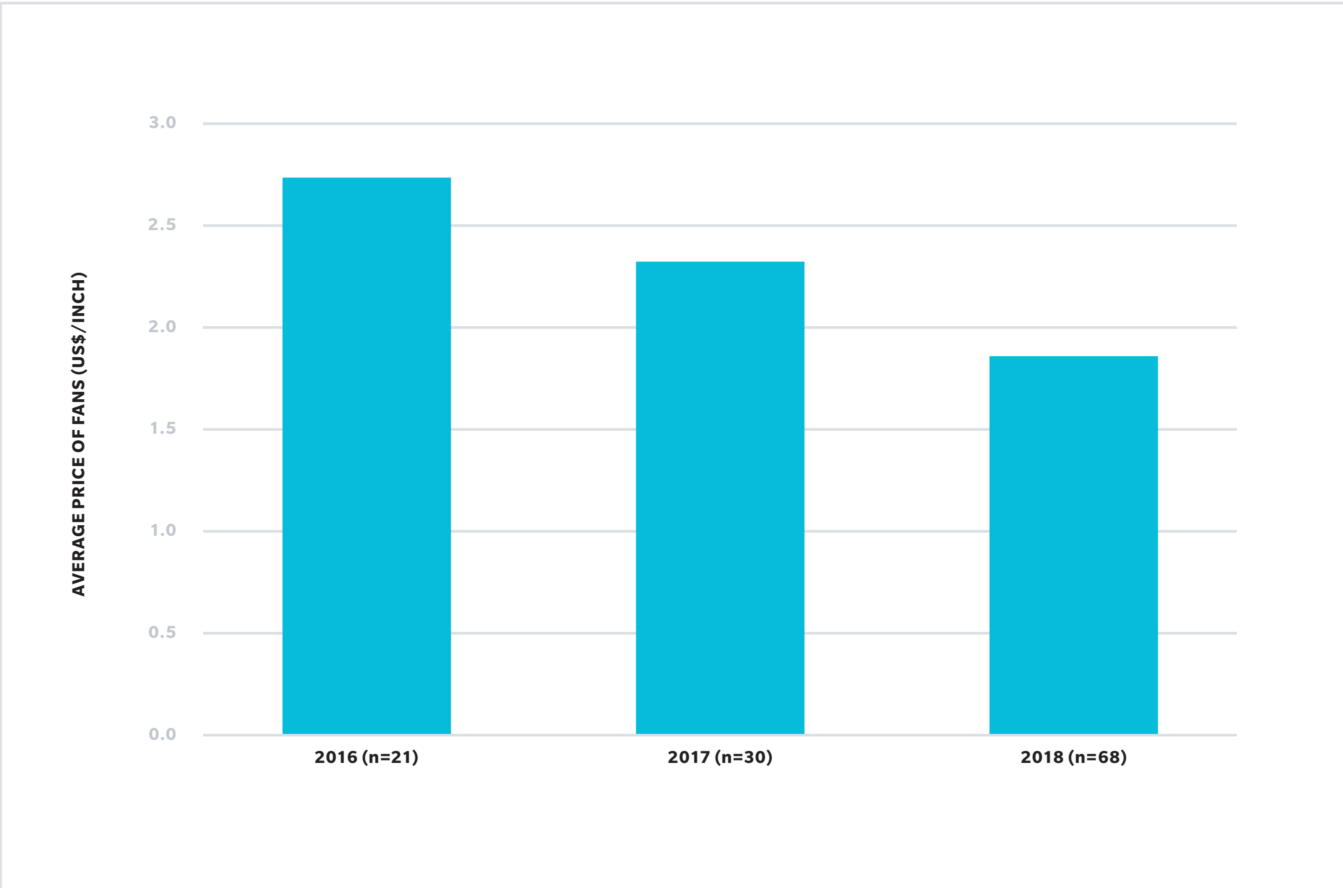
Average fan price has dropped 47% over a two-year period. While individual prices vary considerably, this downward trend in Figure 9 suggests fans may be more affordable to consumers than they were in 2016. We also found a negligible cost difference between market samples and similarly-sized Global LEAP Awards products. The average price index for Awards fans is about US$2.02 and US$2.18 for market samples. This pricing trend signifies that the fan market has becoming highly commoditized and competition is fierce, leading to falling prices.

DEFINITION

FAN PRICE INDEX

Fan Price Index is defined as the retail price in US$ per inch of fan diameter, or US$/inch. The lower the price index, the more affordable the fan.

Figure 9. Average Price Index of Fans Year by Year

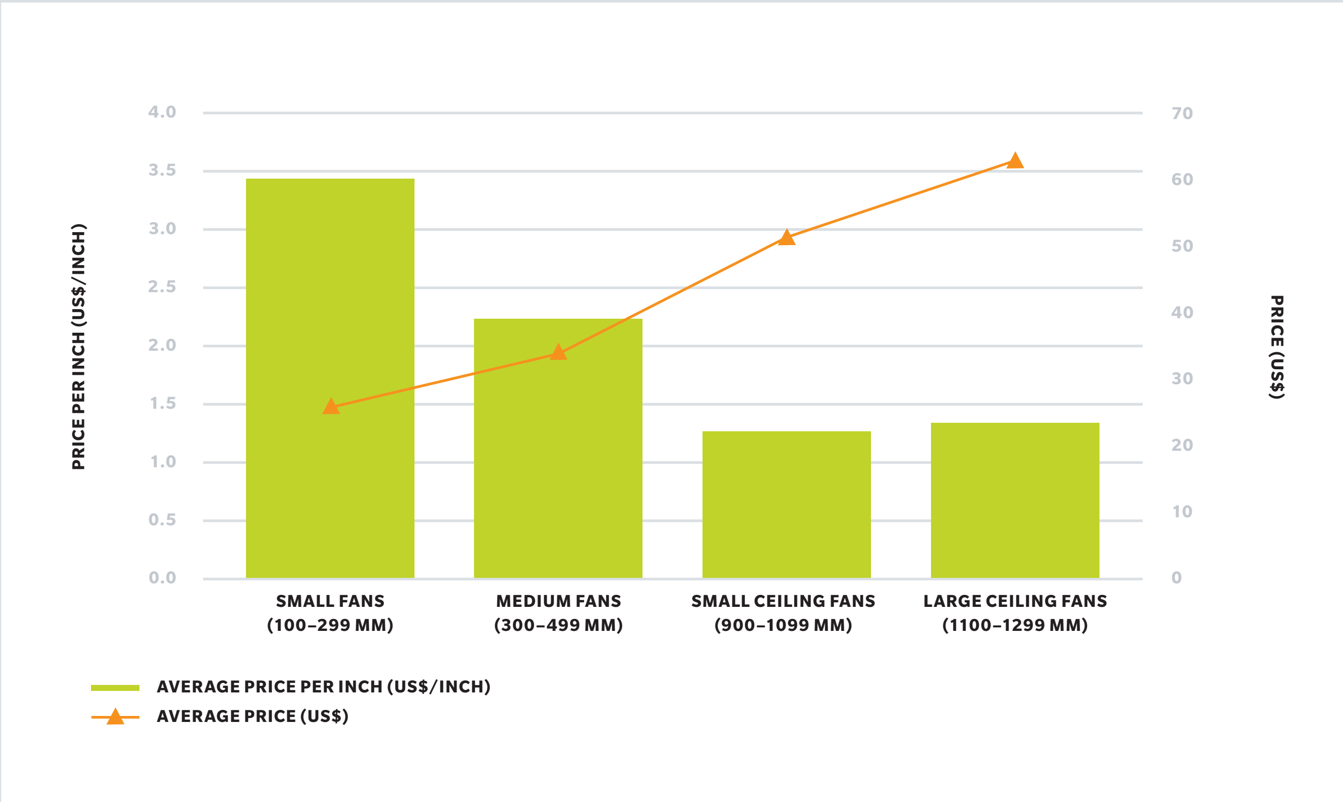


Size and motor type both contribute to fan price. As fan size increases, the cost per inch of fan decreases, with medium fans costing 53% less per inch of diameter than small table and pedestal fans (Figure 10). The type of motor used in the products also has a direct impact on pricing, with DC fans tending to be roughly 1.7 times more expensive, in terms of cost per inch, than AC fans (Table 6). One contributing factor could be the use of highly-efficient and durable DC motors, such as BLDC. One fan manufacturer in Pakistan reported that a BLDC motor cost US$8, while a typical brushed DC or AC motor cost US$5; [xxiv] a 60% price increase.

Table 6. Average Price of DC, AC and AC/DC Compatible Fans

POWER TYPE	SAMPLE SIZE (N=)	AVERAGE PRICE (US$/INCH)
DC	81	1.45
AC	32	0.86
AC/DC[11]	5	7.22

Figure 10. Average Price and Price per Inch of Fans



11. The relatively small sample size of AC/DC fans should be noted when comparing products by power type.

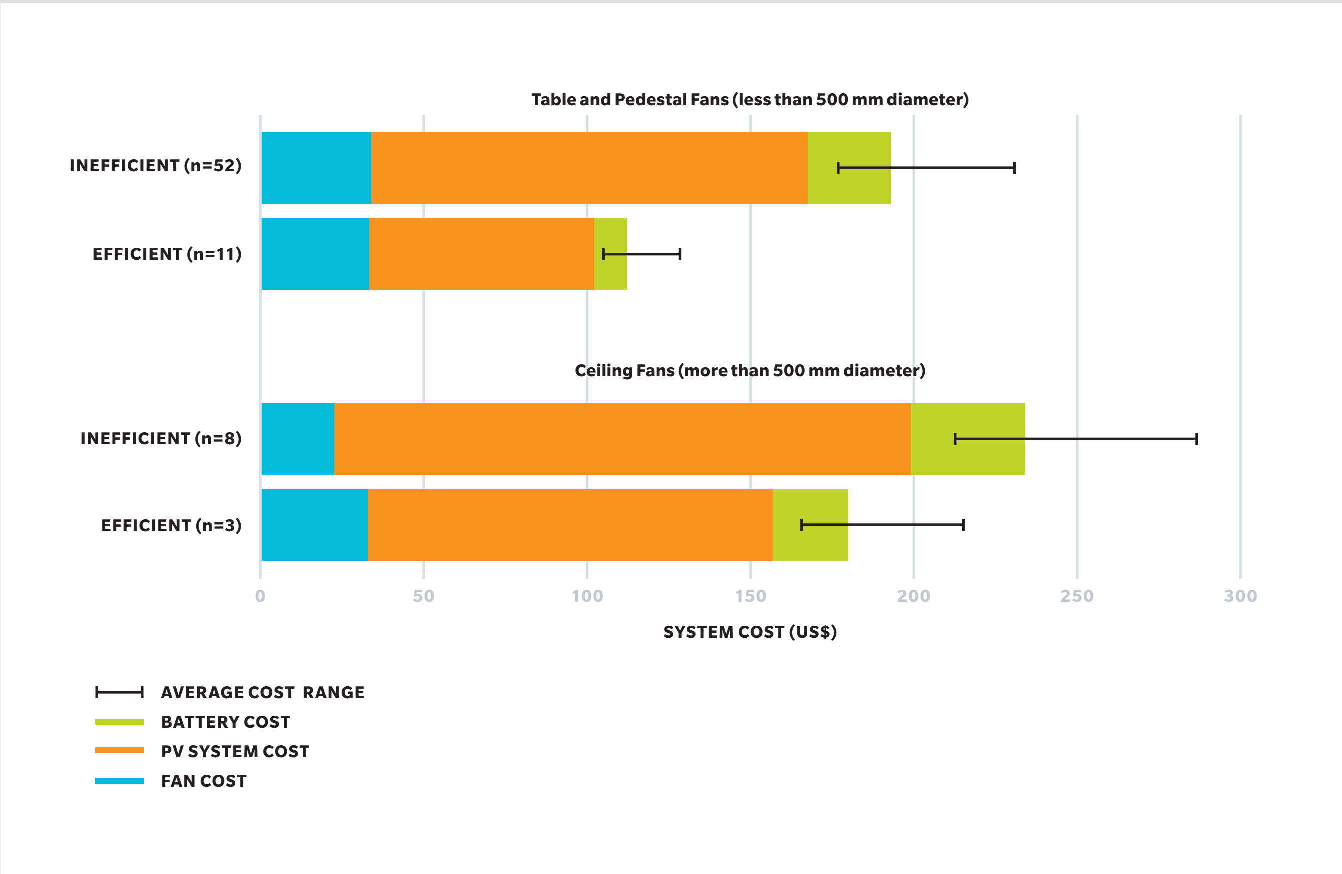
System Cost Analysis

Along with examining product retail pricing, a complete analysis must take into account the solar energy system itself in order to fully understand the upfront purchase costs of off-grid appliances. For fans, the solar energy system's capacity was estimated based on an average of nine hours of use in hot seasons.

Figure 11 compares systems for inefficient and efficient table and pedestal fans (less than 500 mm diameter) and ceiling fans (greater than 500 mm diameter). It should be noted that the cut-offs between efficient and inefficient systems are defined differently for the two size ranges, since larger fans are generally more efficient than smaller ones. In this analysis, efficiency boundaries were defined using the India Star Labelling[xxv] efficiency requirement as a proxy. For ceiling fans smaller than 1200 mm, products needed to perform better than 5.1 m^3/min/W to be defined as efficient, and for ceiling fans 1200 mm and above, 6 m^3/min/W is the threshold. For table and pedestal fans, which are not covered by the same regulations, the minimum energy performance tier for ceiling fans (3.1 m^3/min/W) was used to define efficient and inefficient models.

For table and pedestal fans, the difference in system costs between efficient and inefficient fan systems can be significant – on average, systems with efficient fans are 42% cheaper. Savings of roughly 25% are also observed for the ceiling fans. Given the small price difference between efficient and inefficient fans, the cost of the PV module and battery required to power them becomes more significant. For fans, the solar energy system component accounts for 70% to 90% of the system cost.

