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APPLIANCE DATA TRENDS

Insights on Energy Efficiency, Quality, and Pricing for Off-Grid Appropriate TVs, Fans, and Refrigerators

SEPTEMBER 2018

EFFICIENCY FOR ACCESS COALITION

Efficiency for Access was organized in 2015 as a year-long call-to-action and collaborative effort led by the Global Lighting and Energy Access Partnership (Global LEAP) and Sustainable Energy for All with the aim to harness the power of energy efficiency to accelerate universal energy access.

Now, UK aid, Power Africa, the International Finance Corporation, the World Bank, Rockefeller Foundation, Shell Foundation, Sida, EnDev, Good Energies Foundation, and more have joined together under a scaled-up Efficiency for Access—a coalition promoting energy efficiency as a potent catalyst in global clean energy access efforts.

The Coalition recognizes the latent demand for increased modern energy services and is seizing this opportunity to scale up markets and reduce prices for new super-efficient products, supporting technology innovation and improving sector coordination. In this way, the Coalition supports the United Nations' Sustainable Development Goal 7, to ensure access to affordable, reliable, sustainable, and modern energy for all.

The Efficiency for Access Coalition is jointly coordinated by CLASP, an international appliance energy efficiency and market development specialist not-for-profit organization, and the UK's Energy Saving Trust, which specializes in energy efficiency product verification, data and insight, advice, and research.

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ABBREVIATIONS

AC	Alternating current
Ah	Ampere-hour
°C	Celsius
DC	Direct current
DfID	Department for International Development
DI	Digital inverter
EEI	Energy Efficiency Index
EnDev	Energising Development
in	Inches
INR	Indian Rupee
kWH	Kilowatt hour
LEAP	Lighting and Energy Access Partnership
LED	Light-emitting diode
LEIA	Low-Energy Inclusive Appliances
m	Meters
min	Minute
N	Sample size
PCM	Phase change material
SHS	Solar home systems
Sida	Swedish International Development Cooperation Agency
TV	Television
TZS	Tanzanian Shillings
UK	United Kingdom
UP	Uttar Pradesh
USD	United States Dollar
W	Watt
WHO	World Health Organization
Wp	Watt-peak

BACKGROUND

High-quality, efficient, off- and weak-grid[1] compatible appliances such as fans, televisions (TVs), and refrigerators can improve livelihoods, economic productivity, and wellness in off-grid communities, while sustaining and further developing the distributed clean energy market. However, the market for these appliances remains nascent and disorganized.

Many conventional appliances consume too much energy for solar home systems to power effectively, and there is little information available regarding the performance and quality of appliances designed specifically for off- and weak-grid environments. This prevents stakeholders across the value chain from making well-informed decisions, further inhibiting market growth and making it harder to deliver modern energy services to off-grid communities at scale. For example:

- **Manufacturers and distributors** have little information regarding the potential cost, quality, and service delivery trade-offs that may present themselves when sourcing highly energy efficient products versus generic "baseline" products.

- **Policymakers** do not have sufficient resources and testing capacity to collect comprehensive market data to define and classify off-grid appliances based on their performance and potential for delivering energy access benefits, which inhibits the development of policies that accelerate the market.

- **Investors and lenders** often perceive investments in companies that specialize in off-grid appliance design and manufacturing as too risky. While pay-as-you-go companies are increasingly attracting more investments, access to financing for off-grid appliance manufacturers remains extremely limited. Investors and lenders need more reliable market intelligence to help them understand up-to-date market trends to be able to more accurately assess risks associated with investments in the appliance market segment.

Among existing resources for the off-grid solar sector, very few provide appliance-specific product information. What little information is presented often relies on manufacturers' rated technical specifications, which can be inconsistent and difficult to compare. To fill this significant knowledge gap, the Efficiency for Access Coalition has developed the Off-Grid Appliance Data Platform[2],a program that generates, collects, and shares information about appliance performance and quality in addition to features and functions.

As the Platform expands in size and scope, there is growing potential for rich analyses of important trends in off-grid appliance markets. This report provides a glimpse into current efficiency and price trends for TVs, fans, and refrigerators, the off-grid appliances most in demand by un- and under-electrified consumers.[3]

To shed light on opportunities for future performance improvements for off-grid appliances, our analysis includes comparisons between off-grid and on-grid appliances of similar sizes. Overall, there is a distinct indication that the average on-grid appliances are more efficient than similarly sized off-grid products. However, some of the best-performing off-grid TVs and fans are on par with their on-grid counterparts in terms of efficiency – and even demonstrate higher efficiency in some cases. This highlights the need for consistent investment in R&D and technology transfer efforts in the off-grid sector to unlock an immense potential for product innovations and market scale-up.

1. "Off-grid" refers to populations that live beyond the reach of the traditional grid; "weak-grid" refers to populations that have unreliable grid connectivity and suffer frequent and sometimes lengthy outages.
2. The Platform is supported by the Good Energies Foundation and the UK Department for International Development (DfID)'s Low-Energy Inclusive Appliances (LEIA) Programme, under the Efficiency for Access Coalition. The online Platform is expected to be launched on EfficiencyforAccess.org in early 2019.
3. Efficiency for Access Coalition, Off-Grid Appliance Market Survey, 2018: https://efficiencyforaccess.org/publications/off-grid-appliance-market-survey

OUR APPROACH

The report provides an overview of the efficiency and price trends across off-grid TV, fan and refrigerator markets by:

1. Mapping the performance and price of products tested through the Platform,
2. Creating year-by-year baselines, and
3. Comparing off-grid appliance performance with products sold in the conventional on-grid market.

Product Selection

The test data referenced in this report is collected from two sources:

"Baseline" products are generic AC or DC appliances that are marketed as off-grid compatible and randomly selected from retail outlets in important off-grid markets in East Africa (Kenya and Tanzania) and South Asia (Bangladesh and India). Market sampling and testing is conducted on an on-going basis through the Off-Grid Appliance Data Platform program.

"Awards" products are those that have been submitted by manufacturers and distributors for the Global LEAP Awards[4], an international competition that identifies high-performing off-grid appliances in various categories. As part of the Awards testing process, product samples are randomly selected and tested from manufacturer warehouse stock.

4. Global LEAP Awards: www.globalleap.org/awards

TESTING

Independent laboratory testing and evaluation helps 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- and weak-grid appropriate appliances. For example, appliances that are used with off-grid energy systems must be tolerant to constant voltage fluctuations from solar and battery systems, yet most test methods for grid-powered domestic appliances were not written with this particular factor in mind. To facilitate improved comparisons of such appliances, CLASP developed a set of test methods[5] 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

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 in the Annex.

5. 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. Full test methods available on GlobalLEAP.org/resources

OFF- AND WEAK-GRID TELEVISIONS

Televisions are among the most desired appliances for households and businesses in off- and weak-grid areas. A recent Efficiency for Access Coalition survey found that after lighting, TVs are the next most desired appliance by off-grid consumers.[6] Consumer demand for TVs drives the demand for off-grid energy systems such as solar home systems (SHSs) and mini-grids. Therefore, scaling the global off-grid TV market can contribute to a significant increase in the market penetration of off-grid power systems.

