MARKET SURVEILLANCE TO SUPPORT QUALITY ASSURANCE AND CONSUMER PROTECTION FOR THE SOLAR PAYG PRODUCTS MARKET IN EAST AND WEST AFRICA

By

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A Thesis Presented to

The Faculty of California State Polytechnic University, Humboldt

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Environmental Systems: Energy Technology and Policy

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December 2022

ABSTRACT

MARKET SURVEILLANCE TO SUPPORT QUALITY ASSURANCE AND CONSUMER PROTECTION FOR THE SOLAR PAYG PRODUCTS MARKET IN EAST AND WEST AFRICA

Hamidah Naishur Nakimuli

Off-grid Pay As You Go (PAYG) solar products have become one of the fastest-growing approaches to providing basic electricity services to off-grid households in Sub-Saharan Africa and also in many other parts of the world with limited or no access to the electrical grid. However, sustainably growing the PAYG solar industry requires paying close attention to product quality from the point of manufacturing to the end user. This research examines how to best design market surveillance programs that ensure quality in off-grid PAYG solar products and strengthen the implementation and enforcement of quality standards in the off-grid solar market. It identifies and analyzes the common failures in off-grid PAYG solar products and formulates recommendations for designing an effective market surveillance program that tracks quality-certified off-grid PAYG solar products to ensure that they continue to perform as per the certified quality standards once they reach the market.

Based on information gathered from industry practitioners, certification program laboratory test results, and data from a Kenya solar market study, the most common failures identified included problems with batteries, lights, and switches. According to the Kenya study, problems with batteries accounted for 57% of the failures in solar home kits

and 38% in solar home systems. Although not directly related to the product, some companies noted problems with supporting technology systems for PAYG solar products, such as telecom network service issues that made it difficult for end-users to make payments for their PAYG solar products and to receive activation codes via mobile phone when they are able to make payments. Additionally, the research unveiled challenges associated with ensuring that warranties, which are required according to international standards, are offered to the end-users. A market surveillance program and quality standards that aim at solving these common failures in PAYG solar products can help improve quality in the off-grid solar market, protect consumer interests, and make the industry more sustainable.

ACKNOWLEDGEMENTS

My sincere appreciation goes out to the Blue Lake Rancheria for the financial support towards my graduate degree at California State Polytechnic University, Humboldt through their Blue Lake Rancheria Fellowship for Clean Energy Studies. I would also like to thank my advisor and thesis committee chair Dr. Arne Jacobson for encouraging me to apply to this program and for his continued support through it all. I am thankful to Drs. Peter Alstone and Nicholas Lam for agreeing to be part of my thesis committee and advising me throughout the process of my graduate program.

I am grateful for the work experience at Schatz Energy Research Center which has influenced my research topic for this thesis. I would like to express my gratitude to my supervisor, Margaret Harper for always advocating for me at, work, school, as well as personal life, and for always being there for me to listen to my endless rants on challenges as an international student in Arcata.

Making the decision to go back for a full-time graduate program after so many years of working is hard, but what is even harder is deciding to start school in a foreign country in the middle of a pandemic. I am grateful that I made that decision but even more thankful that I was able to do this with my very supportive husband George Webster Ross IV. It has been a journey of hills and valleys, made possible by a team of supportive friends and family who have cheered me on throughout my time as a student at California State Polytechnic University, Humboldt.

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CHAPTER 1. INTRODUCTION AND BACKGROUND

The global count of people without access to electricity is reported at 770 million, and many of these people live in Sub-Saharan Africa, where over 75% of the population lack access to electricity (IEA, 2020). This is partially attributed to global income inequalities and the distribution of electric grid infrastructure (Sarkodie and Adams, 2020). Off-grid solar companies are stepping in to help mitigate this electricity problem by providing off-grid solar products. However, for the off-grid solar market to be sustainable, close attention to the quality of products and services delivered to end consumers is needed. Internationally defined guidelines and quality standards are being used by quality certification programs to evaluate and certify off-grid solar products at the manufacturer level before they reach the market. Certification programs do this by evaluating and testing sample products through accredited test laboratories.

The laboratories follow internationally accepted test methods (IEC, 2018 and 2020)[1] that evaluate the products to assess their quality, durability, and performance, with a goal of generating test results that are consistent, comparable, and repeatable (VeraSol, 2020a). Manufacturers of off-grid solar products participate in these programs by

[1] The primary test methods for off-grid solar products are published in International Electrotechnical Commission (IEC) Technical Specification 62257-9-5:2018, while the standards that include requirements for passing the tests are published IEC Technical Specification 62257-9-8:2020.

submitting randomly selected samples of their products to accredited laboratories for testing. If the provided samples meet the standards, they are awarded a quality certificate.