Figure 11. Cost of System: Efficient vs. Inefficient Fans



Refrigerators

Refrigerators offer a unique opportunity to stimulate economic and social progress for the billions of people living without reliable access to electricity. They increase food security by reducing food waste and extending the supply of perishable foods, and enable the delivery of vaccines.

However, refrigerators are one of the most challenging appliances to optimize for both energy efficiency and cost-effectiveness and are generally unaffordable for vulnerable consumers and communities. As a result, the global market for off-grid appropriate models remains in its infancy.

Only 17% of households in Sub-Saharan Africa and 30% in India own a refrigerator. The rural subset of Sub-Saharan Africa is even lower at 4%.[xxvi] As the off-grid solar industry has matured, the number of companies developing refrigerators designed for use with SHSs has grown, but sales volumes remain small. In 2019, GOGLA Affiliates reported selling approximately 8,000 solar refrigerator units globally. Despite low penetration rates, the cumulative global market potential for refrigerators was estimated at US$4.4 billion in 2018, with the potential to triple to US$14.3 billion by 2030.[xxvii]

The low penetration rate of refrigerators is due in large part to affordability and access to financing. The upfront cost of a refrigerator without financing is 2.5 times higher than the annual disposable income for the poorest 50% of the off-grid population.[xxviii] In order to be viable in off-grid settings—and suitable for rural customers—refrigerator affordability must be transformed through a combination of measures, including cost reduction through economies of scale, lower taxes and tariffs, consumer financing, and appropriate designs that balance performance and cost. Manufacturers are developing new technologies and seeking sufficient market scale to bring refrigerators within the reach of the average off-grid customer, but other factors driving product pricing also need to be addressed. However, the most recent GOGLA sales data shows that, while the overall pace of refrigerator sales decreased by 18% during the COVID pandemic, sales through PAYGO channels increased by 27%; suggesting that consumer financing can help unlock latent demand.[xxix]

DEFINITIONS

REFRIGERATORS

Refrigerators (denoted "R" in the following analysis) have one or more compartments for the storage and preservation of unfrozen food and beverages, where the average storage temperature ranges from 4°C to 8°C. Some off-grid refrigerators have one or more compartments that can be used as refrigerators or freezers by adjusting the thermostat control. For the purposes of the Global LEAP Awards, this type of product is classified as a refrigerator.

REFRIGERATOR-FREEZER COMBINATION UNITS

Refrigerator-freezer combination units (denoted "R-F") have at least one fresh food compartment and one frozen food compartment, where the storage temperature is below -6°C.

SOLAR DIRECT DRIVE REFRIGERATORS

Solar direct drive refrigerators (denoted "SDD") are designed to be directly connected to a photovoltaic solar panel, and generally include an integrated thermal and/or electric battery to allow for autonomous operation without electricity at night.

EFFICIENCY TRENDS

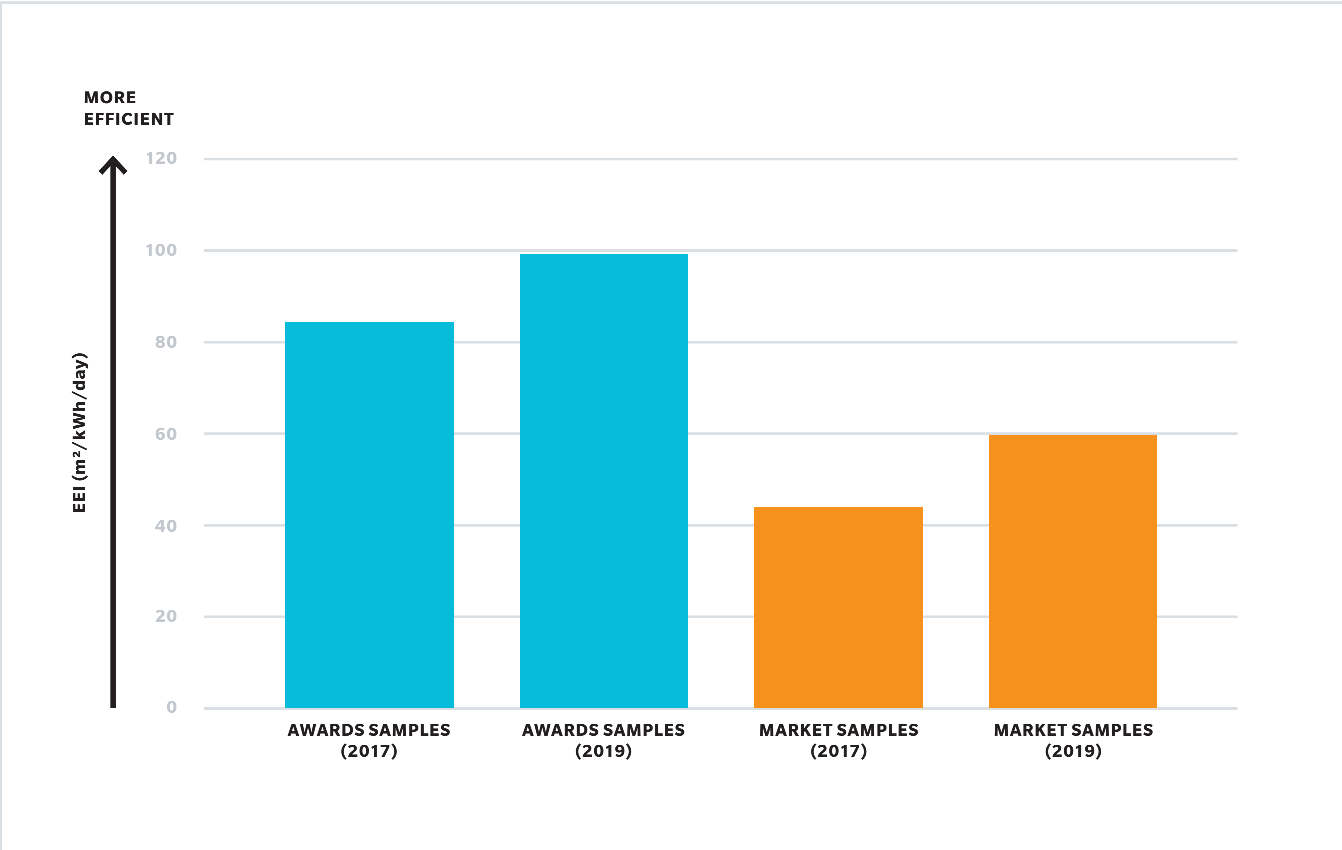
Refrigerator efficiency is improving overall, but there is still a significant gap between market samples and Awards products. 2019 Awards winners demonstrated an 18% improvement in energy efficiency over the 2017 Awards winners (Figure 12). Market samples showed similar improvements during the same period, with average efficiency up by 36%. Although there was still an efficiency gap between market samples and Awards winners, the gap narrowed from 90% in 2017 to 64% in 2019.

DEFINITION

REFRIGERATOR ENERGY EFFICIENCY INDEX

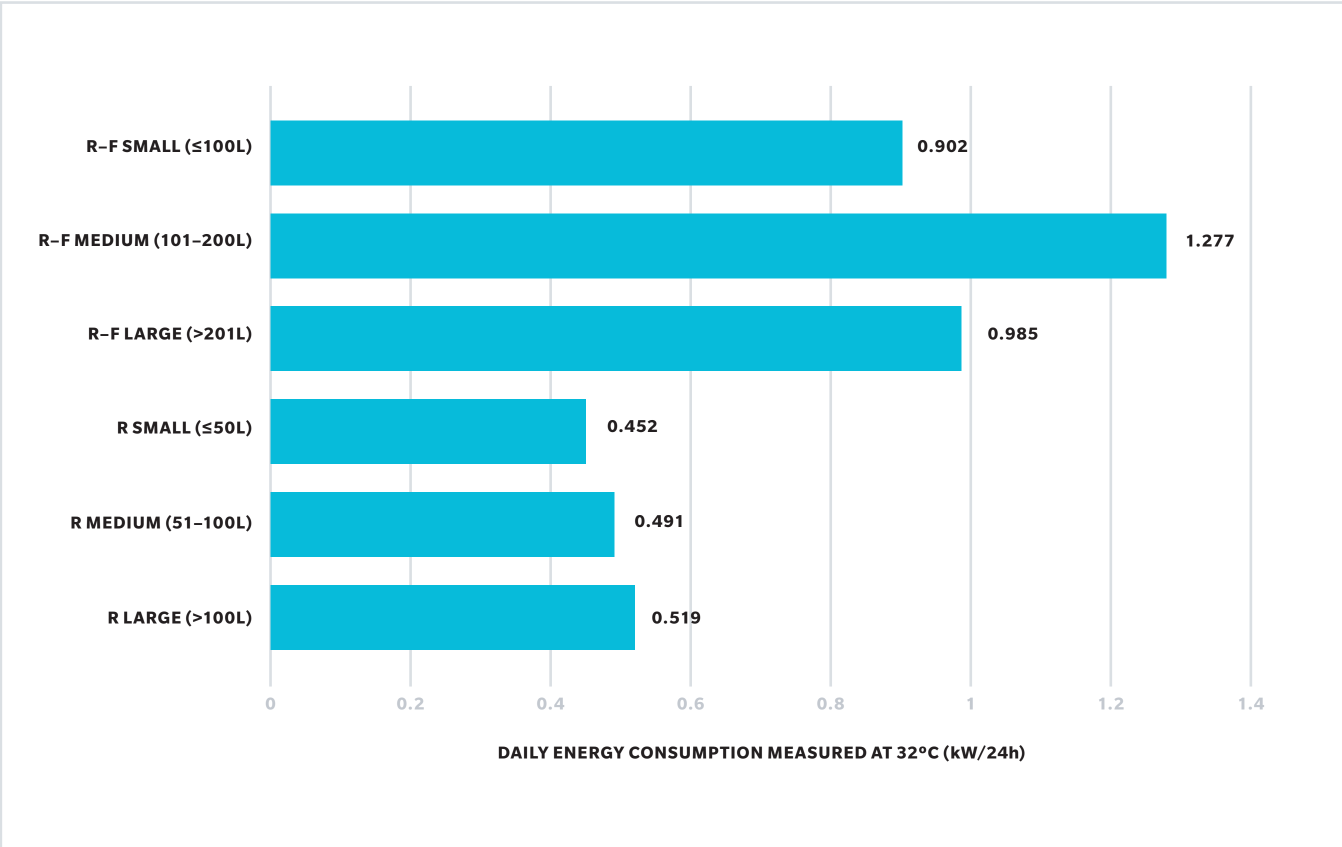
For the purposes of this study, the refrigerator Energy Efficiency Index (EEI) is defined as square meters of surface area per daily energy consumed (kWh): m^2/kWh/day. The higher the EEI, the more efficient the refrigerator.

Figure 12. Refrigerator Energy Efficiency Trends: Average Efficiency of Market Samples vs. Awards Products



A typical refrigerator-freezer can require up to five times more energy per day to operate than a refrigerator. Refrigerator-freezers on average consume around 1 kWh per day at an ambient temperature of 32°C. While higher volume refrigerator-freezers typically consume more energy, the average energy consumption of refrigerator-freezers in the large category is driven down by two highly efficient samples. Refrigerators need less than half as much energy to operate (Figure 13). Under optimal conditions, a refrigerator-freezer combination unit that consumes roughly 1 kWh per day would require a SHS with at least a 350 Watt-peak (Wp) solar panel and a 160 Amp hour (Ah) battery.[12] This type of system costs around US$700[13]– a more significant investment than the overwhelming majority of existing SHS consumers can afford. In comparison, a 50 W panel and 20 Ah battery system with three lights, radio, and a DC fan costs roughly about US$162.[14] The marginal cost for an existing SHS owner to update to a system with a refrigerator is more than US$500, three times more than the cost of their current 50 W home system.

Figure 13. Daily Energy Consumption Across Refrigerator Sizes



12. Based on CLASP's theoretical calculation.
13. Component costs based on retail pricing of Chloride Exide. https://www.chlorideexide.com/
14. Pricing based on Mangoo Marketplace product listing. https://www.mangoo.org/

Comparison of Energy Efficiency Index between Refrigerators Sold in Off-Grid Markets and Refrigerators from the On-Grid Market

The average efficiency of refrigerators sold in the off-grid market was compared with refrigerators of similar types and sizes[15] sold in conventional markets to on-grid consumers in Kenya. Kenyan refrigerators were used for this comparison due to data availability and comparability; Kenya's MEPS for household refrigerators requires testing at an ambient temperature of 32°C[xxx] the same testing conditions used for off-grid appropriate refrigerators.

Refrigerators sold in the conventional Kenyan retail market tend to be less efficient than off-grid appropriate refrigerators sold in the global market (Table 7), with off-grid appropriate refrigerators 82% more efficient on average. The most efficient refrigerators sold in off-grid markets are almost 2.5 times more efficient than conventional Kenyan market samples, while the least efficient off-grid market samples are only 28% less efficient. This is likely due to the mandatory MEPS in Kenya, which effectively prevent the least efficient refrigerators from entering the market. Applying policies such as quality and performance standards to off-grid appropriate refrigerators may help protect consumers, eventually driving the market towards meeting its efficiency potential.

Table 7. Energy Efficiency Index of Refrigerators Sold in Off-Grid vs. On-Grid Markets

REFRIGERATORS	OFF-GRID MARKET SAMPLES	ON-GRID MARKET SAMPLES	DIFFERENCE (%)
Lowest EEI	11	15	-28%
Mean EEI	71	39	82%
Highest EEI	193	80	140%

15. On-grid refrigeration data includes 207 free-standing refrigerators with capacity ranging from 40 to 300 litres. These products are approved by the Energy & Petroleum Regulatory Authority (EPRA) and passed Kenya's Minimum Energy Performance requirements for refrigerators. Data taken from EPRA in November 2020.