TVs can unlock significant social and economic impacts, serving purposes beyond mere entertainment. For communities in rural areas, especially women and children who have less opportunity to access information, TVs are a conduit for national, regional, and global information and perspectives. Though traditionally not considered an income-generating appliance, many business owners and entrepreneurs use them for commercial purposes (e.g. restaurant and café owners). Field research by the Efficiency for Access Coalition also indicates that, with the increasing availability of larger TVs, they can inspire the development of new businesses such as village theaters. In a recent Efficiency for Access survey, TVs were ranked second highest in perceived consumer demand, fifth in potential impact out of 18 categories for household uses, and were included in the top-ten appliances for businesses.[7]

The market for off- and weak-grid appropriate TVs remains nascent and inhibited by various market barriers, despites the market for on-grid TVs being highly developed and commoditized. The off-grid TV market is becoming more competitive, but the pool of TV component suppliers, such as screens, remains limited. There is less and less flexibility for product manufacturers to reduce costs or differentiate their products, and without consumer financing, the average off-grid customer's ability to pay still remains too low to afford a TV in many instances. This interplay between cost and efficiency is key: recent estimates suggest that with efficiency and design improvements, the annual global market for off-grid-compatible TVs could more than triple—from 1 to 3.1 billion USD—while also reducing costs.[8]

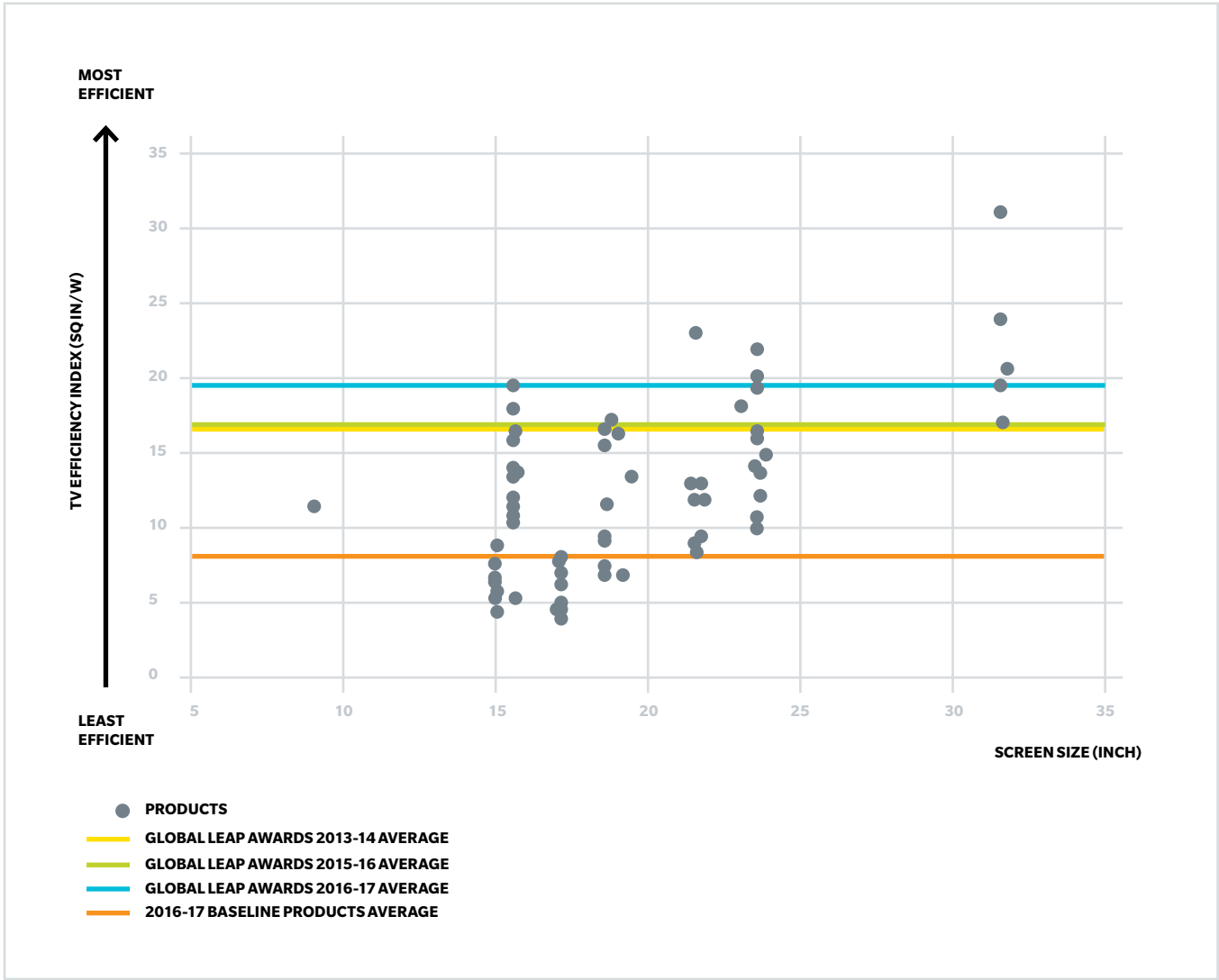
6. Efficiency for Access Coalition, Off-Grid Appliance Market Survey, 2018: https://efficiencyforaccess.org/publications/off-grid-appliance-market-survey
7. Ibid.
8. Global LEAP, The State of the Off-Grid Appliance Market, 2016: http://globalleap.org/s/The-State-of-the-Global-Off-Grid-Appliance-Market-Print-19-April-2016.pdf

Market Trends

The energy efficiency of off-grid appropriate TVs is improving. Test data shows that TV efficiency continues to improve over time, especially among Global LEAP Awards best-in-class market leaders (Figure 1). The analysis indicates that a significant performance gap exists between Global LEAP Award-winning products and market baseline products, demonstrating substantial potential for efficiency improvements across the market. The average Energy Efficiency Index (EEI) – defined as square inches of screen size per Watt – of 2016–17 Global LEAP Award-winning TVs is 19.5 in^2/W, which is more than double the market baseline over the same time period.

The market is largely dominated by 15" to 24" TVs. Many of these products still consume significantly more energy than Global LEAP Award-winning market leaders within the same size category. A small number of manufacturers are starting to offer larger TVs (e.g. 32"), and these size models demonstrate better energy performance. For example, the most efficient model in the dataset is a 32" TV and consumes only 14W—less than most market baseline TVs with 15 to 24" screens.

Figure 1. TV Efficiency Trends, Comparing Average Efficiency of Baseline and Awards Products



DEFINITION: TV ENERGY EFFICIENCY INDEX

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

The retail price for off-grid TVs is decreasing. Available data shows a clear price reduction across tested products between 2014 and 2017. In 2015, the average cost per screen size of Global LEAP Award products was 1.57 USD/in^2. In 2017, the average cost per screen size dropped to 1.06 USD/in^2 for Global LEAP Awards products[9] and even further, 0.65 USD/in^2, for baseline products (Table 1). This cost reduction trend can potentially be attributed to the combined factors of increased consumer demand and lower manufacturing costs as the off-grid TV market becomes more established.

Table 1. Comparison of TV Retail Price between Baseline and Award Products

	AVERAGE PRICE PER SCREEN SIZE (USD/IN²)
2014 Awards (n=6)	1.57
2017 Awards (n=15)	1.06
2017 Baseline (n=7)	0.65

On average, TV screens are getting brighter for baseline products, while the average brightness of Awards products is decreasing over time. Off-grid consumers tend to prefer TVs that are brighter, and thus TV luminance, in units of candelas per square meter, is a key performance metric of off-grid televisions. Luminance settings generally impact how much power a TV consumes. Higher luminance typically results in higher power consumption. When comparing the luminance of baseline and Awards TVs, the data shows that the baseline TVs are brighter than Awards products and the difference between the two product groups becomes more significant in 2017 (Table 2). Off-grid TVs are intentionally designed to work at lower luminance to achieve a higher efficiency and thus require smaller PV panel and battery to power them, making SHS kits more affordable for off-grid consumers. Meanwhile, baseline TVs are designed to have even brighter screen to satisfy off-grid consumer preferences.