Despite the efforts, some products that have gone through quality testing and certification still end up failing on the market before their intended life cycle, indicating a gap in the current quality assurance processes.

The majority of people in Sub-Saharan Africa without access to electricity are also low-income earners, making them a target market for a wide range of off-grid solar products with varying quality and affordability levels. High quality off-grid solar products often come at a high initial cost (Alinda et al., 2021), which makes affordability difficult for some people on the market. Innovations such as Pay As You Go (PAYG), a sales model that allows customers to purchase solar products on installments, are being used to make quality off-grid solar products more accessible for end users. These innovations, among others have attracted several investments into the industry in the past years. In 2019 alone, a UK-based PAYG solar company operating in East and West Africa was backed by Japanese Mitsubishi with $50 million to expand its company's operations in the region (F. Sadouki, pers.comm., 2019).

East Africa has some of the leading markets for PAYG solar products, and the model is also being used increasingly in many West African countries. However, the majority, if not all, of the off-grid PAYG solar products sold in East and West Africa, among other regions, are sourced through importation from China. The off-grid PAYG sector of the solar industry follows the same international off-grid quality standards as the

rest of the industry to ensure sustainability and achieve customer satisfaction, while also protecting the off-grid market from substandard solar products. This approach helps support investment and innovation in the off-grid solar market, including within the PAYG solar segment of the industry.

While many products perform well and provide valuable services to end users, end users still experience product failures or other problems that reduce the level of service they receive from off-grid solar products. Failures can be due to many factors, including use patterns, environmental conditions, product handling in the supply chain, and others. The international nature of off-grid PAYG solar products markets, together with its global supply chain, requires a strong quality assurance market surveillance program that expands the process beyond the original laboratory testing associated with the certification process to ensure quality on the market.

By examining and understanding the most common product failures on the market, this research provides suggestions for designing a robust market surveillance program that can be used to strengthen the implementation of quality standards and ensure the quality of off-grid PAYG solar products on the market.

Background

Despite efforts to improve quality in off-grid PAYG solar, there are many quality-certified products that end up failing when they are in use, and in many cases, this shortens the product life cycle. Product warranties are one of the key criteria used for quality certification of off-grid solar products, including PAYG-enabled solar products. To honor the product warranty and keep the customers happy, distributors and retailers are often obligated to replace or repair failed products. This practice increases their after-sales costs and in some cases accumulates solar product waste, especially for products that cannot be repaired or returned to the original manufacturer. According to the 2020 report by Lighting Global on off-grid solar market trends, over 180 million solar home systems and Pico-PV products (also referred to as pico-solar products) have been sold globally since 2010, but only about 84 million remain operational (GOGLA, 2020). This leaves over 94 million products in accumulated solar waste, and, in cases where products have failed prematurely, buyers and users may have experienced disappointment.

The upfront cost of quality certified products is typically higher than the cost of non-quality certified solar products (Eric et al. 2001), and this is also true for the long-term cost for PAYG solar products since extending payments over time involves costs associated with overhead and the interest rate. While solar distributors and retailers may face some losses when more products than expected fail in the market, especially those that fail within the warranty period and may need replacement, consumers are strongly affected by product failure regardless of the payment terms. When products fail,

consumers are forced to go back to using their previous methods of lighting, which are often kerosene lanterns and candles, or bear the darkness until the product is fixed or replaced by the distributor. In the case of PAYG products, some customers are expected to continue paying for the product even when it has been taken for repair (Guajardo, 2021).

To ensure that quality monitoring for off-grid PAYG solar products is continued in the market, the recommendations in this research are focused on designing a market surveillance program that addresses common failures of PAYG solar products as identified through this study, as well as issues that are already being addressed through existing market surveillance protocols. Successful implementation of a market surveillance regime has the potential to help make the off-grid PAYG industry more impactful and sustainable, as well as attract more innovations and investments into the sector.

The first chapter of this research focuses on introducing the study with a brief background of the importance of quality assurance in energy access using distributed off-grid PAYG solar products. Chapter Two includes a summary of previous literature from different scholars and articles on the research topic. In Chapter Three, I describe the methodology used in the analysis of the data for this study. The results of this analysis are included in Chapter Four. The presentation of the research ends with a discussion of the results in Chapter Five, followed by recommendations and conclusions in Chapter Six.