PERFORMANCE TRENDS

All refrigerator types showed improved autonomy performance. Autonomy—the ability to keep a sealed refrigerator compartment cool without power input—is one of the most valuable features for refrigerator consumers who live in off- and weak-grid environments with highly constrained and/or intermittent electricity supply. Autonomy is evaluated in terms of the time it takes a refrigerator compartment to rise from 4°C to 12°C with no external power supply. Data indicates that the average autonomy of all three refrigerator types slightly improved in 2019 (Table 8). Solar direct drive (SDD) refrigerators, generally designed to include an integrated thermal or electric battery to allow autonomous operation during the night, performed particularly well with an average autonomy time of 133 hours – roughly 5.5 days – without power.

Freezing performance needs to be improved. Freezing capacity testing measures the time in hours required to lower the temperature of a compartment to -6°C, -12°C and -18°C at an ambient temperature of 32°C. -18°C is the freezer temperature recommended by the International Institute of Refrigeration, as well as other national bodies like the US Food and Drug Administration and the European Commission.[xxxi] However, most of the samples tested were unable to reach this target temperature. Only 47% of all tested products could reach -6°C, while only 30% could reach -18°C. Test data also showed that refrigerator-freezer combination units need anywhere from 5 to 32 hours to cool down to -6°C. While these refrigerators may not freeze to -18°C, these units are able to deliver freezing service for specific use case, such as making ice or storing fish and other perishable foods.

Table 8. Autonomy (Hours) by Refrigerator Types

TYPES	2017 AVERAGE AUTONOMY (HOURS)	2019 AVERAGE AUTONOMY (HOURS)
Refrigerators	2.4	3.3
Refrigerator-Freezer Combination Units	0.9	1.1
Solar Direct Drive Refrigerators	133.0	133.1

Refrigerator field-testing performance

Field testing provides useful insights on how consumer behaviour and usage patterns impact refrigerator performance. This information can be used to improve both product design and laboratory testing methods.

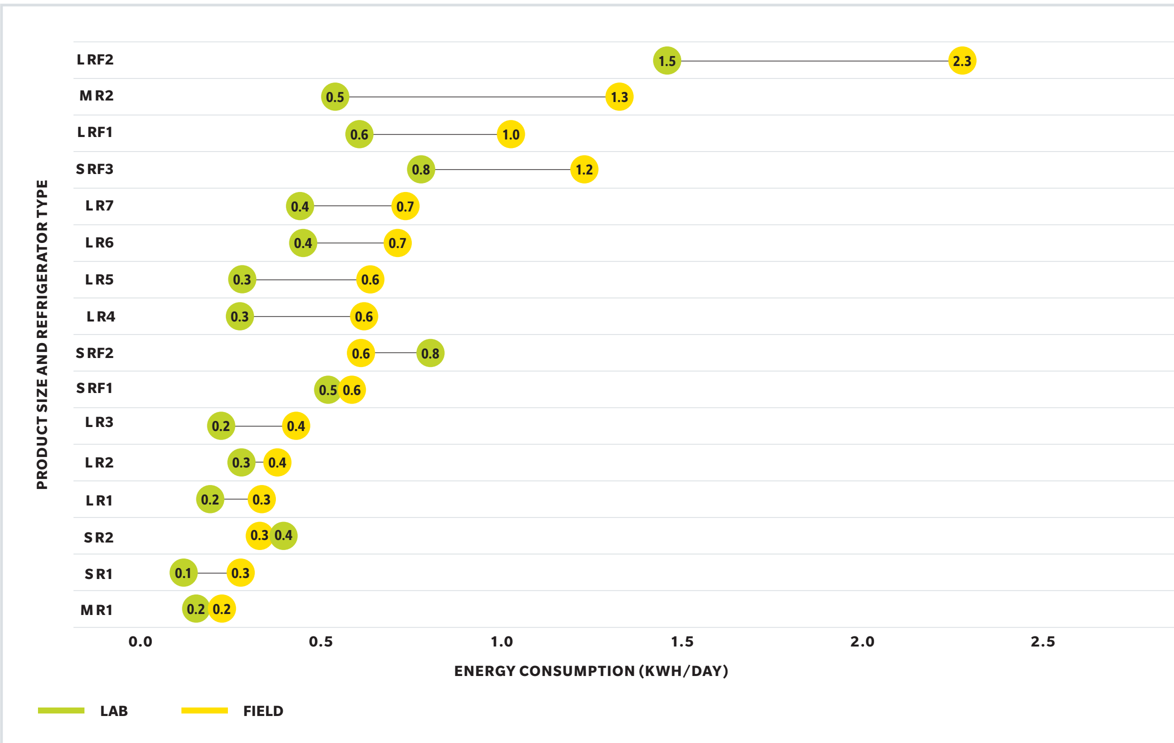
As part of the 2017 Global LEAP Awards, 36 refrigerators were installed in small retail shops in rural Uganda for field testing. The purpose of this testing was to monitor the performance of the refrigerators in real-world conditions and to document use cases, consumer feedback and socioeconomic impacts of refrigerators for first-time users.

The daily energy consumption values measured during field testing differed considerably from lab-tested measurements (Figure 14), with 88% of tested refrigerators consuming more energy in the field than in the lab. The medium and large refrigerators required much larger energy systems to operate than anticipated, consuming on average 124% and 80% more energy, respectively.[xxxii]

This variance in energy consumption of samples tested in the lab versus the field is due to use cases and user behaviour. For example, all the refrigerators were primarily being used for beverage cooling. With end-users loading large quantities of room-temperature bottles into their refrigerators and frequently opening and closing the doors during business hours, refrigerator compressors had to run for longer to cool the compartment, resulting in higher energy consumption. Additionally, several customers were not using the refrigerators correctly (including not fully closing the doors), which also contributed to increased energy consumption. These field data and findings were valuable inputs to strengthen laboratory test method, making the lab-testing process more reflective to real-world conditions.

Two years after installing the refrigerators for field testing, a follow-up visit in 2020 identified quality issues with the off-grid refrigerators. While most products (78%) were still working, 69% of customers reported that the refrigerator was "not as effective as when first bought, but good."[xxxiii] This highlights the fact that durability is critical for long-term product success, especially in remote areas where customers cannot easily access maintenance and repair services.

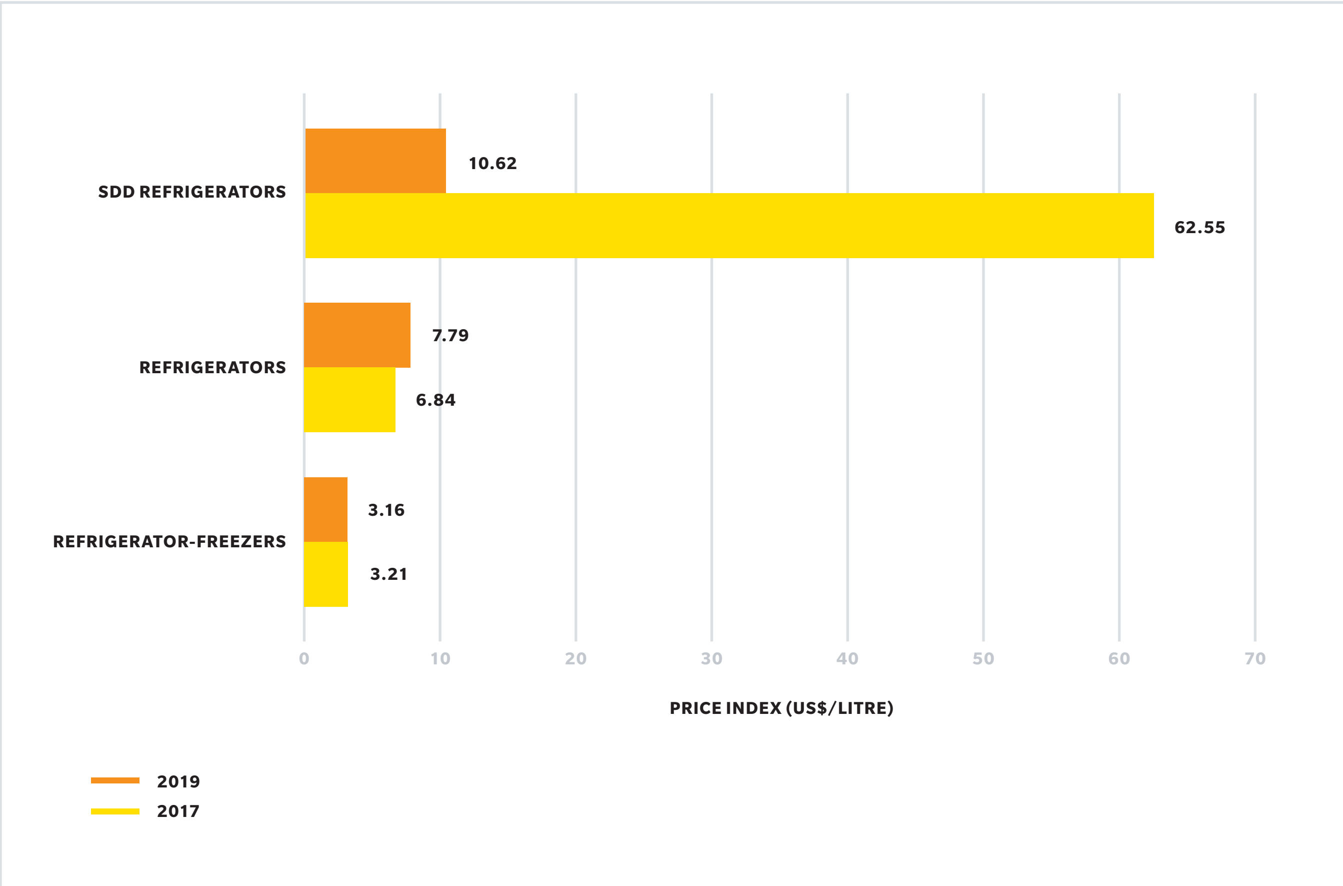
Figure 14. Average Daily Energy Consumption: Field vs. Lab Measurements



PRICING TRENDS

The high price of refrigerators remains a major barrier to consumer adoption. Among the three refrigerator types, refrigerator-freezer combination units cost the least per litre (L) (US$3.16 per L, averaging US$430 per product). Refrigerators are roughly twice as expensive per unit (US$7.79 per L, averaging US$675 per product) than combination units, with SDD refrigerators being the most expensive (US$10.62 per L and averaging US$1500 per product, not including the cost of the solar panel). But while SDD refrigerators were pricier than the other types, they also showed an 83% cost reduction in 2019 compared to 2017 (Figure 15). Furthermore, the cost of a SDD refrigerator should in effect be compared to the cost of regular refrigerators in combination with the cost of a suitably sized battery and solar charge controller (which in practice can be between $100-$200), that SDD units already have included. In 2017, most of the SDD refrigerators available in the market were being designed specifically for medical use, such as vaccine storage; SDD vaccine refrigerators were therefore built to meet stringent temperature performance requirements set by the World Health Organization, resulting in much higher costs. But many manufacturers in the off-grid solar market have since redesigned SDD refrigerators for light commercial use cases, and by 2019 they are already considerably less expensive.

Figure 15. Average Price of Refrigerators by Type in 2017 and 2019

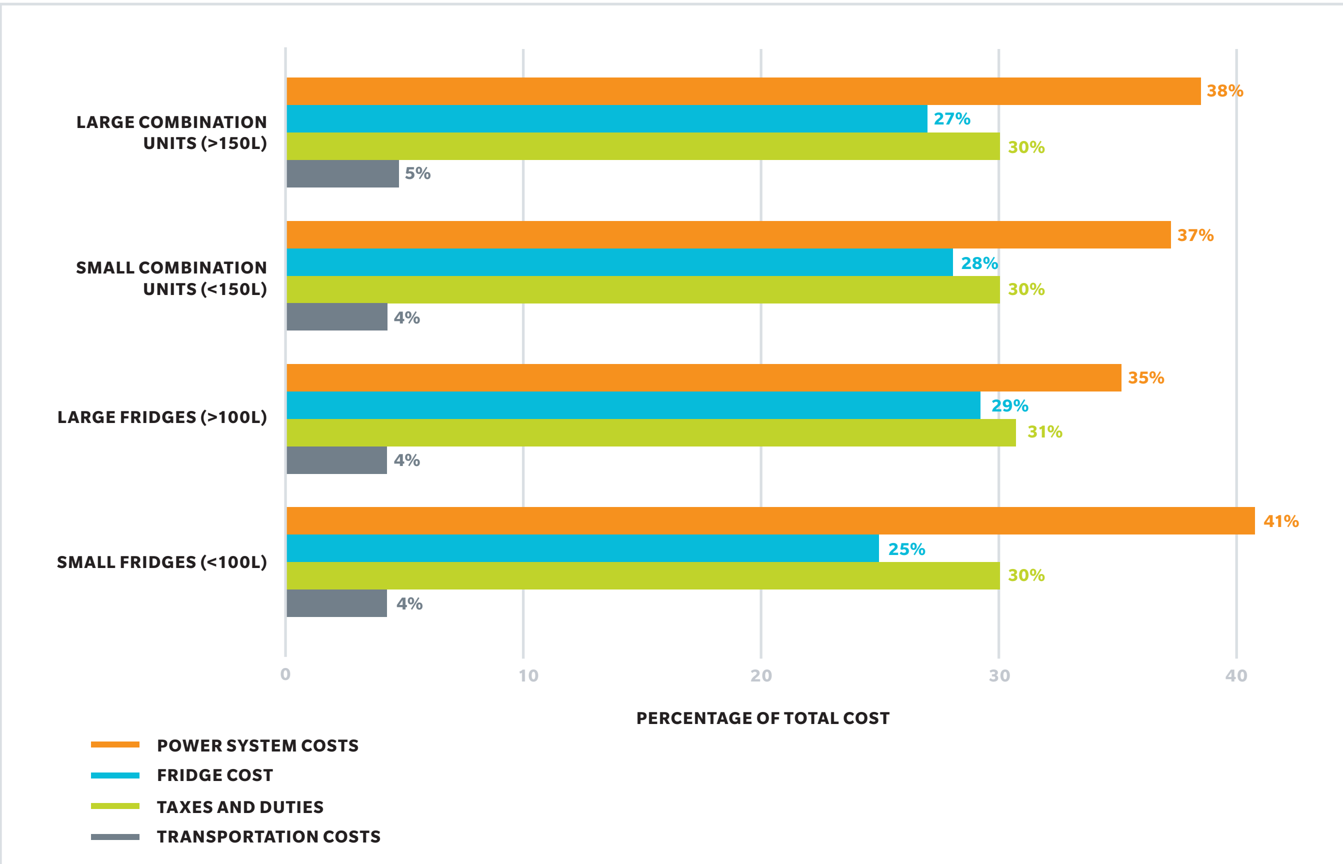


Refrigerator price is correlated with efficiency, but other factors also contribute significantly to a system's cost. More efficient refrigerators typically cost more. However, a recent study by Efficiency for Access also indicates that the majority of a refrigeration system's cost comes from its power components, duties and taxes, regardless of geography or model.[xxxiv] The battery, solar panel, charge controller, inverter, duties, VAT, and shipping costs comprise more than half of the total cost to the end user (Figure 16), suggesting that improved efficiency alone might not be enough to make an appliance more affordable. A holistic approach inclusive of policy and supply chain may be needed to accomplish this goal.[xxxiv]