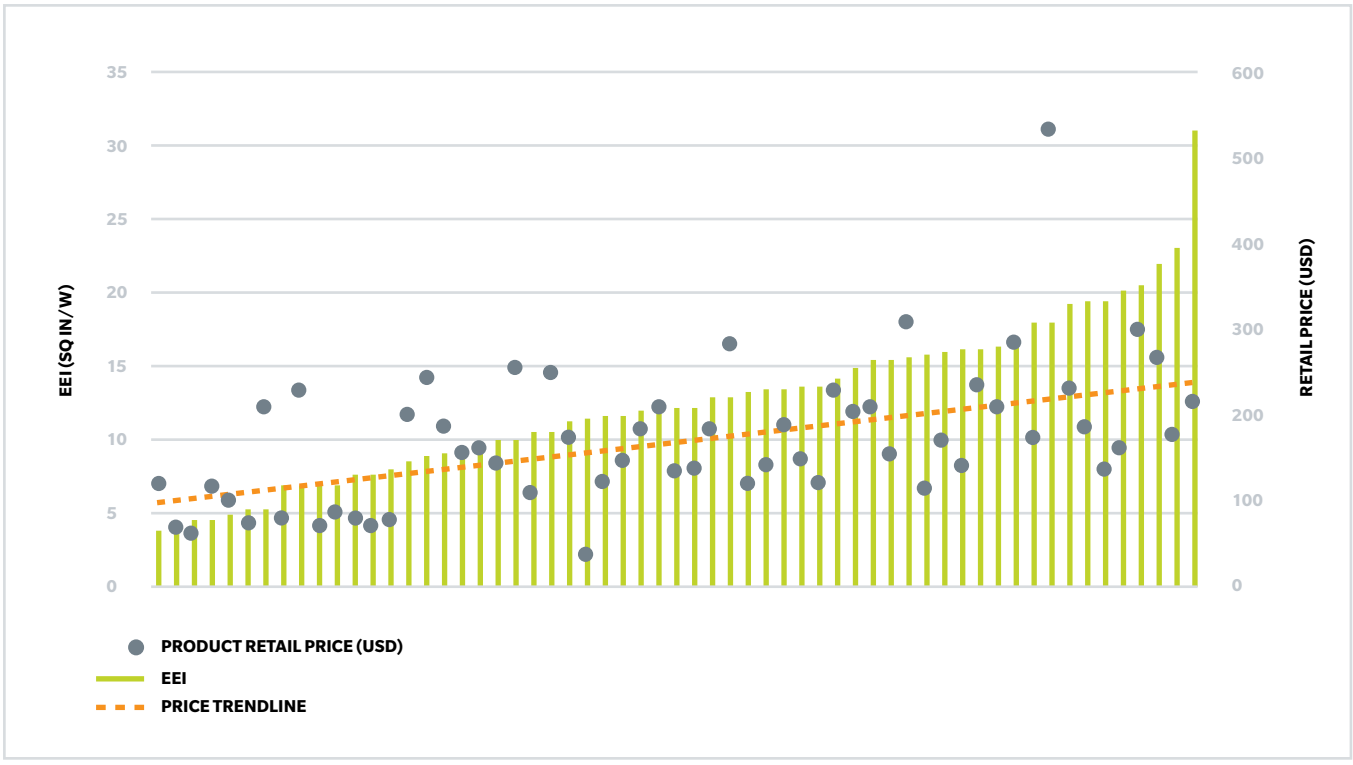
Best-in-class televisions are more expensive than baseline products sold in retail markets. Award-winning products are, on average, 63% more expensive than similarly sized baseline products. While the majority of the baseline products are sold for 150 USD or less, some of the branded baseline products (e.g. LG and Samsung) are more expensive than the Global LEAP Awards products.

There is a distinct correlation between efficiency and price. The data indicated that higher-efficiency televisions tend to be more expensive on average (Figure 2).

Table 2. Comparison of TV Luminance (Cd/m^2) between Baseline and Awards Products

	BASELINE AVERAGE	AWARDS AVERAGE
2016	156	145
2017	221	137

Figure 2. TV Efficiency and Price Distribution



9. The wholesale prices declared by manufacturers are multiplied by a factor of 1.8 to adjust for estimated taxes, duties, supply chain markups, etc.

Comparison with TVs available in the on-grid market

Comparing off-grid products with their on-grid counterparts is helpful in assessing potential future efficiency gains (Table 3). Data suggests that, on average, on-grid TVs are more efficient than similarly sized off-grid TVs. However, the most efficient off-grid TVs tested in this analysis (90th percentile) actually boast a higher efficiency than on-grid TVs[10] across the board.

A luminance comparison (Table 4) also shows that the lowest energy off-grid TV operates at less than half the brightness of the lowest energy on-grid TV.[11] The data also indicates that off-grid TVs demonstrate higher average luminance efficacy, defined as candela per square meter per Watt, than on-grid TVs. The luminance efficiency of the brightest off-grid TV was nearly double that of the brightest on-grid TV.

Table 3. Comparison of Efficiency Index Between Off-Grid TVs and On-Grid TVs from the European Market

ENERGY EFFICIENCY INDEX	OFF-GRID PRODUCTS	ON-GRID PRODUCTS
EEI (mean)	12.12	14.03
EEI (90th percentile)	19.45	15.07

Table 4. Comparison of Luminance Measurements Between Off-Grid TVs and On-Grid TVs from the European Market

LUMINANCE (CD/M^2)	OFF-GRID PRODUCTS	ON-GRID PRODUCTS
Lowest	36	76
Median	158	173
Highest	425	299
LUMINANCE EFFICACY ($CD/M^2/W$)	**OFF-GRID PRODUCTS**	**ON-GRID PRODUCTS**
Lowest	3.93	3.45
Median	12.10	6.11
Highest	31.08	15.30

10. Off-grid test data was compared with manufacturers' declared energy consumption data of 18 A+ rated TVs of a size range selected to be similar to off-grid sets (24-40") from Topten UK, which features best in class models on energy efficiency from the UK market: http://www.toptenuk.org/.
11. Tests measured luminance in retail mode. This was compared to data from 20 randomly selected TVs under the ComplianTV project: http://www.compliantv.eu/eu/about-the-project/home

RURAL OFF-GRID APPLIANCE MARKETS IN ZANZIBAR, TANZANIA

Low availability of off-grid appliances persists despite high consumer demand

Zanzibar is a semi-autonomous region off the coast of Tanzania. Zanzibar City was once the capital of the Sultanate of Oman and Zanzibar continues to maintain strong ties and trading relationships with the Arab world. The appliance market in Zanzibar is unique from that of mainland Tanzania due to the region's unique historical background, separate port system, and distinct regulations for customs and imports.

In March 2018, CLASP conducted a survey of off-grid appropriate appliances being sold in 10 rural markets in Zanzibar. The survey identified 16 unique brands across 12 TVs, 11 fans, and 2 refrigerators. TVs were found to be the most commonly available product, most in the 15"-22" size range, with retail prices running from 130,000 to 400,000 Tanzania Shillings (57 to 175 USD).

For a rural consumer, it is difficult to identify and locate appliance vendors in Zanzibar. Solar shops are dispersed, selling mostly solar panels and lighting and charging products, in addition to some small appliances like radios. Compared to Dar es Salaam, the largest city in Tanzania, the availability of solar fans, televisions, and refrigerators in Zanzibar is limited. Most shops carry only two or three types of each product, and inventory is low.

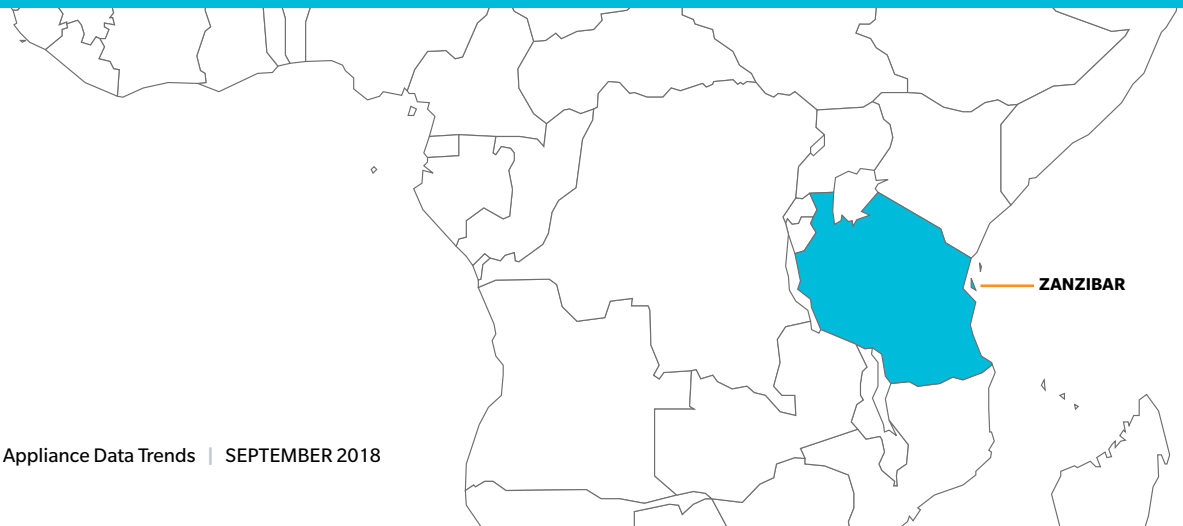
While product availability is limited, retail shop owners believe there is a large consumer base in Zanzibar: approximately 80% of the 1.3 million population in rural Zanzibar does not have access to municipal power supplies and relies on off-grid technologies. Notably, shop owners reported that approximately half of their customers buy solar home system kits to supplement municipal power supplies.