CHAPTER 2. LITERATURE REVIEW

Off-Grid Energy Access

Extending the centralized grid system to electrify off-grid communities remains a challenge, especially in Sub-Saharan Africa. In 2015 the United Nations announced the Sustainable Development Goals (SDGs), one of them being "Goal 7: Ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030" (UN, 2015). Since then, many countries in East and West Africa, among other regions, have established ambitious goals to maximize electrification. However, connecting rural communities to the centralized grid system is close to impossible for many, especially in countries where the majority of people that lack electricity access live in hard-to-reach rural communities. In Uganda's vision for 2040, the country set an ambitious national electrification target of 80% electricity access by the year 2040 (Uganda NPA, 2017). In early 2018, the Kenyan government, working together with World Bank, launched a Kenya National Electrification Strategy for 100% electricity access by 2022, and by the end of 2018, the country had increased its access to 43% from 32% access in 2014 (Akurut, 2018).

Africa receives some of the highest levels of solar radiation globally and is endowed with many other natural resources (Mahboob, 2014). Many African countries, especially in the Sub-Saharan region, have adapted to off-grid solar to address the electrification challenges and meet set targets. Distributed solar is one of the main off-grid solutions used in many countries, especially in East and West Africa, to solve

electrification challenges (Baurzhan and Jenkins, 2016). There are mainly three options used in many of these countries to provide electricity services to areas lacking grid connectivity. They include Pico PV (solar lanterns and other systems with solar modules rated at 10 watts or less), solar home systems (SHS), and micro-grid systems. Below, in Figure 1, Figure 2, and Figure 3 are examples of Pico PV (single lantern and small solar kit), a solar home system, and a micro-grid system respectively.

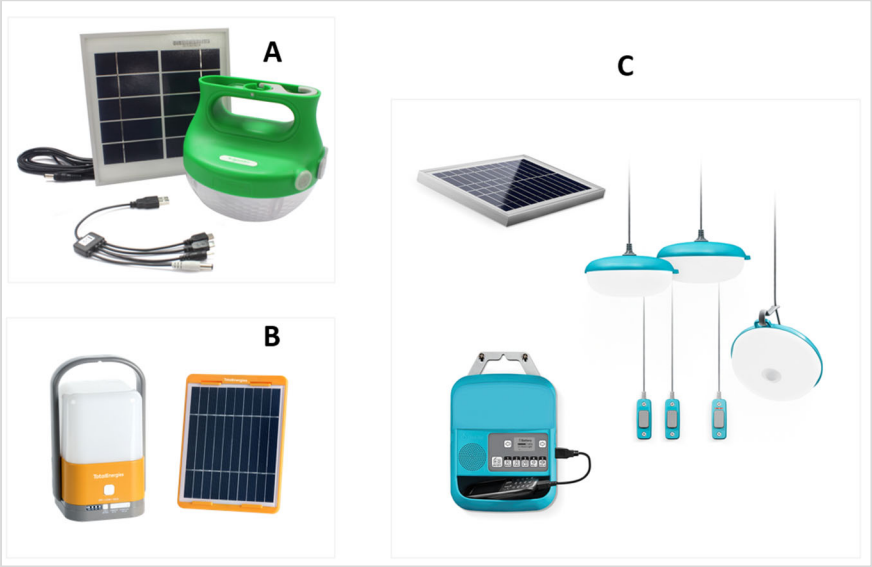

Figure 1. Examples A, B, and C show Pico-PV products with different components. "**A**" is a single Pico-PV lamp with mobile phone charging accessories and a 3.4 watt solar panel. "**B**" is a single Pico-PV lamp and a 2.9 watt solar panel. "**C**" is an example of a Pico-PV system with multiple lights and phone charging with a 6.3 watt solar panel. (Source: VeraSol product database).