Policy Consideration: Duties and VAT are a Hindrance to Refrigerator Affordability

Most off-grid appliances, including refrigerators, have no specific code to classify them as solar during the importation process, and so they are categorized the same as their on-grid counterparts. This means off-grid appliances are usually classified as nonexempt from duties, even if there is a policy in place that makes solar products exempt.[xxxvi] Refrigerators are considered a luxury good in many key markets, and thus are taxed at high rates –up to 50% with an additional 10-15% VAT. Solar system components are also taxed, but often at a lower rate than the refrigerator. In many African markets, solar panels, and controllers are duty free, but the batteries are taxable. These varying rates across components can present complications for manufacturers when deciding how to ship and classify their products. To avoid higher duties, some companies leverage in-country assembly to enable them to ship components instead of a fully assembled product. For example, a refrigerator compressor shipped to Kenya could have a duty rate around 8.3% whereas a fully assembled refrigerator could have a duty rate around 25%.[xxxvii]

Figure 16. Relative Cost Breakdowns for the Average Refrigeration System in Kenya[xxxv]

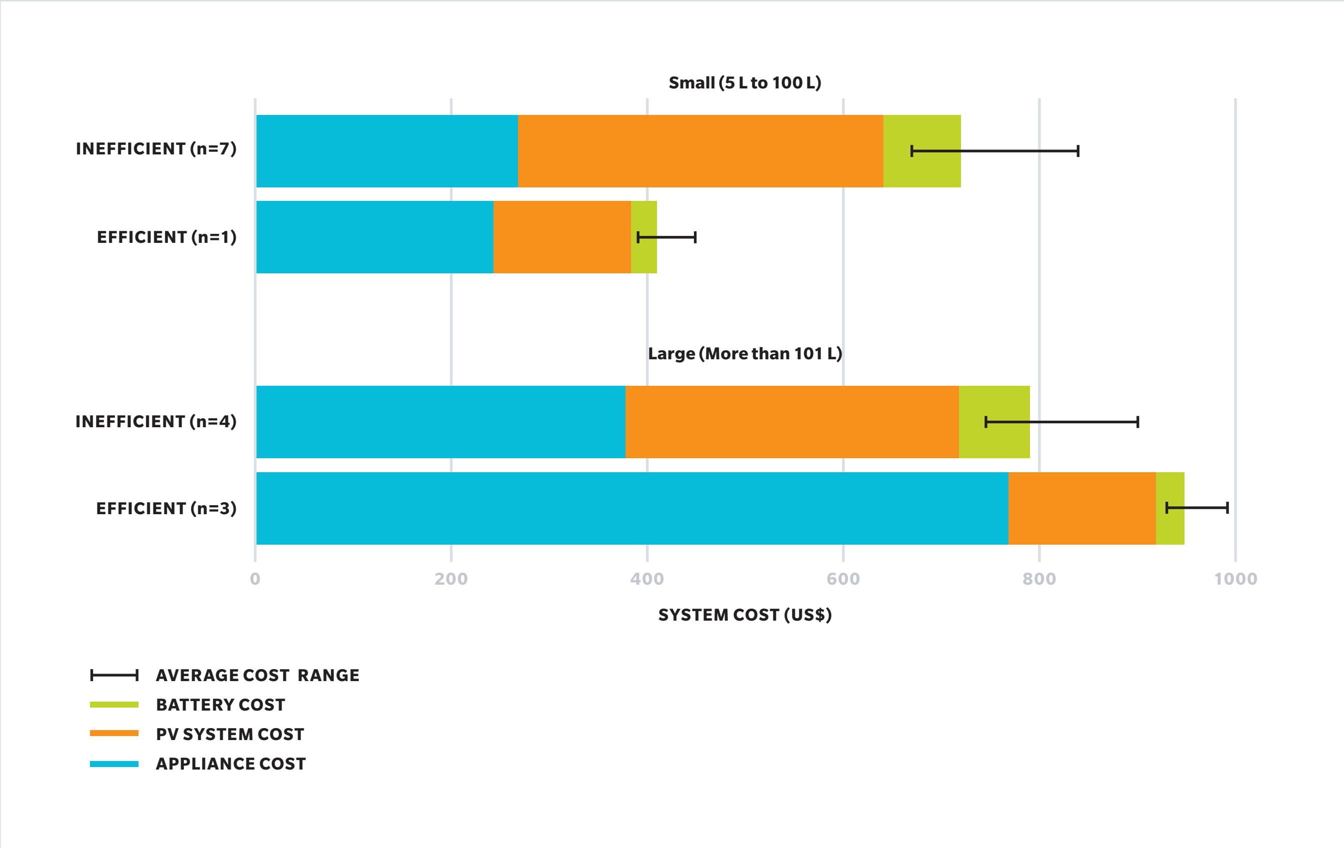


System Cost Analysis

The cost of system analysis provides a cost estimate for purchasing a refrigerator along with the solar energy system it requires. The solar energy system's capacity is estimated based on a refrigerator's energy consumption over 24 hours at an ambient temperature of 32°C. This cost estimate, however, does not include taxes/duties and transport costs, which could be more expensive than the cost of the refrigerator.

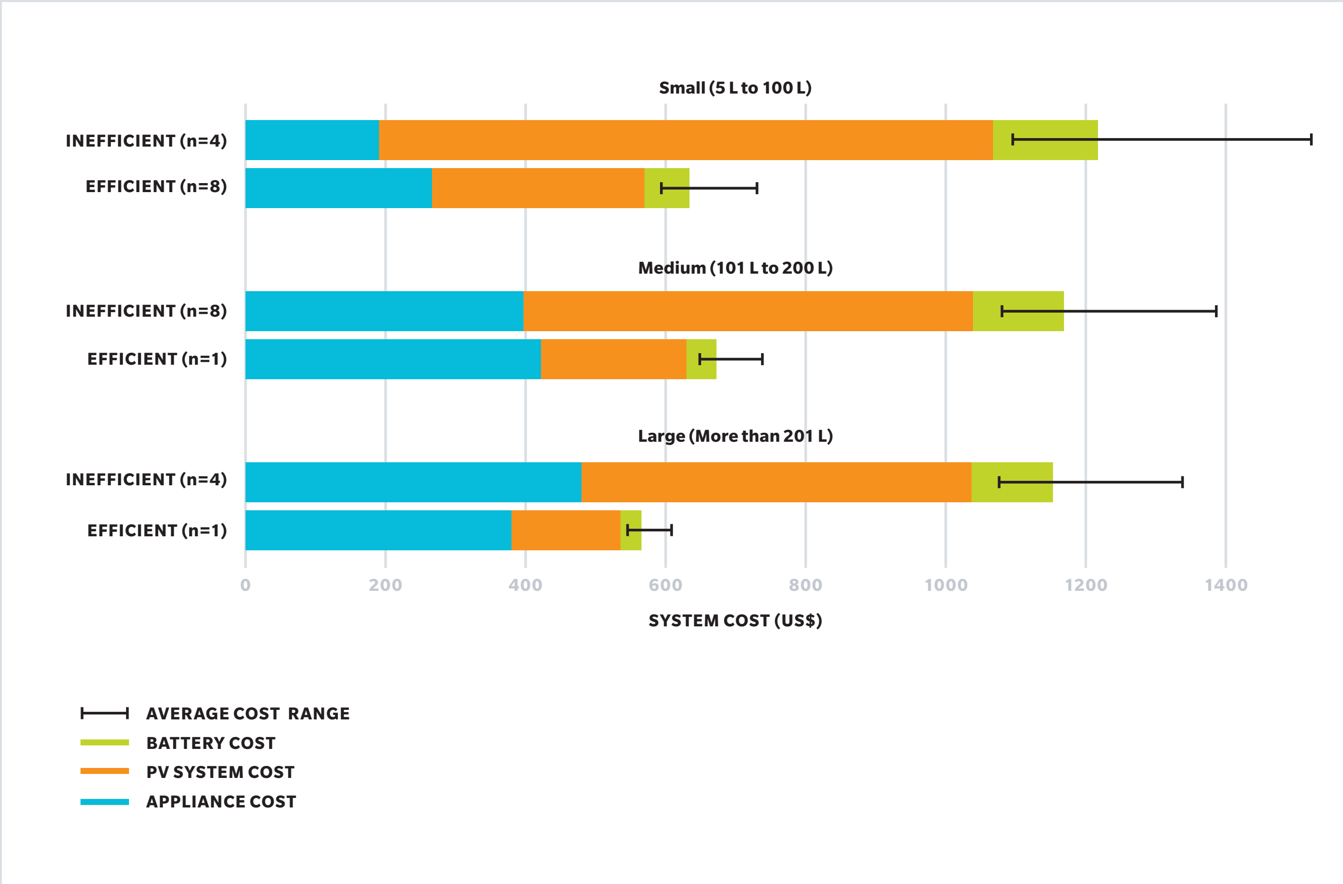
Figure 17 and Figure 18 compare average total system costs for systems using inefficient and efficient refrigerators in different size categories. In the absence of off-grid refrigerator standards, the European Union's energy labeling classes for refrigerating appliances[xxxviii] were calculated for off-grid refrigerators to define efficient and inefficient models. Refrigerators that meet the class A tier (42 ≤ EEI < 55) in the European Union energy labelling were defined as efficient models. Refrigerator-freezer combination units that meet the class D tier (95 ≤ EEI < 110) were considered efficient.[16]

Figure 17. Cost of System: Efficient vs. Inefficient Refrigerators



16. The Energy Efficiency Index (EEI) in the European regulation is defined as the annual energy consumption of the refrigerator (AEc) over its standard annual energy consumption (SAEc): EEI = AEc / SAEc x 100.

Figure 18. Total Cost of System: Efficient vs. Inefficient Refrigerator-Freezers



There is a potential for more than 40% total system cost savings for most scenarios, except for large refrigerators. The difference in total system cost between efficient and inefficient refrigerators ranges from 42% to 53% depending on the type and size of the appliance, with the greatest difference appearing in refrigerator-freezer combination units. This shows the cost benefits of using a highly efficient refrigerator.

However, with the rapid decreasing PV pricing – from US$359 per megawatt-hour in 2009 to $40 per megawatt – hour in 2019[xxxix], it is possible for inefficient models to achieve lower total system cost and be more affordable for consumers, as seen in the large refrigerator scenario. For large refrigerators, a system with an inefficient model costs 20% less than one with an efficient unit, due to considerably higher product costs. It should also be noted that some of these efficient large refrigerators have multi-temperature compartments that can be used as a refrigerator or a freezer based on a consumer's preference and use case, and these units are built with thicker insulation. In the Global LEAP Awards test method, this type of product was tested and evaluated as a refrigerator. The design features such as multi-use compartment and the wide range of storage temperatures of these refrigerators may explain the high price.

Solar Water Pumps

Energy efficient and affordable solar water pumps have the potential to enable economic growth and improve food security for more than 500 million smallholder farmers worldwide. Approximately 95% of farmed land in Sub-Saharan Africa and 60% in South Asia relies solely on unpredictable seasonal rainfall to meet water needs.[xl]

Situated at the heart of the water-food-energy nexus, solar water pumps (SWPs) can play an important role in delivering a sustainable water supply in an increasingly climate-sensitive world, all while reducing or preventing harmful greenhouse gas emissions and improving the incomes and resilience of rural households worldwide.

According to the 2020 Off-Grid Appliance Market Survey, industry stakeholders ranked SWPs as the number one productive use appliance in both perceived consumer demand and development impact potential, marking an important intersection between demand and improved livelihoods.[xli] But despite high perceived demand, sales remain relatively low, with high upfront costs being the main barrier to wider adoption.

In the second half of 2019, GOGLA affiliates reported sales of 25,000 SWPs. That number dropped by 87% in the first half of 2020, though this may be due to lower participation of SWP companies in the sales data collection, or to the fact that bulk procurement programs in South Asia had slow uptake in the first half of 2020. Compared to the volumes recorded in the first half of 2019, sales of SWPs have increased by 10% globally.[xlii]

The SWP market is expected to grow significantly over the next ten years. As solar water pump technology improves and more distributors and financers enter the market, prices will drop, and SWPs will become more accessible to a wider variety of consumers. In Sub-Saharan Africa, the addressable SWP market is projected to triple to US$1.6 billion and expand to 2.8 million households within the next decade. In India, the most developed SWP market in South Asia, an estimated 150,000 pumps have already been sold through government subsidy programs; it is estimated that a further 4.2 million farming households have demand for a SWP and are able to afford one.[xliii]

DEFINITIONS

HEAD

Vertical distance that water can be lifted.