The mismatch between local product availability and product demand may be due to a variety of factors:

- **The population that uses solar energy is not co-located with solar markets.** A rural customer interested in buying solar products from Zanzibar will need to spend 3,000 TZS (1.32 USD) round-trip to visit these shops—equivalent to more than a day's wages for many families. There are some rural shops that have a few appliances here-and-there, but the selection is extremely limited, with many shops only offering panels, batteries, and lighting.

- Zanzibar City is relatively close to Dar es Salaam—two to four hours by boat. If there is demand for a given appliance, distributors can then travel to Dar to refresh their inventory when an order comes in. Therefore, **distributors typically prefer to keep low product stock.**

- Because Zanzibar has a separate government and port, **importers may face additional barriers complying with local laws for a relatively small market.** For example, a distributor in Dar es Salaam may be willing to complete the paperwork and navigate regulations to import solar products because they know that there is a significant local and regional market. However, the market in Zanzibar is smaller, and any additional regulation compliance required by a local distributor may be a significant enough barrier to deter some importers.



OFF- AND WEAK-GRID FANS

The World Health Organization (WHO) forecasts that nearly 100,000 deaths could be caused by heat waves each year by 2030.[12] With high up-front cost and energy requirements, air conditioners are out of reach for most rural households and communities. In many parts of the world, fans thus play an important role as a cost-effective, low-energy cooling solution.

Fans, often considered a luxury good that provides comfort, are one of the most overlooked cooling solutions that could be life-saving, especially for women and children in sweltering living conditions. Research indicates that using a fan could help regulate the human core body temperature during heat waves when ambient temperature is at 42°C.[13] In addition, fans deliver positive social impacts. For example, in Bangladesh, school attendance by girls increased significantly once electric fans were used to made classrooms more comfortable.[14]

Local environmental conditions are a major determinant of demand for fans in off-grid markets. A recent Efficiency for Access Coalition off-grid appliance market survey indicated that fans ranked fifth in terms of consumer demand globally—but ranked first in the hot and humid climates of South Asia.[15] In more temperate off-grid markets such as East Africa, the demand for off-grid fans is lower.

Despite the fact that product demand is limited to certain geographies, the off-grid fan market has the potential to grow exponentially. Estimates suggest that annual spending on off-grid fans could reach 500 million USD in 2020, especially if energy efficiency and design improvements are more widely adopted.[16]

Market Trends

The range in fan efficiency varies significantly across the market (Figure 3). Among table and pedestal fans, the EEI of the most efficient fan is more than four times that of the least efficient product.

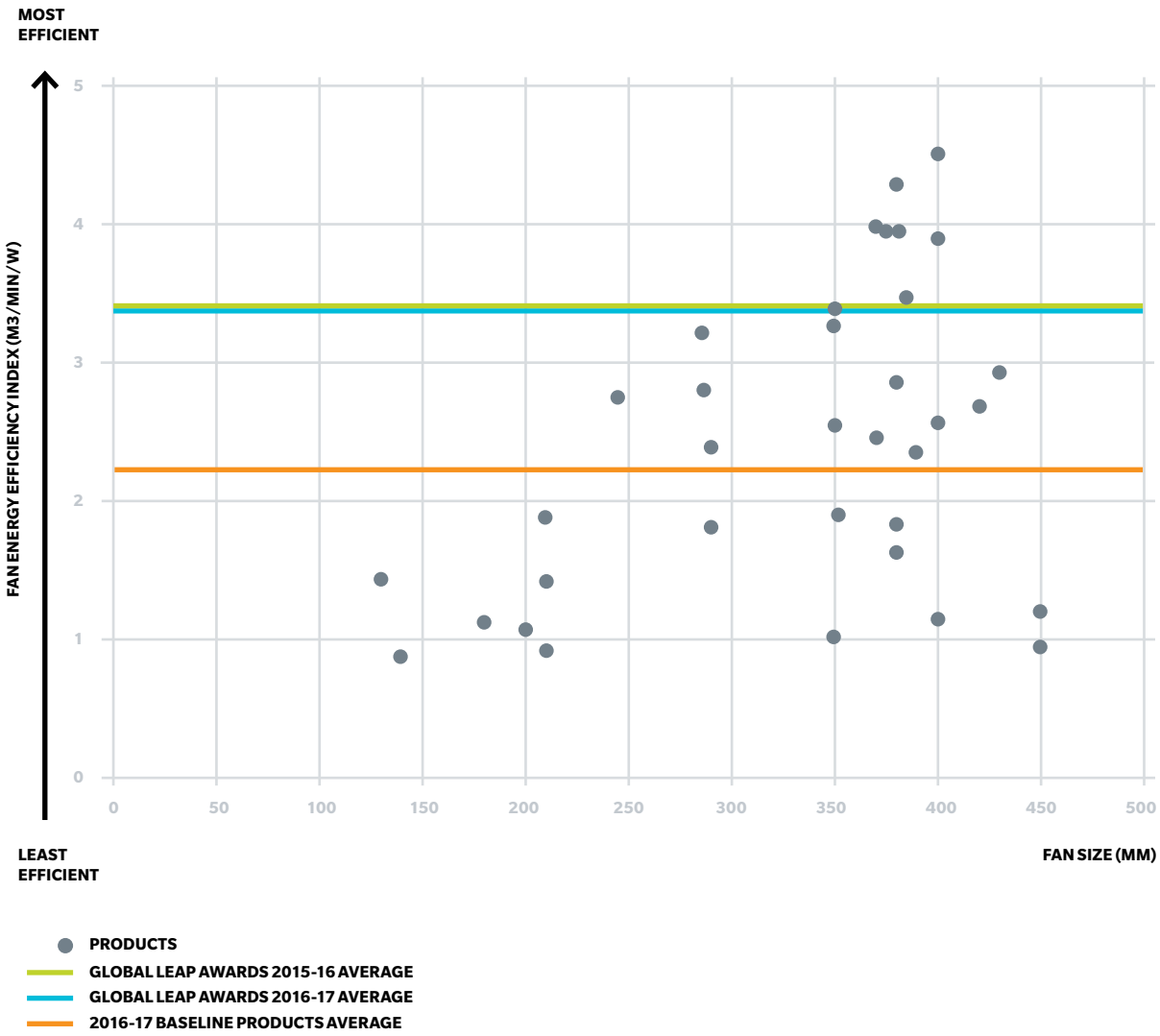
Baseline fans still have a long way to catch up with the best-in-class products. A significant performance gap exists between Awards products and market baseline

12. The World Health Organization, Climate change and health. (2018). Resource document. http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
13. Electric fan use in heat waves: Turn on or turn off?, Temperature 2016; 3(3): 358–360. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5079223/
14. Rewald, Rebecca, Energy and Women and Girls: Analyzing the Needs, Uses, and Impacts of Energy on Women and Girls in the Developing World, Oxfam Research Backgrounder series (2017): https://www.oxfamamerica.org/explore/research-publications/energy-women-girls
15. Efficiency for Access Coalition, Off-Grid Appliance Market Survey, 2018: https://efficiencyforaccess.org/publications/off-grid-appliance-market-survey
16. Global LEAP, The State of the Off-Grid Appliance Market, 2016: http://globalleap.org/s/The-State-of-the-Global-Off-Grid-Appliance-Market-Print-19-April-2016.pdf

products. The EEI of 2016-17 Global LEAP Awards fans is 3.35 m^3/min/W, 35% better than the average of baseline products tested during the same time period.