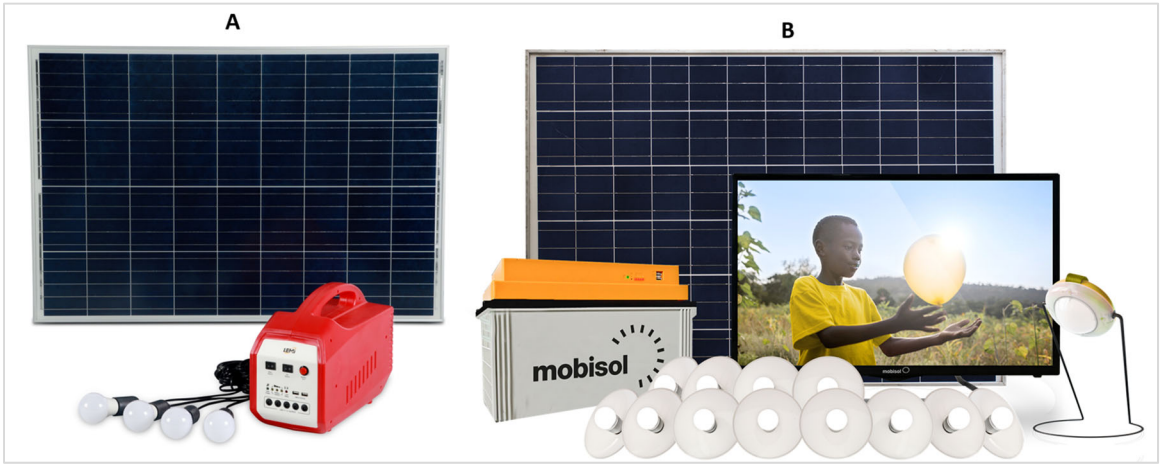

Figure 2. Examples of a solar home systems with different components. “A” is a solar home system with multiple lights and a 79 watt solar panel. “B” is a solar home system with multiple lights, a television, and a 200 watt solar panel. (Source: VeraSol product database)

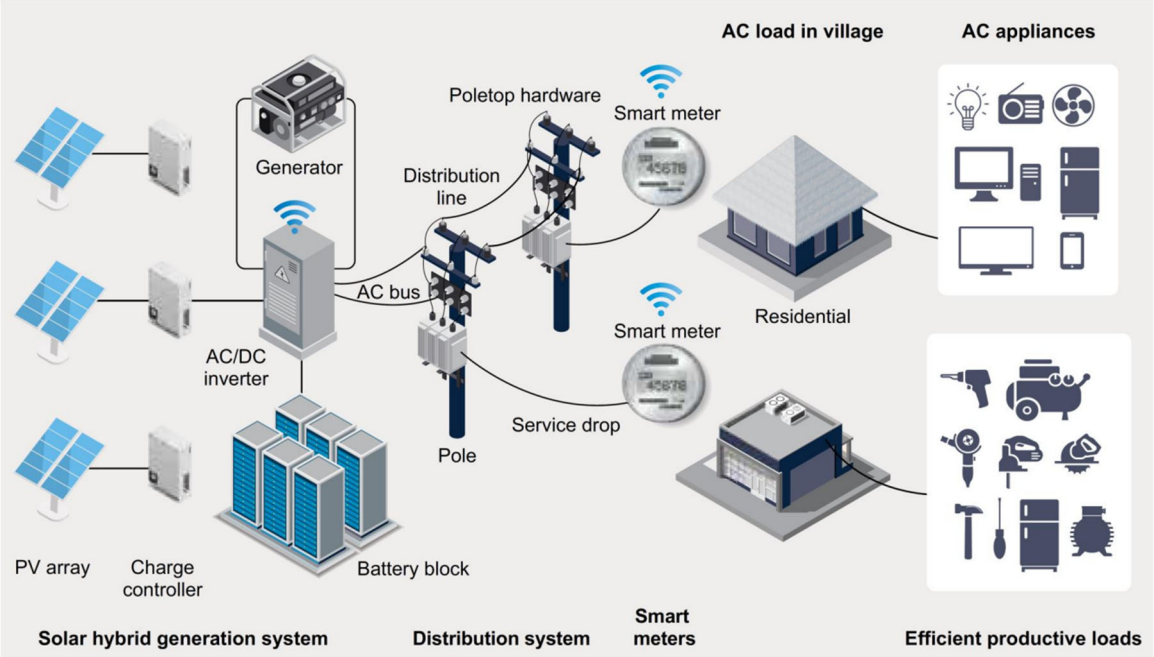

Figure 3. An example of a stand-alone micro-grid system commonly used in Africa and other parts of the world to provide power to remote villages. The system consists of a solar hybrid generation system i.e., PV array, charge controller, battery storage, AC/DC inverter, and generator, a distribution system i.e., poles, AC bus, distribution and lines, a smart metering system, and loads i.e., residential, and commercial loads. Note: AC is alternating current, DC is direct current, and PV is photovoltaic. (Exel, 2020).

These products have been categorized into a multi-tier framework with five tiers by Sustainable Energy for All to help distinguish the different levels of off-grid solar PV access (Rysankova et al., 2016). They are classified according to energy capacity, the number of components and appliances they can power, as well as the run time after a full solar charge, as shown in **Error! Reference source not found.** below.