WIRE-TO-WATER EFFICIENCY

Hydraulic power generated by an electric pump divided by the measured input power.

HYDRAULIC ENERGY (WH/DAY)

Metric representing “service delivery” across a solar day. Defined as energy output by the pump, and measured by the volume and distance of water moved per solar day. There are three “hydraulic energy per day” values listed for each pump, one for each simulated solar day of three specific ‘solar day profiles’ that are used with different levels of cloud cover.

PRODUCT TECHNOLOGY OVERVIEW

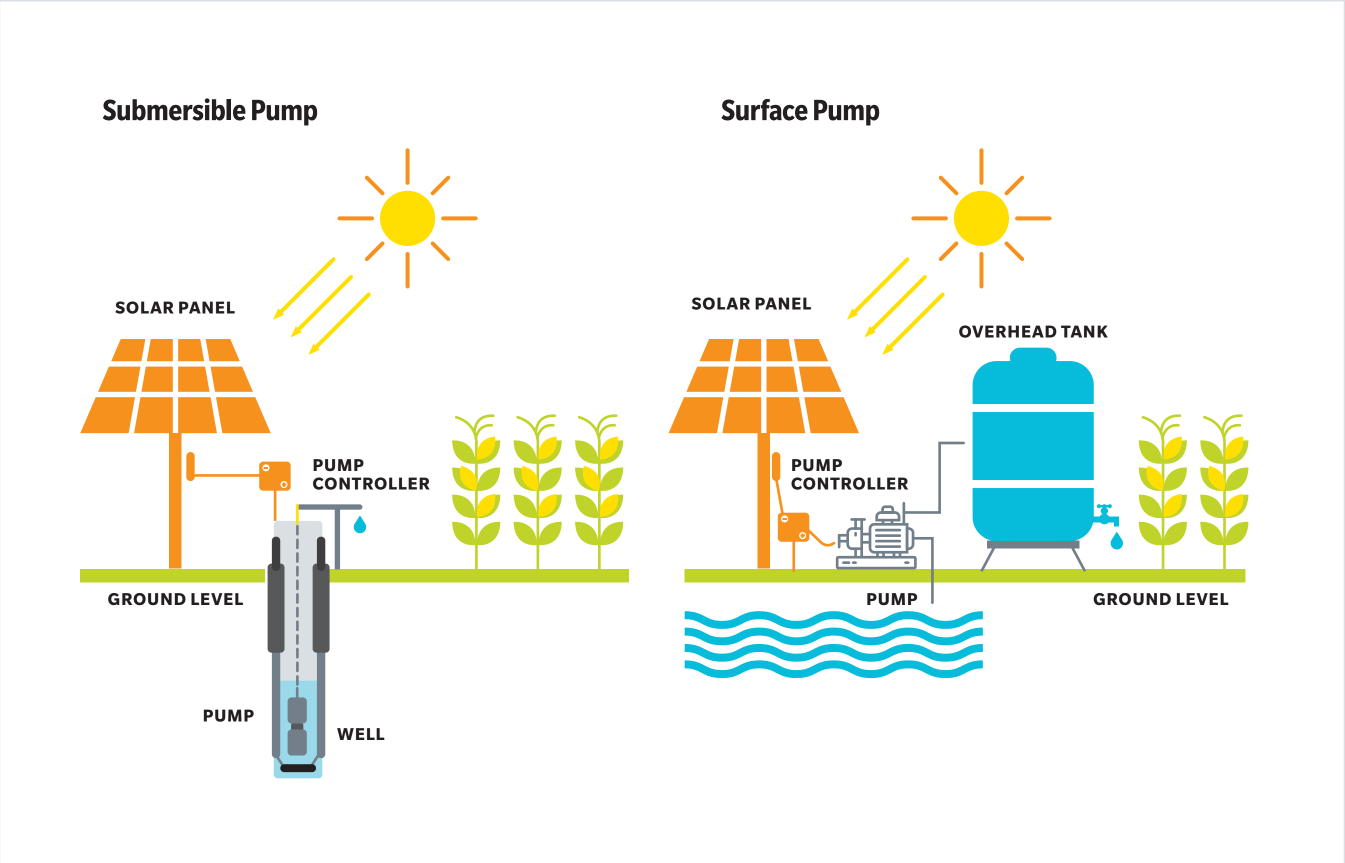
The data presented in this analysis was gathered from manufacturers and from tests conducted by a third-party laboratory as part of the 2019 Global LEAP Awards Solar Water Pump Competition. The competition focused on small SWPs designed for use by smallholder farmers irrigating one to five acres. For this report, pumps are organized by three main product types: surface, submersible and battery integrated (Figure 19).

Surface pumps are designed to operate above the waterline or adjacent to the water source, i.e. not submerged in water below surface or in a borehole. Surface pumps are preferred for pushing water long distances horizontally.

Submersible pumps are designed to operate underwater, usually in a borehole. Most submersible pumps have high lift capability, but they are sensitive to dirt and sand in the water.

Battery-integrated pumps are designed with a battery integrated into the control unit. Battery-integrated pumps may have a more controlled, constant power input since current is drawn from the battery instead of being reliant on solar resource at the specific time of use.

Figure 19. Basic Components of Submersible and Surface Pumps

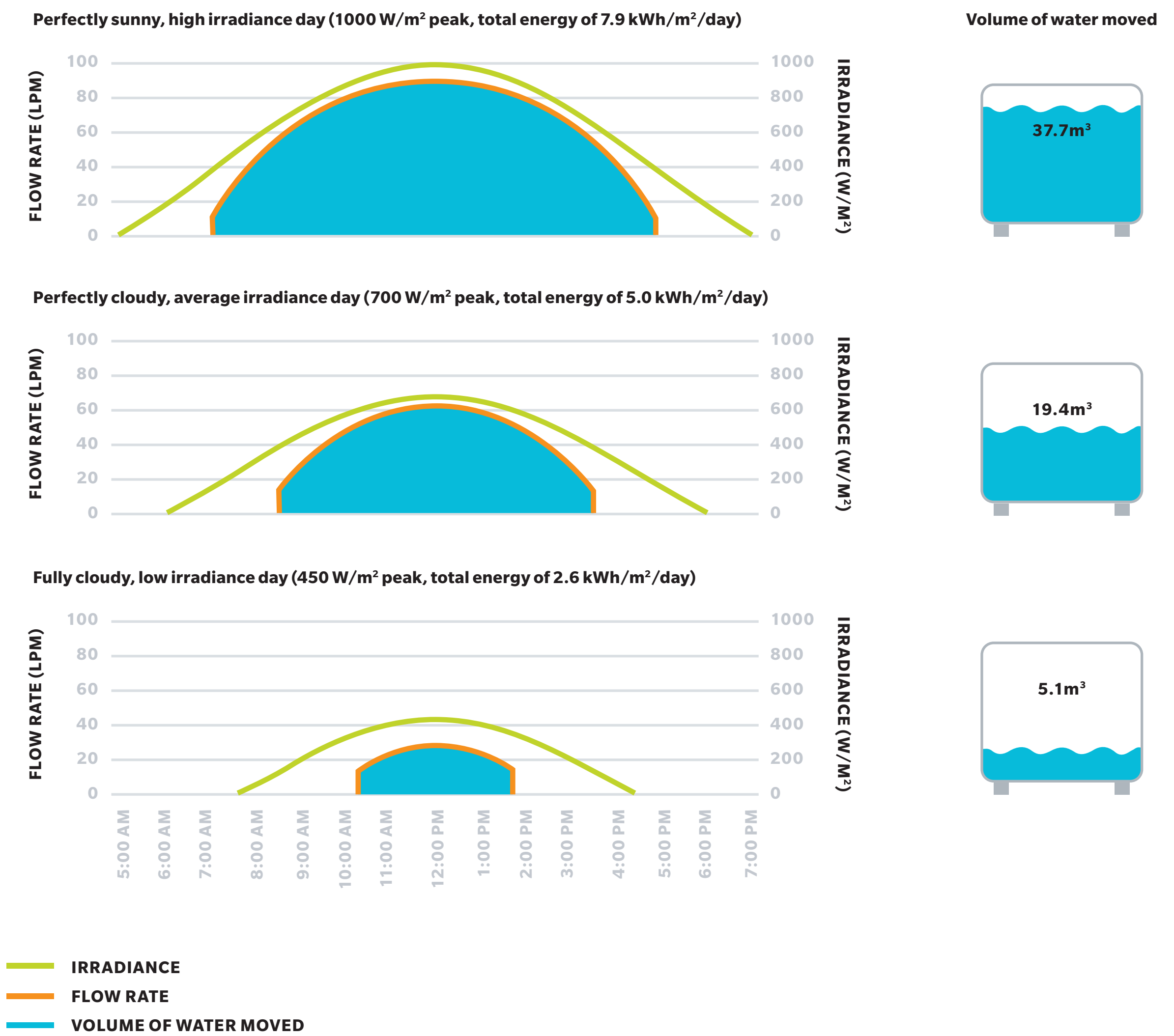


To mimic a range of environmental conditions and give stakeholders a better sense of product performance across geographic locations, service delivery and performance testing were performed by simulating three solar day scenarios:

1. A perfectly sunny, high irradiance day (with peak irradiance of 1000W/m² peak, and total energy of 7.9 kWh/m²/day)
2. A partly cloudy, average irradiance day (700W/m² peak, and total energy of 5.0 kWh/m²/day)
3. A fully cloudy, low irradiance day (500W/m² peak, and total energy of 2.6 kWh/m²/day)

The charts in Figure 20 provide an example of the different flow rates and total volumes of water an indicative pump could move during each of the three simulated solar days. Each solar day is defined by a different irradiance curve, where irradiance is the intensity of the sun hitting a surface ground measured in power per unit area (W/m²). The total volume of water moved across a solar day varies depending on the amount of solar energy available to power the system. The figure also indicates the daily hours of operation, represented by the start and end points of the flow rate line on the x-axis.

Figure 20. Indicative Pump Performance on Different Solar Days



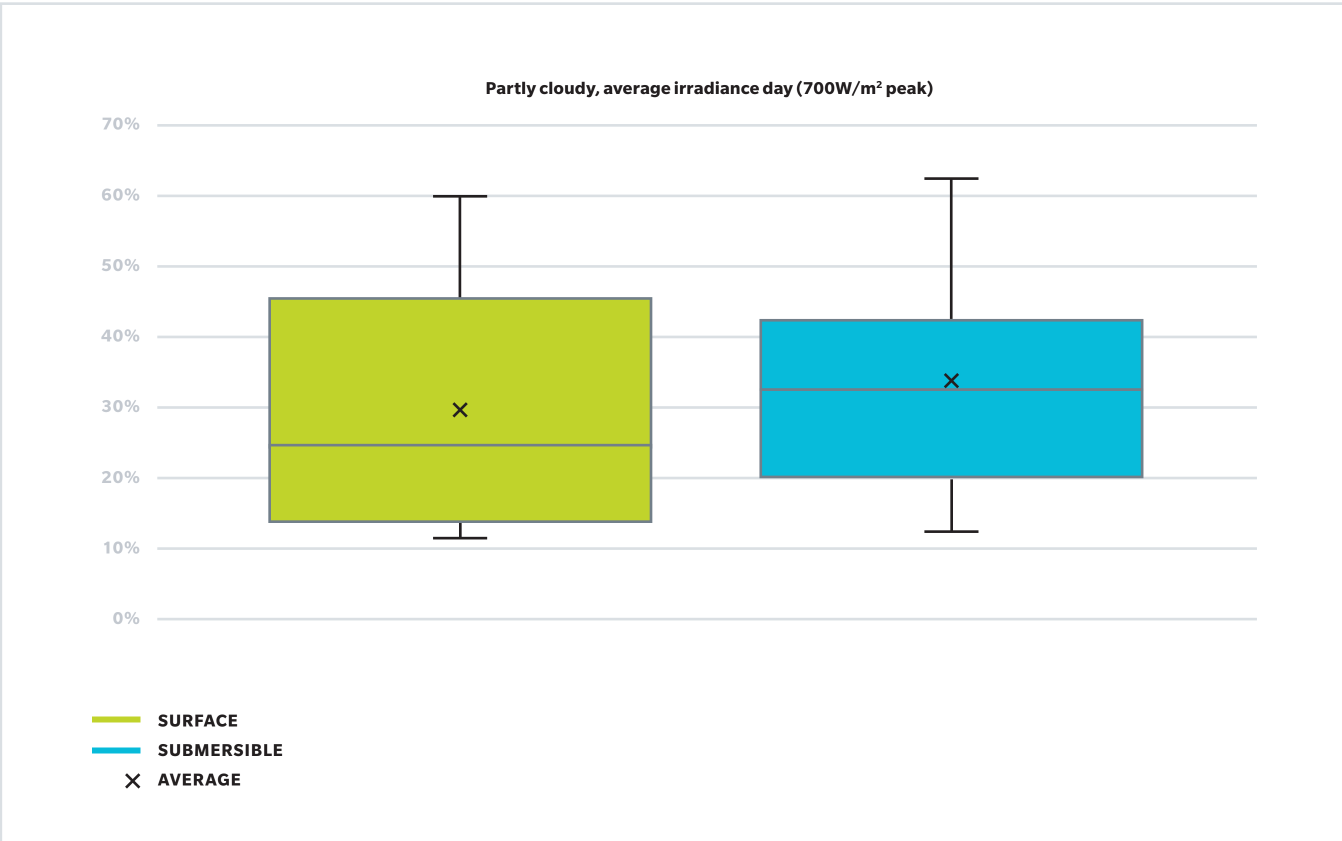
EFFICIENCY TRENDS

Unlike other common household appliances, the efficiency of SWPs varies throughout the day. As the energy provided by the sun changes based on its position and cloud cover, the power made available to the pump and the water output vary. Since pump performance varies across its operational power range, the pump efficiency, defined by average daily wire-to-water efficiency (%), changes as well. However, several other factors also contribute to efficiency, including the specified head and PV array used for a given pump. Wire-to-water efficiency is highly sensitive to the size of the PV array, and an array not optimally sized for a particular pump or for certain solar conditions can reduce efficiency and overall performance.