Fans that use DC motors are becoming more common, and are driving the off-grid fan market towards higher efficiency. The motor is the most significant driver of fan energy consumption. An efficient motor (e.g. a brushless DC motor), could increase energy fan efficiency by more than 50% compared to a common AC motor.[17] An assessment of the efficiency of DC versus AC fans indicate that the average EEI of a pedestal fan with a DC motor is about 3.19 m^3/min/W—approximately 1.8 times better than pedestal fans that use AC motors. This is a key consideration when weighing cost and power usage (including whether to use DC appliances or AC models with an inverter) for product selection to be paired with any given distributed energy solution.

Figure 3. Fan Efficiency Trends, Comparing Average Efficiency of Baseline and Awards Products



DEFINITION: FAN ENERGY EFFICIENCY INDEX

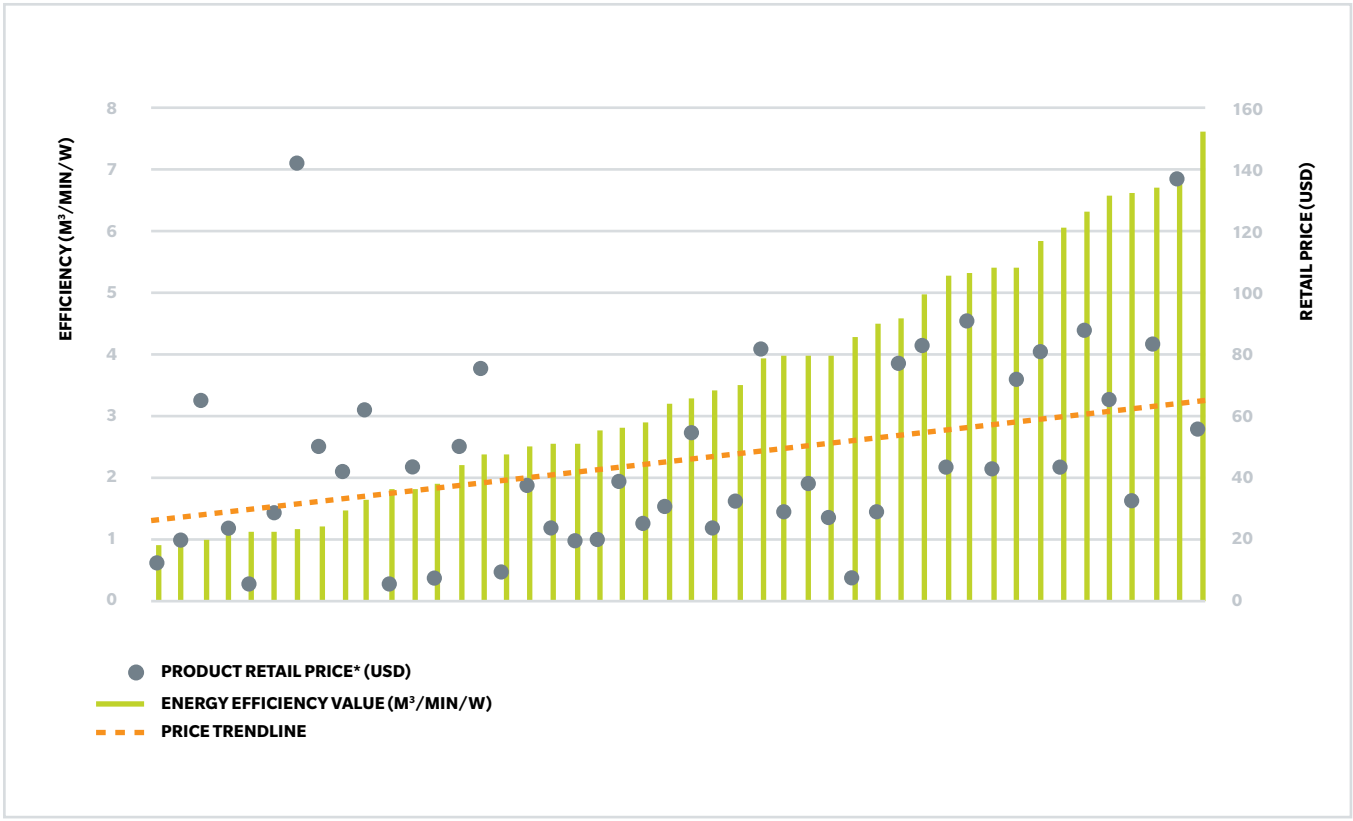
For the purposes of this study, fan Energy Efficiency Index (EEI) is defined as the volume of air delivered, in meters-cubed per minute, per Watt of input power, or m^3/min/W. The higher the EEI, the more efficient the fan.

17. Global LEAP, The State of the Off-Grid Appliance Market, 2016: http://globalleap.org/s/The-State-of-the-Global-Off-Grid-Appliance-Market-Print-19-April-2016.pdf

Fan retail prices vary significantly, indicating that the off-grid fan market is still largely disorganized and volatile. As indicated in Figure 4, there is a slight correlation between cost and efficiency. However, when comparing prices of baseline products with similarly sized Global LEAP Award-winning products, the cost difference is not significant—the 2016-17 Global LEAP Awards-winning fans on average costs about 2 USD per inch of fan diameter, while baseline fans on average costs 3 USD per inch of fan diameter. Notably, this observation differs from other product categories, where efficiency and quality more strongly correlate with price.

Unlike on-grid markets, the majority of fans in the off-grid retail market are not marked with a declared energy performance value. The lack of clear performance rating on the product package or nameplate makes it extremely difficult for distributors and consumers to factor energy consumption into purchasing decisions or make meaningful comparisons between products.

Figure 4. Fan Efficiency and Retail Price Distribution



The average price of baseline fans varies by market, and shows some correlation with certain market characteristics (e.g. market size, climate). The cost analysis based on pedestal fans between 350 to 450mm tested between 2016 and 2017 indicates that the average pricing was 34.57 USD in this time period. A further market-by-market comparison based on data collected in 2018 indicates that in Pakistan and India, where there is an especially high consumer demand for fans due to climate conditions, the average retail price is relatively low compared to East Africa (Table 5).

Table 5. Price Trends by Country for Pedestal Fans

COUNTRY	AVERAGE PRICE (USD)
Pakistan	26.07
India	15.73
Kenya	42.03
Tanzania	29.09
Uganda	27.30

* Data collected by CLASP in 2018. The wholesale prices declared by manufacturers are multiplied by a factor of 1.8 to adjust for estimated taxes, duties, supply chain markups, etc.

Comparison with fans available in the on-grid market

As part of the assessment of fans, we also compared the size and energy efficiency between off- and on-grid markets (Table 6). Test data from off-grid models was compared with manufacturer specifications for on-grid table and pedestal fans in the European market.[18] This comparison showed higher levels of efficiency for off-grid fans at both average values and at the top of the range.

In terms of size trends, the median sized off-grid fans appear to be smaller and rated as using significantly less power (64% lower for table fans and 31% lower for pedestal fans respectively) than fans in the on-grid European market.