Submersible pumps were more efficient on average than surface pumps. When wire-to-water efficiency for pumps is split by product type (Figure 21)[17], the data shows that the average efficiency of surface pumps is 29% on a typical solar day, compared to 33% for submersible pumps. Submersible pumps tend to be more efficient because the pumps are already submerged in water and the pressure naturally pushes water into the pump, thus requiring less energy to move water. There was a wide range of average daily wire-to-water efficiency of all pump types tested, with a minimum of 11% and maximum of 60%.

Efficient motors are key to reducing pumps' energy consumption. All but one of the SWPs tested for the Global LEAP Awards used a highly efficient BLDC motor, an indication that market leaders have already adopted these technologies to increase overall pump efficiency. Given that almost all pumps in this data set use BLDC motors, there is insufficient data to compare the efficiency of pumps with BLDC motors versus those with brushed-DC motors. As the Efficiency for Access team tests more market samples, further analysis can be done to identify efficiency improvements based on motor type.

Figure 21. Average Daily Wire-to-Water Efficiency by Pump Type



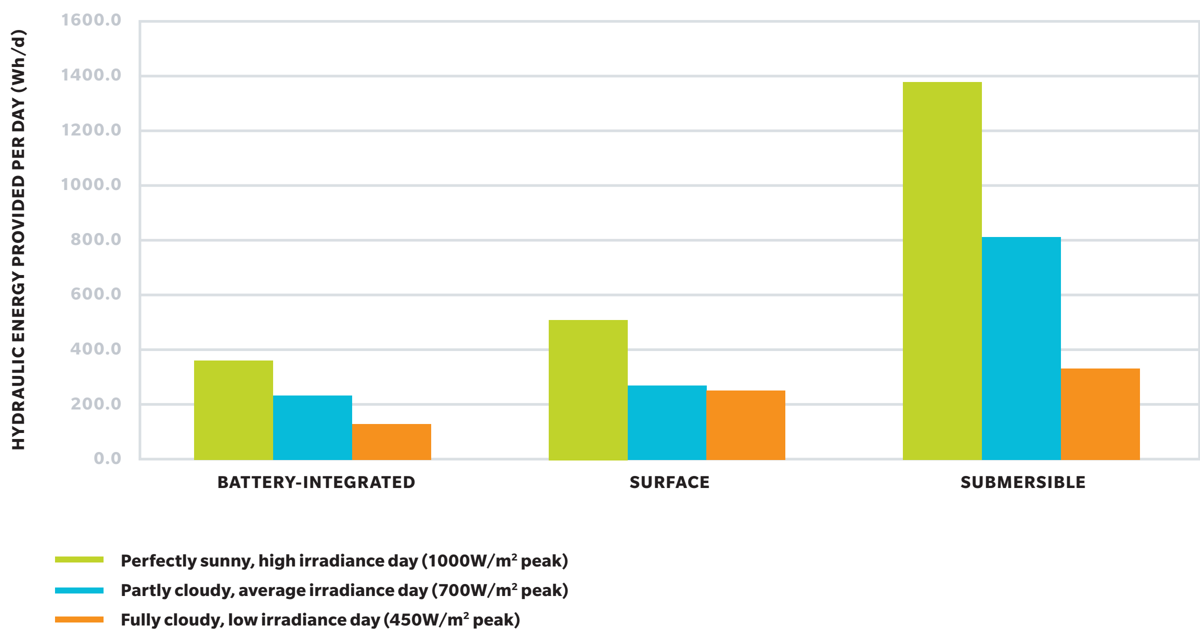
17. Battery-integrated pumps were not included in this analysis because the wire-to-water efficiency is calculated using hydraulic energy per day divided by the PV power input for each head, and PV power input is irrelevant for pumps with a battery.

PERFORMANCE TRENDS

The service provided by a SWP is highly dependent on solar conditions. The primary service delivered by a SWP is the movement of water over a given distance measured either by the total volume of water moved per day (m^3/day) or the hydraulic energy of water moved per day (Wh/d). The former measurement is useful for end users, such as farmers who need to irrigate land with a given volume of water. But the latter represents a standardized unit of production per day that combines the volume and the vertical distance the water moved, making it possible to compare SWPs operating at different head depths. As seen in Figure 22, across all pump types, the hydraulic energy output of the pump operating on a fully cloudy day is 70% lower than it is on a sunny day. As expected, the power consumption of the pump also drops on lower irradiance days, since less energy is generated by the PV system. While energy generated is directly proportional to irradiance, hydraulic energy is not because a SWP will stop running entirely beyond a certain power threshold. This indicates that SWP purchase decisions must take into careful consideration the annual solar conditions and use case of the pump, as well as the performance metrics being reported, which sometimes indicate only the maximum (peak irradiance) or momentary (not aggregate daily) values.

Durability is key to pump performance but it is difficult to measure through lab testing. Given that SWPs are expensive investments for off-grid consumers and require substantial resources to service after installation, durability is essential. The Global LEAP Awards testing process surfaced some of the most significant challenges related to SWP durability. Rust and corrosion were the most common issues identified during assessment, while other common failure points include a lack of dry run protection, improper water ingress protection and battery issues.[18] While laboratory testing for the Global LEAP Awards is useful in identifying issues that may affect pump durability, performance, and safety, it is limited by a small sample size and short testing duration to comprehensively evaluate SWP lifetime and durability. Future updates to the laboratory test method could consider an enhanced version of the visual screening, intake, and functional durability tests that help detect early failure signs, and could use field testing to understand pump durability over time in "dirty water" (i.e. water with high levels of sand, clay, or salinity).[xliv]

Figure 22. Average Hydraulic Energy per Day (Wh/day) by Pump Type



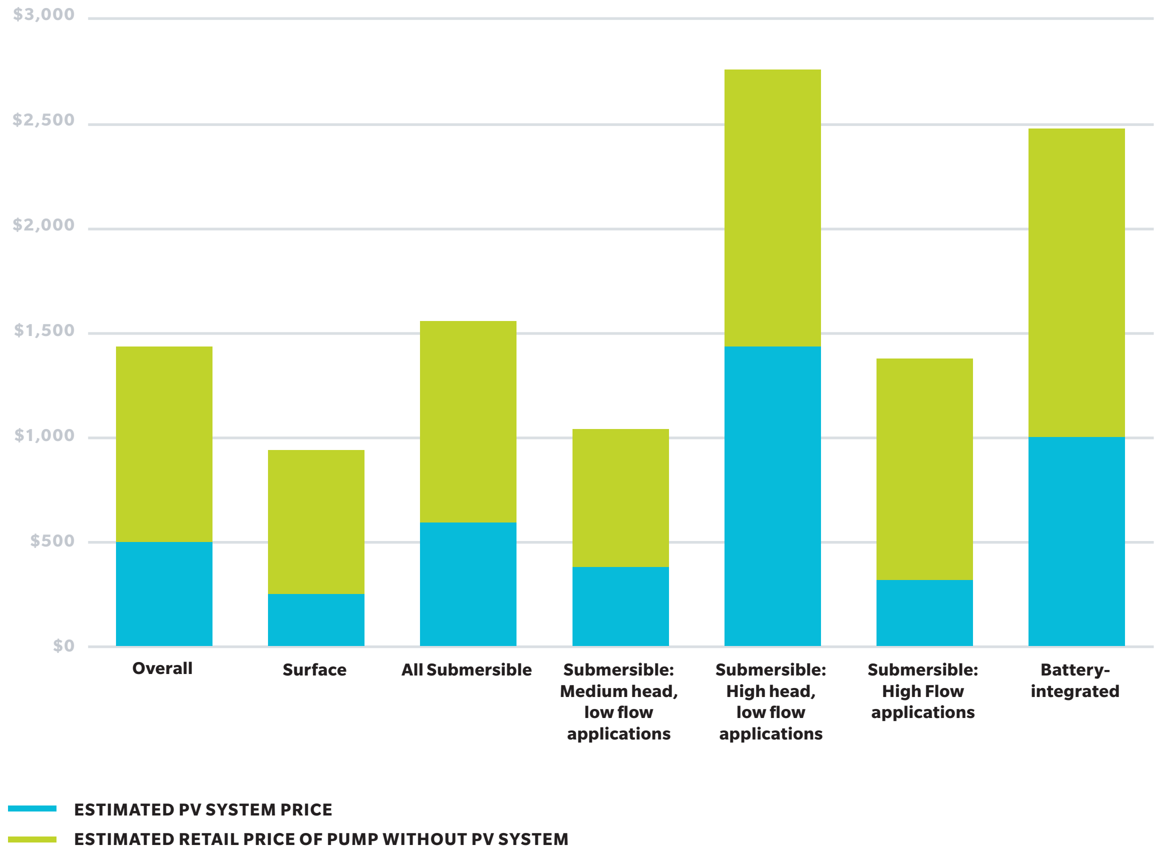
18. Only two of the SWPs tested for the Global LEAP Awards included batteries.

PRICING TRENDS

The price of SWPs varies widely depending on type and use case. SWPs are often customized according to the buyer's needs and the environment in which the pump is going to be used. Accordingly, there are multiple pump types (broadly categorized into surface and submersible) and a full spectrum of PV array sizes that drive wide variations in price. Across all pumps, the PV array accounts for roughly a third of the overall price of the SWP system. In the 2019 Global LEAP Awards competition, the total cost of SWPs that include a PV array ranged from US$382 to US$4,108, with an average retail price[19] of around US$900 for surface pumps and US$1,600 for submersible pumps.

Submersible pumps are the most expensive pump type, likely due to larger capacity and design features that allow them to be submerged. But the price still varies widely depending on the size category. Figure 23 shows a breakdown of costs for the PV system and pump based on the pump type, with submersible pumps further segmented by head size and flow application. Overall, submersible pumps are more expensive than surface pumps; they average US$986 without the PV system, while surface pumps average US$601. Looking at the breakdown of submersible pumps more closely, submersible pumps designed and set up for medium and high head applications are between 37-222% more expensive, with an average retail price of $1,165 without a PV system, than those for low head applications, which average US$695.

Figure 23. Average SWP and System Price by Pump Type

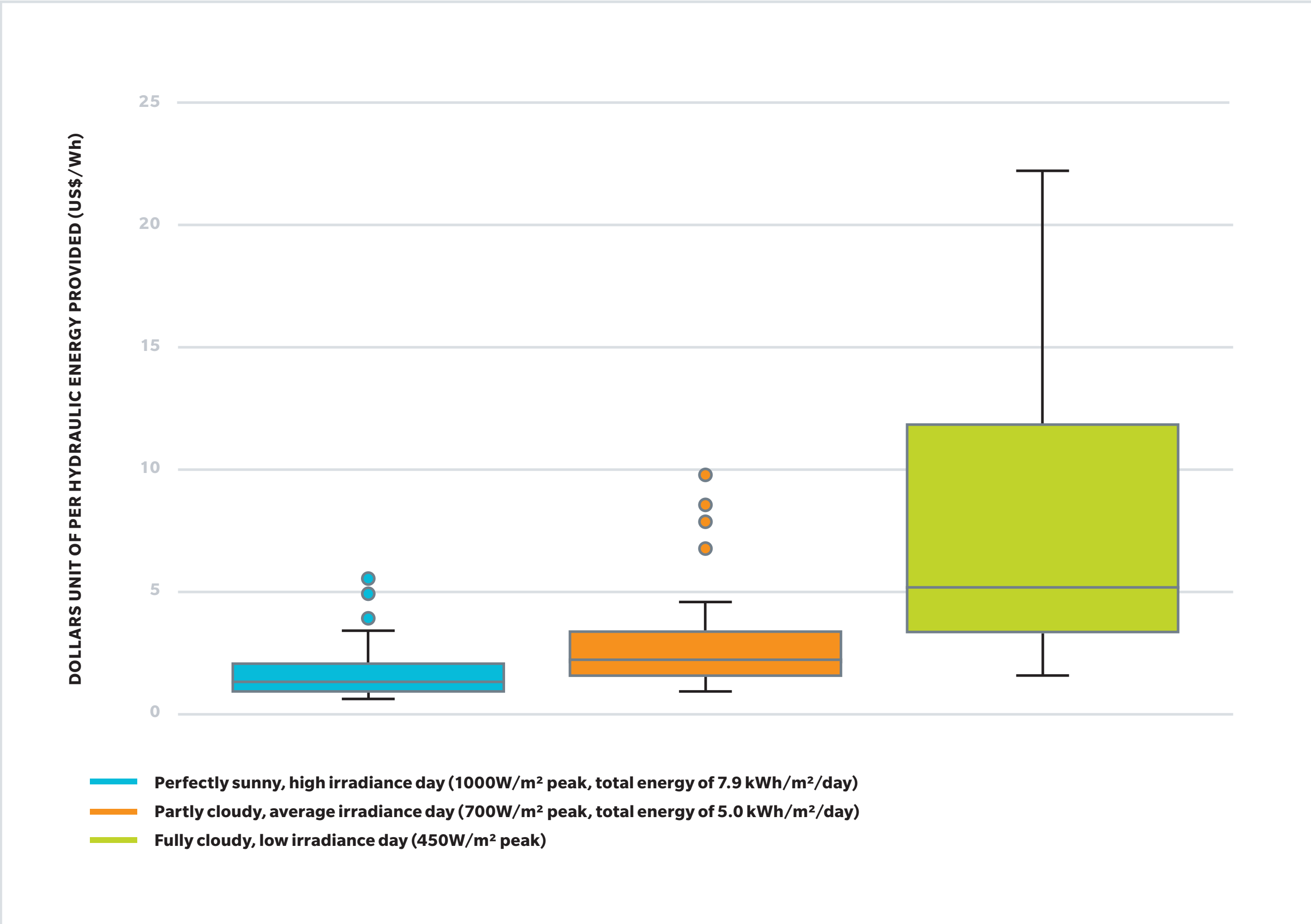


19. To calculate retail price, the Efficiency for Access team used the FOB price of the pump without a PV system as declared by the manufacturer, and a standardized price per watt for the PV array size that was used for testing each product.

The price of moving water increases substantially under poor solar conditions. Figure 24 shows the costs involved in producing one watt hour (Wh) of energy required to move a volume of water over a distance, during three different simulated solar days. The dollar values reflect the retail price of the pump combined with the estimated cost of a PV module.

The price of moving water is substantially higher on cloudy days, averaging US$7.92/Wh on a fully cloudy day compared to US$1.79/Wh on a perfectly sunny day. This is because PV costs are fixed, and lower irradiance means that SWPs cannot operate as long or as effectively, thus substantially increasing the price to pump water.

Figure 24. SWP Price to Produce One Watt-hour of Hydraulic Energy per Day



Early Technology Insights on Electric Pressure Cookers

Four billion people still lack access to clean, efficient, safe and affordable cooking energy.[xlv] Of these four billion, 1.25 billion are transitioning to use modern cooking services, while the rest face high barriers to adoption.[xlvi] Until now, increased access has been hindered by a lack of funding and the absence of solutions that are fully responsive to the needs of lower-income households and rural communities.[xlvii] Without further intervention the global community will fall short of achieving universal access to clean cooking by 2030.

The expansion of decentralized energy systems and advances in cooking technology and commercial innovation present an opportunity to transition rural communities from biomass cooking to modern energy cooking services. Electric pressure cookers (EPCs) are rising as one of the promising cooking technologies for consumers living in off-grid and weak-grid conditions. EPCs are electricity-powered appliances with airtight pots that seal in steam during cooking, increasing the pressure and therefore the maximum temperature of liquids within the pot. The higher temperatures and pressurized steam that infuses the food allow for much shorter cooking times.[xlviii] Durable, energy-efficient electric pressure cookers (EPCs) represent a safe and affordable cooking solution, combining low-energy consumption with high pressure to cook household staples.

In 2020, the Global LEAP Awards launched its inaugural EPC competition, with 40 products nominated to undergo energy performance, quality, and safety tests. Manufacturer-reported data provides a glimpse into the key qualities and characteristics of EPCs available in the commercial market. At the time of publication, the Global LEAP Awards was testing EPC samples to validate manufacturer claims; this test data will be made publicly available on the VeraSol product database in 2021.

AC-powered EPCs hold market dominance. Of the 40 models participating in the EPC Competition the vast majority (82.5%) were marketed as AC compatible, while only 10% were DC compatible and 7.5% were AC/DC compatible. This reflects a broader pattern of EPCs being designed and marketed mainly to consumers with reliable grid connections. Given their relatively high energy consumption, EPCs are more likely to be used on-grid or with mini-grids rather than with solar energy kits, which explains why AC-powered EPCs are more common throughout the sample. The lack of available DC-powered EPC options also highlights the adoption barriers faced by off-grid communities using SHS kits.

Medium EPCs between 4-7 litres are most common in the market. We divided our sample of 40 EPCs into three categories: small (≤3 L capacity), medium (4-7 L capacity) and large (≥8 L capacity). Medium EPCs accounted for roughly half of the sample (55%), followed by small EPCs (30%) and large EPCs (15%) (Figure 25). Of the 40 models sampled, the average capacity was 5.4 L. The smallest EPC had a capacity of 2 L and the largest had a capacity of 20 L, which would be expected to be used in commercial and institutional settings.

There is a positive correlation between EPC size and price, but variation exists within each category. In general, price increases with product size (Figure 26). The data shows a strong, positive linear correlation between the Free on Board (FOB)[20] price and EPC capacity, but there is also a wide range of prices within each size category. For example, the FOB price for a single small EPC ranges from US$21 to US$280, with an average of US$53.15 and a median of US$30. The average FOB price for a medium EPC was US$39.05 and US$102.50 for large EPCs.

Figure 25. Categorization of Samples by Size (L)

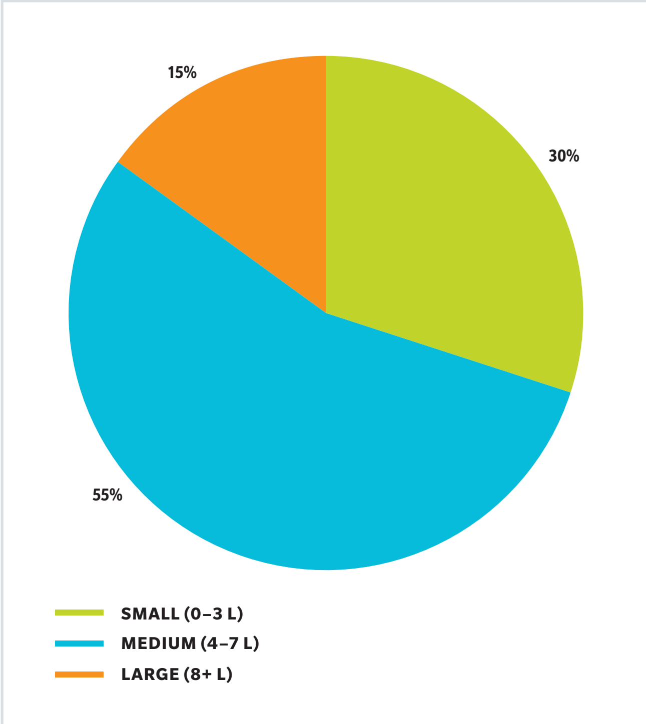
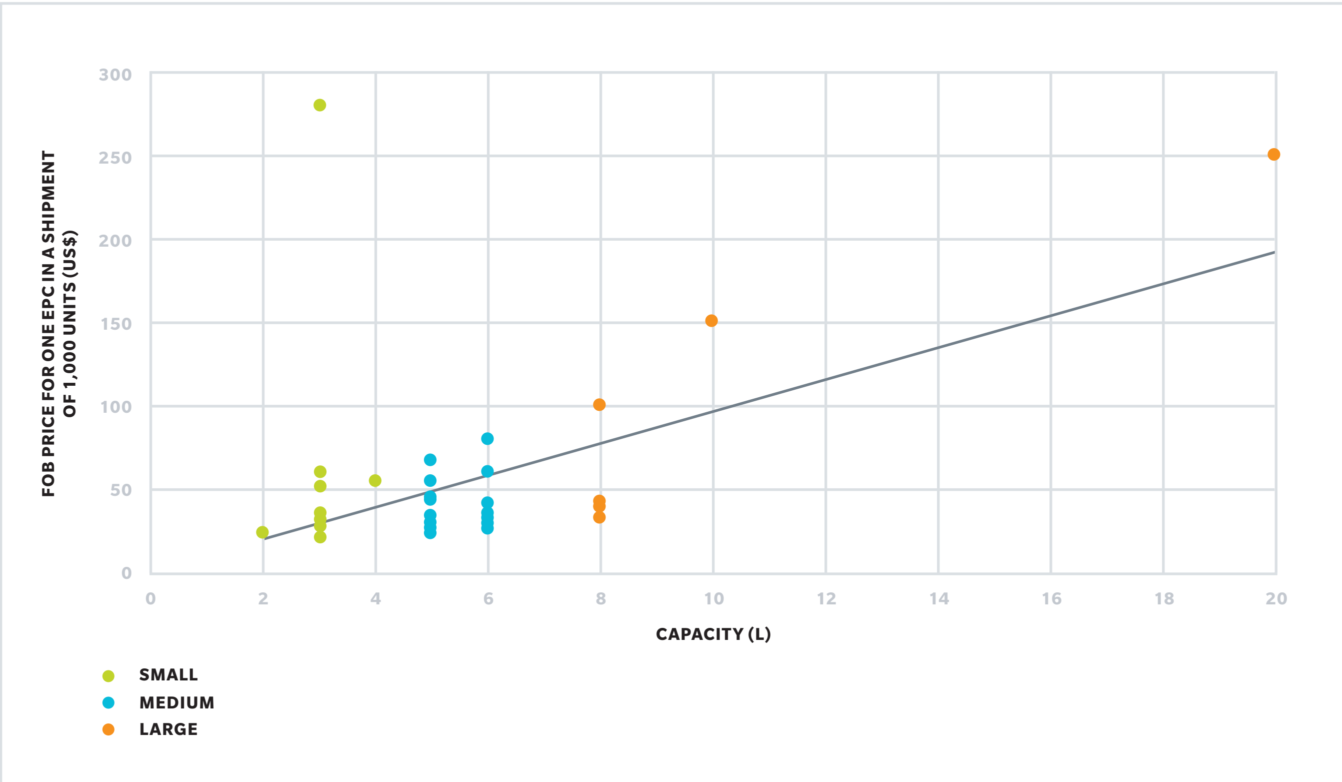


Figure 26. Correlation between EPC Capacity and FOB Price

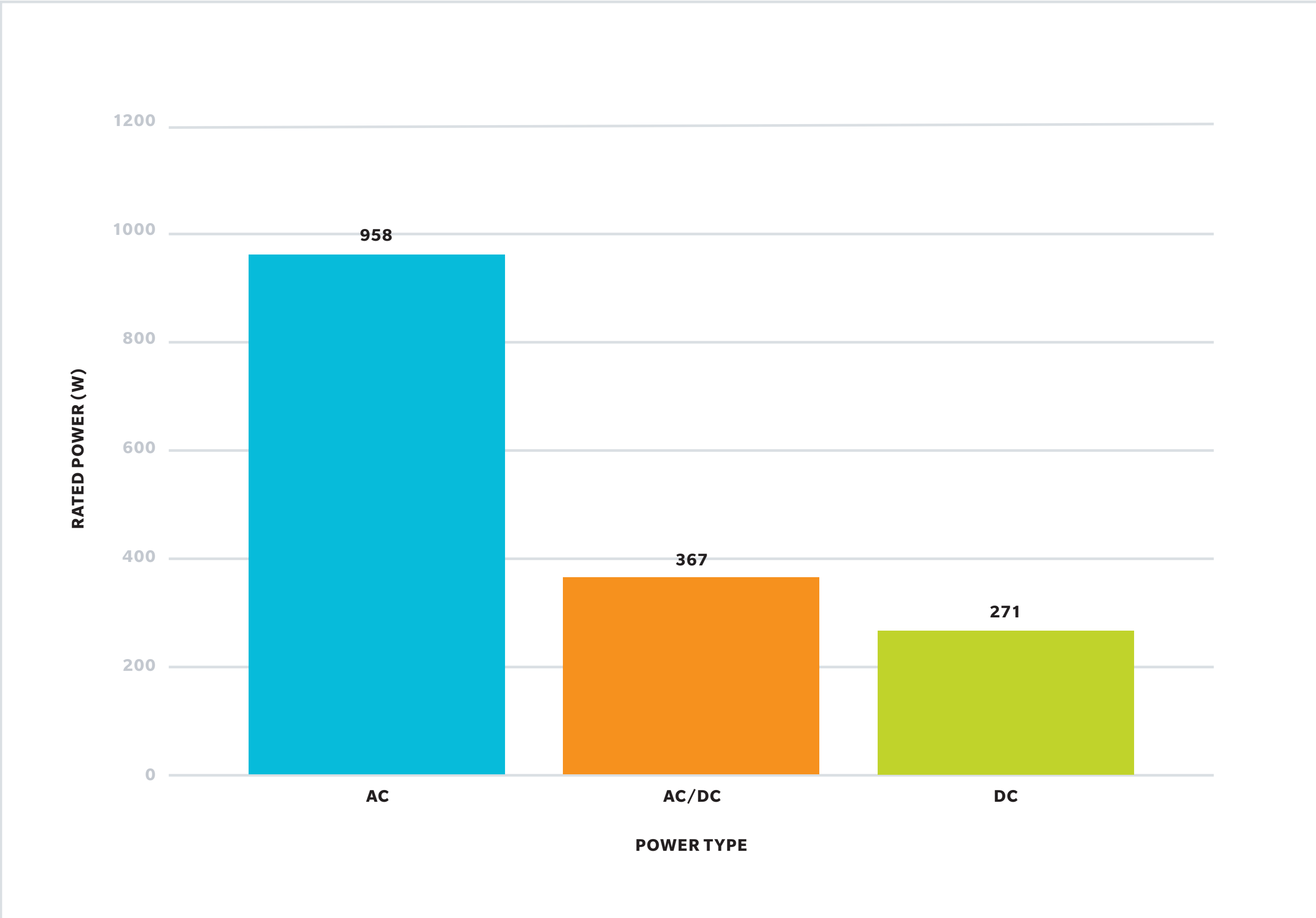


20. FOB costs include transportation of the goods to the port of shipment, loading the goods onto the shipping vessel, marine freight transport, insurance, and unloading and transporting the goods from the arrival port to the final destination. EPC manufacturers include the FOB price for one unit from an order of 1,000.

An EPC requires more energy than most off- and weak-grid appropriate appliances. Power ratings can help users estimate the size of the system or the cost of the energy needed to power an appliance or set of appliances. The average power rating for an EPC was 845 W, with a minimum of 84 W and a maximum of 1,400 W. In comparison, the input power rating of a typical large refrigerator ranges from 50 W to 130 W. Due to their high wattage, EPCs may require a higher-capacity solar energy system than is typical in most off-grid markets today.