Table 6. Comparisons of Energy Efficiency Index, Size, and Rated Power Input Between Off-Grid and On-Grid Fans

TABLE FANS	OFF-GRID TEST DATA (N=17)	ON-GRID PRODUCTS (N=39)
ENERGY EFFICIENCY INDEX		
EEI (mean)	2.04	1.00
EEI (90th percentile)	3.93	1.27
SIZE		
Median Size (inches)	11.60	13.95
POWER		
Median Rated power input (W)	14.40	34.40
PEDESTAL FANS	**OFF-GRID TEST DATA (N=11)**	**ON-GRID PRODUCTS (N=29)**
ENERGY EFFICIENCY INDEX		
EEI (mean)	2.68	1.26
EEI (90th percentile)	3.97	1.61
SIZE		
Median Size (inches)	15.20	18.60
POWER		
Median Rated power input (W)	17.50	46.80

18. Data from 39 table fans and 29 pedestal fans featured on Topten Switzerland: https://www.topten.ch/

OFF- AND WEAK-GRID REFRIGERATORS

The market for off-grid and weak-grid refrigeration products is nascent, and the penetration of refrigerators in developing countries remains extremely low—overall market penetration is below 40% in Nigeria and below 30% in India. Rural market penetration is even lower, just 6% in Bangladesh (the world's largest off-grid market) and 1% in Kenya.[19]

This low penetration rate is mainly due to the difficulty of last-mile delivery in off-grid areas, especially as the delivery cost for larger appliances is significant. It is also due to the lack of affordable off-grid appropriate refrigerators, high associated cost of energy supply, as well as the availability of consumer financing.

Conventional AC refrigerators typically found in retail markets require a significant amount of power, which makes them incompatible with intermittent grid connections or the limited amount of electricity provided by distributed energy systems. In order to be viable in off-grid settings—and suitable for rural customers—refrigerators must be less expensive and run on far less energy than most conventional products.

Despite low penetration rates, latent demand for off-grid refrigerators is significant. Refrigeration can significantly enhance the rural economic value chain, and holds immense potential for unlocking productive use applications, especially in terms of agro-processing.

Global LEAP research estimates that current annual spending on refrigerators by off- and weak-grid households is approximately 75 million USD. If efficient, appropriately-priced products become accessible to all households with the purchasing power to buy a refrigerator, spending could increase to 1.1 billion USD by 2020—a 38% compound annual growth rate—despite lower per unit costs.[20]

19. Global LEAP, The State of the Off-Grid Appliance Market, 2016: https://storage.googleapis.com/clasp-siteattachments/The-State-of-the-Global-Off-Grid-Appliance-Market-Report.pdf
20. Ibid

Definitions

REFRIGERATORS

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

REFRIGERATOR-FREEZER COMBINATION UNITS

Refrigerator-freezer combination units (denoted "R-F") have a combination of at least one fresh food and at least one freezer compartment, where the storage temperature is below -18°C.

REFRIGERATOR ENERGY EFFICIENCY INDEX

For the purposes of this study, refrigerator energy efficiency index (EEI) is defined as units of surface area (meter square) per daily energy consumed (kWh per day) – m^2/kWh/day.[21] The higher the EEI, the more efficient the refrigerator.

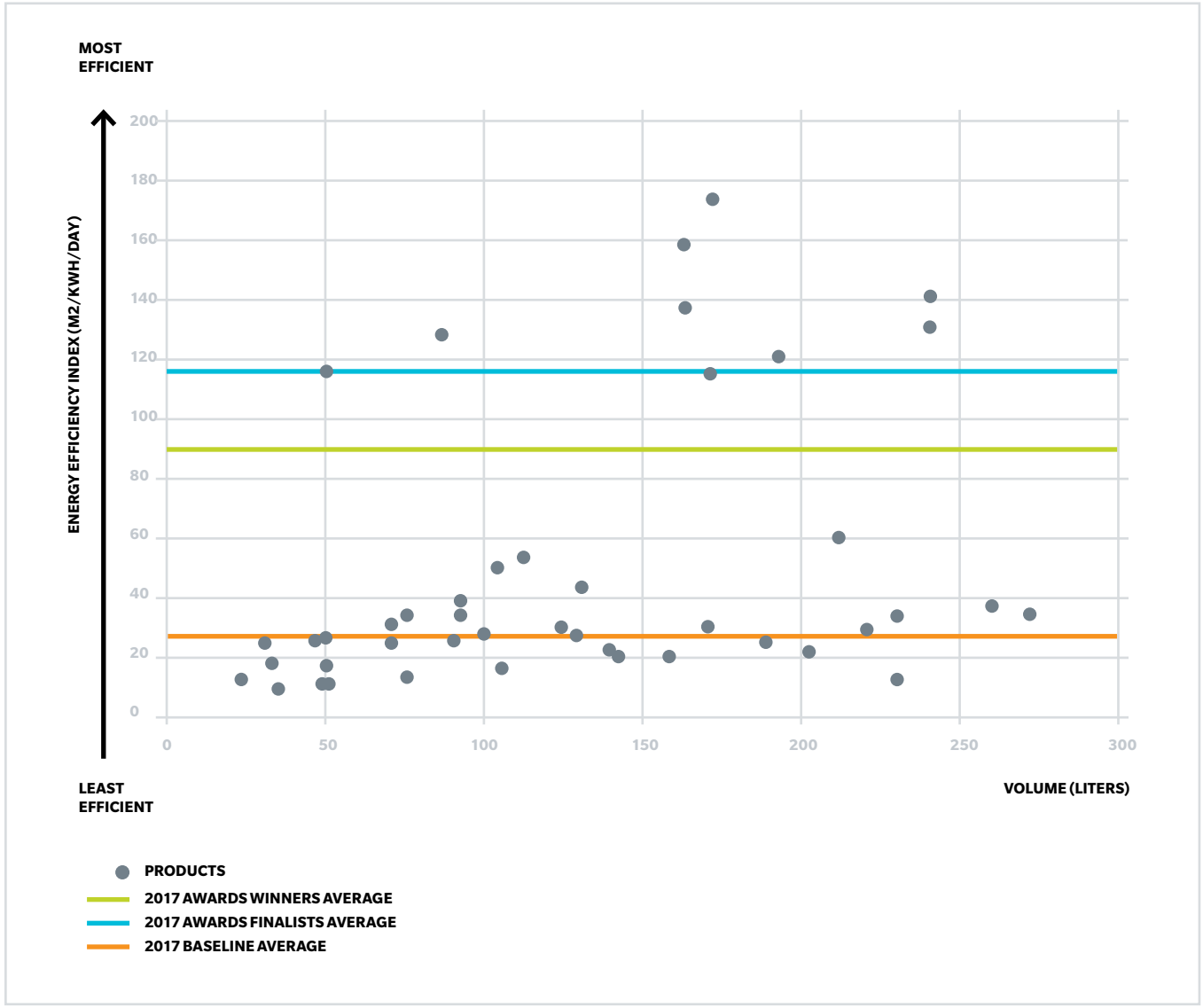
21. The daily energy consumption is measured based on the Global LEAP Off-Grid Refrigerator Test Method, which references IEC 62252:2015. Based on the test method, the daily energy consumption is measured at 32°C and does not include a load during testing.

Market Trends

Efficiency values vary significantly across the refrigerators tested and a significant gap exists between baseline and Awards products. The worst performing refrigerator in the 2017 dataset uses 19 times more energy per unit surface area than the most efficient refrigerator tested. On average, the efficiency of baseline products is 28 m^2/kWh, while the average efficiency is 57 m^2/kWh for Global LEAP Awards Finalists and 84 m^2/kWh for Awards Winners—representing a 92% and a 141% efficiency improvement compared to the baseline average, respectively (Figure 5).

The daily energy required to operate a typical off-grid refrigerator is high. The average refrigerator requires 0.74 kWh per day to operate in an ambient temperature of 32°C. Under optimal conditions, this would require a SHS with at least a 200 Wp solar panel and a 160 Ah battery.[22] An overwhelming majority of existing SHS consumers still cannot afford a system in this size. Based on the 2018 Off-Grid Solar Market Trends Report[23], the predominant medium size of SHSs affordable by off-grid consumers is within the size range of 50-100 Wp. In order to be supported by a 100 Wp solar system, off-grid refrigerators would need to become much more efficient to consume on the order of 0.4 kWh per day.[24]

Figure 5.Refrigerator Energy Efficiency Trends—Comparing Average Efficiency of Baseline and Awards Products



22. Based on CLASP's theoretical calculation.
23. IFC, Off-Grid Solar Market Trends Report, 2018: https://www.lightingglobal.org/wp-content/uploads/2018/03/2018_Off_Grid_Solar_Market_Trends_Report_Full.pdf
24. Based on CLASP's theoretical calculation.

Highlights of Refrigerator Performance Findings

Average daily energy consumption at 32° C:

0.74
kWh/day

Average daily energy consumption at 43° C:

1.25
kWh/day

Changes in ambient temperature impact energy consumption

The impact of test temperature on energy varies widely across products. For each product, daily energy consumption generally increased as ambient temperature increased. The average daily energy consumption of refrigerator tested at 32°C was 0.74 kWh/day, while the average daily energy consumption at 43°C was 1.25 kWh/day—a 41% increase.

Lowest autonomy measure:

22
minutes

Highest autonomy measure:

133
hours

Autonomy performance varies greatly across products

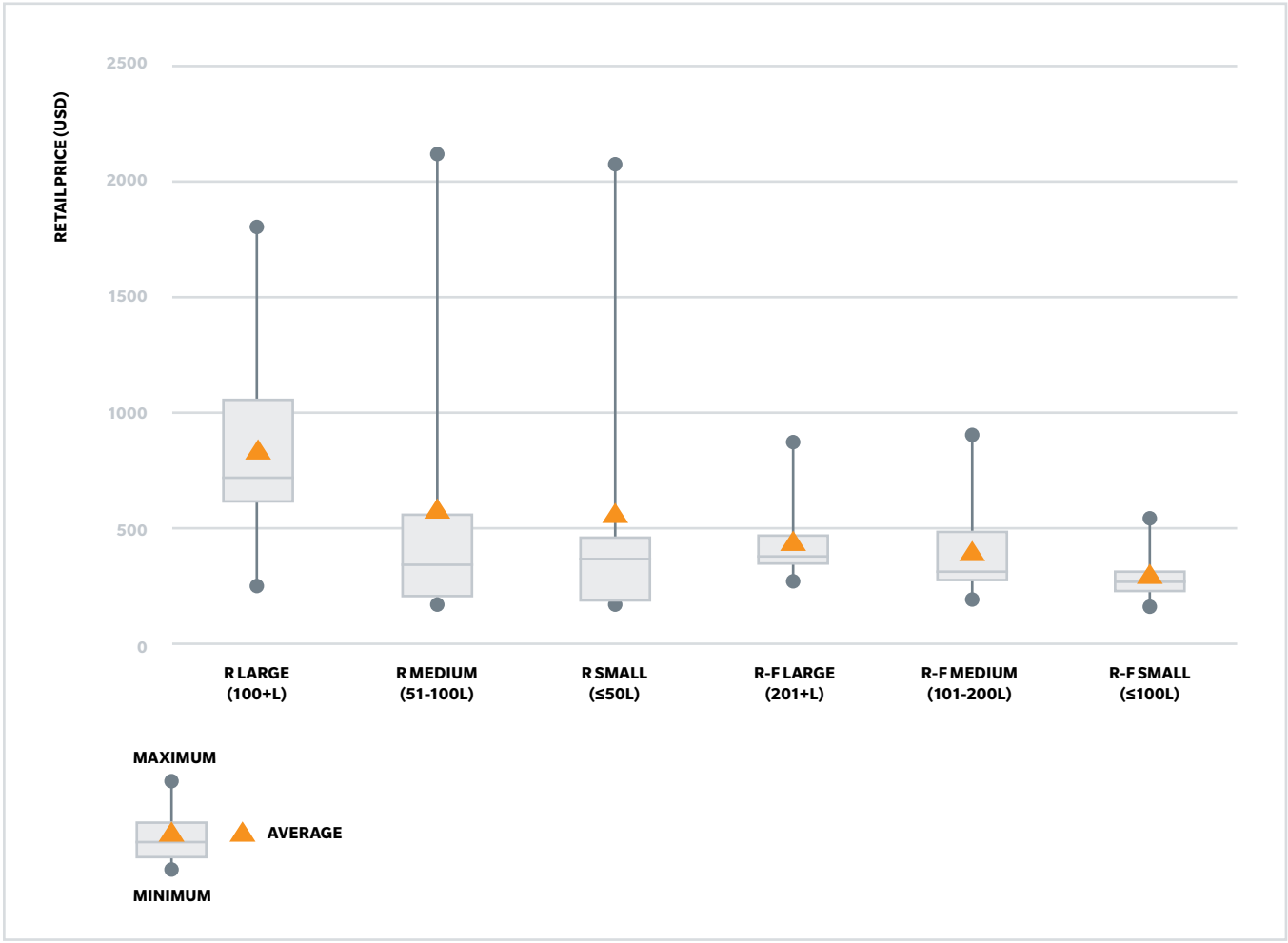
Autonomy—the ability to keep a sealed refrigerator compartment cool without input of power—is one of the refrigerator characteristics most valued by consumers who live in off- and weak-grid environments with highly constrained and/or intermittent electricity supply. Autonomy is a measure of the time it takes a refrigerator compartment to rise from 4°C to 12°C with no external power supply. Across all products tested, autonomy ranges from a low of 22 minutes to a high of 133 hours. The product that can hold 133 hours is a thermal refrigerator that uses phase-change materials (PCMs), i.e. water packs, commonly used in direct-drive vaccine refrigerators to decrease energy use and enhance thermal performance.

The high price of refrigerators is a critical barrier to consumer adoption. Off- and weak-grid consumers are price-sensitive, especially for larger, "investment" appliances such as refrigerators. The price of refrigerators ranges roughly from 300 USD on the low-end to roughly 2,200 USD on the high-end (Figure 6). There are increasingly more specialized off-grid refrigerators that incorporate phase change material (PCM) technology[25] to improve thermal performance, but these products come with a much higher price tag which, even with monthly installments, would still be out of most off-grid consumers' reach.

The retail price of off-grid refrigerators varies significantly but slightly correlates with product size. Within each product type and size category, the data shows wide variance between the highest and lowest product prices.

A higher price is not always associated with better energy performance or quality. Data indicates that among products that perform similarly in terms of energy efficiency (with EEI values around 130 m^2/kWh), the retail price ranges from roughly 360 to 1300 USD, a 3.6 times difference. This price inconsistency, coupled with the lack of clear performance specification declared on product nameplates and packaging, makes it challenging for consumers and distributors to make an informed decision based on efficiency, quality, and other features.

Figure 6. Minimum, Average, and Maximum Refrigerator Retail Prices by Type and Size



25. The refrigerators that have the highest retail price tend to be specialized off-grid refrigerators that are either designed to be used as a vaccine refrigerator, or use phase-change materials (PCMs)—a new cooling technology that uses water or other chemical substances to absorb and release thermal energy as its melting and freezing. Source: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=2043&context=iracc.

Comparison with refrigerators available in the on-grid market

The average efficiency of off-grid refrigerators was compared with the most efficient on-grid refrigerators—products that carry A++ or A+++ European Energy Labels[26]– in similar types and sizes.[27]

The analysis indicated that, on average, A++/A+++ on-grid refrigerators are two times more efficient than off-grid refrigerators (Table 7). The best-available off-grid refrigerator has the smallest efficiency gap with its on-grid counterpart. For refrigerator-freezer combination units, the data indicates that there significant potential efficiency improvement opportunities , e.g. compressors with higher efficiency and better insulation technologies, for off-grid refrigerator-freezers to catch up with on-grid products.