AC compatible EPCs have higher power rating than DC or AC/DC-compatible EPCs (Figure 27). The average rated power of AC EPCs was 958 W (198 W/L). The average rated power for DC and AC/DC compatible EPCs was 271 W (61 W/L) and 365 W (104 W/L), respectively. This trend is reflective of the market for most EPCs, which are designed for and marketed to consumers with stable, reliable grid connections.

Figure 27. Average Rated Power of Sample by Power Type



Interoperability

Interoperability is a key consideration in any appliance market. This term refers to the ease with which systems and components work together and exchange information, important features of mature markets for a variety of technologies around the world. Energy systems, appliances and devices need to be interoperable to operate effectively and offer consumers choice and flexibility. A lack on interoperability can hinder market scale -up as off-grid appliances hope to reach level of commoditization found in other appliance markets.

The absence of standardisation in in the distributed energy sector has resulted in different operational voltages, variations in plug type and multiple communication protocols that hinder the interoperability of systems, appliances and devices in the market. In this gap, proprietory and incompatible systems have been developed by manufacturer. Though these bespoke systems guard customers against combining non-compatible systems and appliances, they also offer little flexibility, locking customers into specific manufactures. This could lead to markets that are not competitive on price, performance or quality rather on onyl competing on intial customer aquisition.

Such closed systems are common in SHSs, with manufacturers using brand-specific plugs combined with a proprietary digital protocol to communicate with other devices. Some companies believe that the closed system design improves consumer service and experience, as well as reducing default risk for PAYGO companies. But consumer choice is limited by the fact that a device used in a closed system is not readily interchangeable with systems from other brands. A new concept called 'Open Solar' allows SHS devices to be interchangeable with others, regardless of brand. Adopting this idea would require industry-wide standardization on connectivity, which would allow the user greater flexibility, reduce e-waste and open new commercial opportunities, including a secondary appliance market.

In the case of appliances, data shows that the vast majority of the 76 AC devices tested (including fans, TVs and SWPs) operate on a voltage of between 100 V and 260 V, which is expected for AC devices that need to comply with common grid voltages. Out of 270 DC devices tested, most could operate on 12 V, but the range of voltages was wider. This reflects the lack of DC voltage standardisation.

Efforts are underway to help tackle the interoperability issue. The Efficiency for Access Interoperability Roadmap presents a pathway to ensuring that incompatibility barriers around power use, plugs and cables do not discourage the uptake of DC devices. GOGLA – the global association for the off-grid energy industry – is working with partners and members to define standards that would enhance interoperability for 12V SHS kits and appliances (read more here).

Key Takeaways

The solar appliance market has matured significantly since the last edition of this report, with promising efficiency innovations and price reductions in nearly every appliance type. This trend will help millions of people move up the energy ladder. However, more work needs to be done to bring the markets for new, productive use technologies such as refrigerators and SWPs to scale. The section summarizes the key takeaways from the data analysis presented in previous sections.

Near-to-market technologies, such as TVs and fans, have made great strides in improving efficiency.

The average efficiency of market sample TVs are 149% more efficient than samples tested in 2018 and 52% more efficient than samples tested in 2017, far exceeding the efficiency of best-in-class models from 2017. In some cases, the best available TVs and fans sold in off-grid markets are even more efficient than conventional products sold in European markets. With TVs and fans continuing to mature and reach scale, prices are decreasing. The price of an average fan fell by 47% from 2016, while the price index for TVs (price relative to size) dropped by 44%. As prices decrease, demand for larger products is increasing, with large-screen TVs gaining major traction in the off-grid market.

Further improvements in efficiency and cost are needed for refrigerators to achieve scale.

While refrigerator efficiency is improving, there are gaps between market samples and products selected for the Global LEAP Awards. Competitions such as these, along with results-based financing and government support, can help companies deliver more efficient, affordable products. The high price of refrigeration remains a key challenge for both product manufacturers and consumers. Due to the relatively low sales volumes of refrigerators, it is a challenge to reach the economies of scale needed to drive down costs. In addition, improving product efficiency alone may not be sufficient to drive the refrigerator's price down. Other costs along the value chain before the product reaches end-users, such as import taxes and duties, may exceed 30% of the total system cost.[xlix] In this case, savings associated with energy efficiency may be outweighed by the initial purchase price of the refrigerator. Currently, the price of a 100 L refrigerator ranges from US$300 to US$600; to be considered affordable for the off-grid market, the price needs decrease to between US$200 to US$300.[l]

Price and maintenance costs remain key barriers to the wider adoption of solar water pumps.

Like refrigerators, solar water pumps (SWPs) without consumer financing are too expensive for most smallhold farmers in off-grid and weak-grid communities. The average price of a Global LEAP Awards pump with a solar system was US$1,865, which is extremely high for the average off-grid consumer given that the disposable annual income of the lowest income half of off-grid consumers is US$168.[li] Durability also presents a unique challenge as pumps require ongoing maintenance and these costs might not be evident to the customer upon the initial purchase. One company interviewed reported that maintenance and other ongoing costs may total as much as 10% of the initial purchase price each year. Performance and pricing data for SWPs were shared for the first time in this report. More data, particularly from market samples, is needed to track trends and compare performance and quality.

Newer products appropriate for use in off-grid context are emerging, such as electric pressure cookers.

This report analyses manufacturer-reported technical specifications of the EPCs submitted to the Global LEAP Awards. Although the data provided for EPCs has not yet been independently verified through laboratory testing, it still allows for valuable early insights into size, power input and power consumption. The vast majority (82.5%) of products submitted to the Awards were AC powered, signalling that most EPCs are primarily intended to be used with the central electric grid or with mini-grids. The average rated power consumption of EPCs was 845 W, which is more than other common household appliances, including refrigerators. Low availability of DC EPCs and the products' high power consumption suggest that most EPCs on the market are probably out of reach for SHS consumers. In early 2021, Efficiency for Access will publish lab-tested data on the VeraSol Product Database to allow for more accurate performance and quality evaluation of the EPCs mentioned in this report.

Product quality and durability are important considerations.

As TV and fan markets continue to mature and competition drives down prices, quality considerations will be elevated in purchasing and investment decisions. To help market actors differentiate product quality for standalone off-grid TVs and fans, Efficiency for Access piloted a quality assurance framework to test and evaluate products based on quality criteria. The results revealed that the most common failure points for products were related to inaccurate performance reporting[21], the lack of a warranty and user manual, and safety. For example, more than half of the fans tested failed the ingress protection test, meaning that a child's finger could pass through the fan guard, potentially causing serious injury. Other product quality considerations, such as durability, reparability, and recyclability, also need to be considered and factored into future quality criteria. It is becoming increasingly important to achieve consensus on key quality criteria among product manufacturers, development programs and policymakers, and to use these criteria to guide the market towards higher quality. Meanwhile, larger, more expensive productive use equipment such as SWPs face major challenges related to durability. Field testing will play an essential role in evaluating pumps and identifying failures in real-world conditions. Efficiency for Access is currently field testing several pumps and refrigerators in sub-Saharan Africa and will publish the results in 2021.

21. Performance reporting requires that certain performance metrics and units be presented on packaging and other consumer-facing materials and are accurate

Credit: Futurepump

Permanent magnet (PM) motors may radically transform the energy efficiency of certain appliances.

PM motors, including brushless DC motors, are well suited for the off-grid appliance market considering their high efficiency, ability to utilize smart features, versatility, and reliability in voltage fluctuations. Despite their higher price, BLDC motors are already a popular choice for high-quality solar fans. As highlighted in the Pakistan case study, the adoption of BLDC motors allowed local fan manufacturers to substantially improve their fans' efficiency. Harness Energy, a Pakistani fan manufacturer and a grantee of the Efficiency for Access Research and Development Fund, is developing a super-efficient rechargeable 12 V BLDC pedestal fan that consumes no more than 15 W, with an extremely high air flow of 1,760 m^3/min. Efficiency for Access's upcoming report, Market Opportunity for High Efficiency Permanent Magnet Motors in Off-and Weak-Grid Appliances, further analyzes these motors, helps characterize the market and identifies potential opportunities to integrate PM motors across various product technologies including fans, refrigerators, SWPs and cold chain.[lii]

Tackling interoperability challenges could be a game changer for the solar appliance market.

Due to a lack of standardization, appliances and devices in the off-grid market are often incompatible with one another and/or it is not possible to determine whether they are compatible or not, making it challenging for users to mix and match appliances and systems. This limits choice of buyers of off-grid and weak-grid appropriate appliances, even as products becomes more available. However, a new concept called 'Open Solar' allows SHS and other devices to be interoperable. This would require the industry-wide standardization of connectivity, allowing the user greater flexibility, reducing costs for companies, and opening up other commercial opportunities. The Efficiency for Access Coalition and GOGLA have been organizing sectoral stakeholders and working to identify technological pathways towards standardization. If achieved, interoperability has the potential to deliver further cost reduction, give customers a wider choice of appliances and reduce e-waste.

Annex: Methodology

This annex outlines the sources of data and methodologies used to analyse key efficiency and price trends.

TESTING AND PRODUCT DATA

Independent laboratory testing and evaluation assess the extent to which products meet their advertised performance claims and incorporate design elements that make the products appropriate for off-grid use. Standardized test methods that evaluate product design, quality and energy performance enable consistent product-to-product comparisons. However, few test methods are designed specifically to evaluate off-grid appropriate appliances.

To facilitate improved comparisons of off- and weak-grid appropriate appliances, CLASP[22] developed and maintains a set of test methods[23] to evaluate energy performance, quality and durability of appliances designed for off- and weak-grid settings:

Off-Grid TV Test Method

Off-Grid Fan Test Method

Off-Grid Refrigerator Test Method

Off-Grid Solar Water Pump Test Method

Off-Grid Electric Pressure Cooker Test Method

The appliance performance data used in this report was generated through a robust laboratory testing process based on the relevant off-grid appliance test methods listed above.

22. CLASP

23. These test methods were originally developed for use in the Global LEAP Awards, but CLASP manages and updates the test methods on an ongoing basis for use in broader product testing efforts.

TOTAL COST OF SYSTEM ANALYSIS

This report includes a total cost of system analysis to estimate the total purchase costs of appliances and solar energy system components. This represents the overall cost to the consumer better than looking at product cost alone.

The total cost of system is made up of the following:

Appliance price

Using retail price collected from key off-grid energy markets or estimated retail price based on FOB provided by manufacturers.[24]

PV solar system and battery costs

The PV system and battery size requirements were estimated through a time-based simulation that uses hourly energy generation and consumption data over the period of an entire year. The theoretical operational hours for each appliance were determined using a set of assumptions detailed in the section on each appliance. The power consumption for each hour was determined using the data obtained in laboratory testing. Three solar generation profiles were modelled to highlight the range of potential system costs and any variation between different locations. These correspond to cumulative energy per area per day of 4.5, 5.5 and 6.5 kWh/m², all typical to the areas of interest in this report. For each hour within a year, the model calculated the energy required to power the appliance and the amount of energy that had been generated. Where demand exceeded generation (e.g., at night), energy was taken from the battery to power the appliance; conversely, when generation exceeded demand, the battery was charged for later use. The PV size and battery capacity were varied, and the model ran iteratively to ensure a certain number of desired operational hours for the appliance (detailed within each appliance section). Standard cost assumptions for solar energy system components were used to estimate the initial capital cost of a solar energy system. The assumption was made that the PV and battery sizes were only sufficient for a single appliance. Future modelling could be refined to include a system upgrade scenario, which simulates an existing owner of a basic home system and lighting kit upgrading to larger system that includes other appliances. This approach will allow a more realistic calculation of a marginal cost for extra panels, battery, and charge controller capacity due to the upgrade, rather than a single appliance system.

24. For Awards products, the wholesale price declared by the manufacturer is multiplied by a factor of 1.8 to adjust for estimated taxes, duties, supply chain mark-ups, etc.

LIMITATIONS

Efficiency for Access has made every effort to provide a comprehensive overview of the efficiency and price trends for TVs, fans, refrigerators and SWPs. However, several limitations should be noted:

Field testing data is needed to complement lab testing data.

In the 2018 Data Trends Report, the Efficiency for Access team identified that field testing is a necessary complement to laboratory testing to continue improving appliance quality and energy efficiency. While laboratory testing provides comparable and consistent results, it cannot predict how a product will perform in real-world conditions. To address this gap, the Efficiency for Access Coalition team has undertaken several field testing projects for refrigerators and SWPs to measure the performance of products while they are being used by consumers. The data collected from these projects is forthcoming and is not included in this report. This field testing data will be used in the next iteration of the Data Trends Report to provide a more comprehensive overview of product performance.

Sample size may be relatively small for some years or product types.

For some of the analysis, it's important to note that the sample size is relatively small and so this should be taken into account when comparing products and trends (e.g., there are a small number of AC/DC fans). For these cases, the authors included information on more data being needed to draw concrete conclusions. Due to COVID-19 lockdown restrictions, there was also limited data available on market samples for TVs, fans, refrigerators and SWPs in 2020, and so they were not included in this report.

Market sample data is unavailable for SWPs.

Efficiency for Access has not started testing market samples for SWPs, so only Awards data was available to perform the data analysis.[25] The 2019 Global LEAP Awards for Solar Water Pumps competition tested pumps designed for 1- to 5-acre smallholder farmers. It is important to note that the size and capacity requirements for Awards SWPs may be different than other products available in the market. Therefore, the SWP analysis should be viewed as an analysis of one market segment, but not a complete overview of the SWP market.

25. Efficiency for Access will begin testing market sample SWPs in mid-2020, so the forthcoming market sample data will be included in the next iteration of the Data Trends Report.

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