Table 7. Energy Efficiency Index Comparison Between On-Grid and Off-Grid Refrigerators

REFRIGERATORS	OFF-GRID[28]	ON-GRID[29]	DIFFERENCE (%)
Lowest EEI	11	63	472
Mean EEI	69	133	93
Highest EEI	173	245	41
REFRIGERATOR-FREEZER COMBINATION UNITS	**OFF-GRID[28]**	**ON-GRID[29]**	**DIFFERENCE (%)**
Lowest EEI	9	58	560
Mean EEI	25	92	265
Highest EEI	60	135	125

26. European Commission: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products
27. On-grid refrigeration data includes 58 single-compartment refrigerators, chest freezers, and two-compartment refrigerator-freezers with capacity ranged between 82 and 412 liter. These products are rated A++ and A+++ based on European Energy Labeling requirements. Data taken from Topten UK in July 2018: http://www.topten.info/.
28. Data taken from CLASP, Off-Grid Appliance Data Platform, 2017.
29. Data taken from Topten, 2018: http://www.topten.info/

OFF-GRID APPLIANCE MARKET IN LUCKNOW, INDIA

Interviews with shopkeepers indicate that Indian off-grid consumers have low demand for DC appliances

Lucknow is the capital and largest city in the northern Indian state of Uttar Pradesh (UP), one of three states in India with a household electrification rate below 50%. Lucknow alone has 13.3 million unelectrified households, and serves as the main market where rural customers in UP shop for appliances.[30]

In Lucknow, a customer can buy appliances in medium-sized consumer electronics stores or conventional retail and wholesale shops—but most of these stores sell cheap or unbranded products. According to some local retailers, the improved electricity supply in UP in recent years has also led to a decrease in demand for solar products. The stock of DC solar appliances is extremely limited. According to shop owners the **demand for DC appliances is low compared to AC products**, and they receive frequent complaints from customers on the quality. The majority of off-grid appliances found in the market are solar lights, followed by fans—a product only sold in the summer to meet seasonal demand.

Many store owners are unaware that DC products even exist. Off-grid customers would typically purchase an AC TV and a DC to AC inverter so that they can power the TV with a solar home system. Shop owners reported that their customers typically think that LED TVs are already highly energy efficient, so they do not see the need for additional energy savings offered by DC TVs. However, some of the LED TVs found in the market are counterfeits and do not deliver the expected energy savings. TVs in this market typically have a 12-month warranty and range from 2,800 INR (40 USD) for the unbranded models to 11,300 INR (165 USD) for brand names.

There are very few DC refrigerators in the Lucknow market. However, there is a **growing demand for refrigerators with digital inverter (DI) compressors because they consume less power and are compatible with grid-connections or solar home systems.** Samsung's SMART DI Series[31] holds the strongest market presence and are marketed as refrigerators that can run on solar energy. For off or weak-grid customers, single door, 192 L refrigerators with DI technology are the highest demand, and typically cost around 16,500 INR (240 USD), according to a sales representative in Lucknow.

30. Hindustan Times, https://www.hindustantimes.com/lucknow/44-rural-households-in-up-still-powerless/story-tNX5EyIjEHH5ao55G3K07L.html
31. Samsung SMART DI Series: https://news.samsung.com/in/samsung-brings-home-meaningful-innovation-with-revolutionary-smart-convertible-5-in1-smart-digital-inverter-refrigerators

Discrepancies Between Laboratory versus Field Performance

The data used in this report was collected in a controlled laboratory environment to ensure that test results are repeatable, consistent, and comparable. Despite best efforts to simulate real-world conditions, laboratory testing can never truly predict a product's actual energy performance in the field. Field testing is thus a necessary complement to laboratory testing to support continued progress towards improved appliance quality and energy efficiency.

For example, a mini-grid developer conducted refrigerator field testing in Tanzania and reported that that the daily energy consumption was considerably higher than both the manufacturer's claim and the lab-tested results.[32] The manufacturer's specification sheet claimed the refrigerator would consume 440Wh per day under worst-case conditions. In laboratory testing, the refrigerator consumer about 800Wh per day measured at 43°C ambient temperature. However field data showed consumption of 1000-1500Wh per day for an entire month. The monitoring equipment installed on this field sample also showed that the compressor of the refrigerators is running 24/7, which leads to high energy consumption.

Accuracy of Claimed Energy Performance Values

We assessed the variance between manufacturers' rated energy performance and laboratory test results for fans and TVs, and found large discrepancies. Two-thirds of TVs' tested power consumption fall outside of the +/- 20% range of the rated values listed on the products. This level of discrepancy underscores the challenges of making purchasing decisions based solely on manufacturer claims. Where consumption is higher than expected, this may lead to problems with unexpected power shortages or battery drainage in off-grid markets. Greater accuracy and consistency in product energy performance ratings, combined with communication about how energy performance may vary in real-life settings, is critical for consumer protection and to support the ongoing development of off-grid appliance markets.

Enhancing Product Durability & Quality

Durability and quality are of vital importance for rural consumers, many of whom are first-time purchasers who have made a substantial financial investment in their solar home system. Off-grid consumers often live in remote areas with almost no access to repair technicians or replacement components. Product failures and bad user experiences can quickly erode consumer confidence in appliances and their brands. Our testing found that two-thirds of fans failed certain aspects of the drop test[33]—malfunction of motors, shattered motor casings, or damaged fan guards. In order to sustain the growing demand for off-grid appliances, consumers must have confidence that their products will deliver great service for a long time. Quality and durability also improve investor confidence, enhance consumer safety, and help minimize e-waste. Having appropriate quality assurance frameworks in place that look at these broader quality issues, such as truth-in-advertising and warranty, more holistically is a vital part of market development to inform stakeholders and champion quality products.

32. Proprietary data, shared in a case study interview.
33. A drop test is a test designed to examine the durability of table and pedestal fans. The products are dropped from a one meter height onto a surface from four directions.

Stay Connected

With the continued support of the Good Energies Foundation and UK DfID, the Efficiency for Access Coalition is planning to launch a public-facing, user-friendly, web product database in late 2018, which will enable greater data transparency. This improved solution will give users access to the most up-to-date product information available, enabling them to easily compare and evaluate products based on critical attributes such as energy efficiency, quality, pricing, innovative features, and market availability.

Find out more about the Off-Grid Appliance Data Platform

Connect with us and share performance test data:
info@efficiencyforaccess.org

OFF-GRID APPLIANCE TESTING PARAMETERS AND MODIFICATIONS

Product	Commonly-Used Test Methods for On-Grid Household Products	Modified Tests to Address Off-Grid Performance Characteristics
 FANS	• IEC 60879 (air delivery, power input, and energy efficiency value) • IEC 60335-2-80 (fan blades and guards)	• Quality and workmanship inspections • Voltage fluctuation conditions (± 15% of rated voltage) • Harsh environment exposure conditions (40C ± 2°C temperature and 93% ± 3% relative humidity) • Physical Ingress Protection (IEC 62257-9-5) • Drop test (IEC TS 62257-9-5)
 TVS	• IEC 62087 (On Mode power consumption) • IEC 62301 (Standby Mode power consumption) • ENERGY STAR® Televisions Test Method (luminance)	• Quality and workmanship inspections • Voltage fluctuation conditions (± 15% of rated voltage) • Harsh environment exposure conditions (40C ± 2°C temperature and 93% ± 3% relative humidity) • Physical Ingress Protection (IEC 62257-9-5) • Viewing Angle (IEC 60107)
 REFRIGERATORS	• IEC 62552 (steady-state operation power consumption at 16^{0}C, 32^{0}C, and 43^{0}C, load processing efficiency, freezing capacity) • WHO/PQS/E003/RF05-VP.4 (autonomy time, pull-down time)	• Quality and workmanship inspection • Voltage fluctuation conditions (± 15% of rated voltage) • Harsh environment exposure conditions (43°C ± 2°C temperature and 93% ± 3% relative humidity)

The test methods were developed through a rigorous research, consultation, and review process that included a working group of off-grid energy industry stakeholders, appliance manufacturers, policymakers, and test facilities.

The Efficiency for Access Coalition is in the process of updating the off-grid refrigerator test method based on lessons learned from the baseline and Global LEAP Awards testing in 2017 and feedback from industry stakeholders.

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