Table 1. A multi-tier range of off-grid solar PV products and powered appliances. (Rysankova et al., 2016)

	Tier 1	Tier 2 & 3	Tier 4 & 5
Definition	Task lighting and phone charging 4 hours of power/per day 1 hour of power/evening	General lighting, phone charging, television, and fan (if needed) 4 hours of power/day or 8 hours of power/day + 2 hours of power/evening or 3 hours of power/evening Electrical lighting, air circulation, television, and phone charging are possible Any medium-power appliances	Mini grids with a capacity of 5.5 KW to 15KW
Technology	Solar lanterns	Stand-alone solar home systems	Utility-scale generators/mini-grids
	Pico-PV Systems <10.999Wp	solar home system >11Wp	solar home system >11Wp

	Tier 1			Tier 2 & Tier 3			Tier 4 & 5
Category	Single Light only	Single Light & Mobile Charging	Multiple Lights & Mobile Charging	SHS, Entry Level (3-4 lights, phone charging, powering radio, fan etc.)	SHS, Basic Capacity (same as for Entry Level system, plus power for TV, additional lights, appliances, and/or other additional capacity)	SHS, medium capacity (same as for Basic Capacity system but with extended capacity)	SHS with higher capacity (similar to medium capacity SHS but with extended capacity).
Solar Module Capacities	0 - 1.499 Wp (Indicative)	1.5 - 2.999 Wp (Indicative)	3 - 10.999 Wp (Indicative)	11 - 20.999 Wp	49.999 Wp	50 - 99.999 Wp	100 Wp+
Note: A solar lantern meets Tier 1 on the Multi-Tier Framework for a household if it provides at least 1,000 lumen-hours (lm-hr) / day and sufficient energy to keep a well-used mobile phone operational.							

Off-grid solar products, both Pico PV and SHS, have been made relatively affordable and accessible using the PAYG model in East and West Africa, where competition amongst off-grid solar companies is strong and the distribution networks in countries such as Kenya, Uganda, and Nigeria are relatively well-established. This has been made possible through financial inclusion models and flexible payment sales approaches that are allowing customers with low financial capabilities to afford off-grid solar products on installment payments. Working with telecom companies that provide mobile money services, solar companies use the PAYG model for off-grid solar to eliminate the burden of high initial costs for distributed off-grid solar products. Off-grid solar companies are leveraging the PAYG approach to stand out from competitors based on their product offers and payment terms. In the year that kicked off the COVID pandemic (2020), over 2 million off-grid solar products were reported sold using PAYG sales models in East and West Africa combined (GOGLA, 2020).

As customers worry less about the initial cost of distributed off-grid solar products because of the PAYG model, more questions about quality are arising. Last-mile distributors of off-grid solar products spend considerable sums of money on after-sales services, especially product repairs and collection of failed products (Chirumamilla, 2014). As such, they have called on development agencies and foundations to support the sector by enhancing product certification schemes and quality assurance, frameworks improving market intelligence, funding social-impact research, and fostering the use of more harmonized business-performance metrics (Global Distribution Collective, 2019).

With the need to reach last-mile customers in off-grid rural communities, distributors of PAYG solar products face infrastructure challenges, higher costs of transportation and fuel, safety risks, and unfavorable tax and regulatory regimes such as import duties levied or VAT not waived on OGS products (World Bank, 2020).

Quality in Off-grid Solar Products

Emphasizing quality for off-grid solar products, including those that are PAYG enabled, is critical to electrifying off-grid communities and for keeping the industry sustainable. PAYG solar distribution companies incur a lot of costs in after-sales services to make sure that the customer has a functioning product, especially during the payment period which is often between 6 months to 24 months (Harrington, 2021). In some cases where the payment period is longer than 6 months, distributors are forced to exchange failed products for new products to keep their customers satisfied. This comes at a cost for the customer, as they wait in darkness to receive a new product or go back to using the same kerosene lights that they were using before the solar product, and it is also a cost to the distributor in terms of product replacement and the logistics involved. This same arrangement applies to products that break down within their warranty period. There are also incidences where failed products are just left to the customer to deal with, especially if they live in hard-to-reach places. Ethnographic research by Cross and Murray on the fate of failed products showed that “65% of solar products are kept or left in the home when they stop functioning” (Cross and Murray, 2018).

In efforts to make off-grid solar products more "safe, affordable, and durable," VeraSol, an evolution of World Bank Group's Lighting Global Quality Assurance program, evaluates products to ensure that they meet quality standards for off-grid PAYG and non-PAYG solar products. The standards are published by the International Electrotechnical Commission (IEC), and product warranty requirements are one element that is covered by the IEC standards (VeraSol 2021). While it is not easy for off-grid customers to fully understand all the technicalities of the established quality standards (IEC, 2020) to know what to look out for in quality-certified products, most customers understand the value of a warranty and often associate quality with warranty terms. Customers trust products with a long-term warranty, often 1 year and above, to be of high quality (Davies, 2018). It gives them a certain level of confidence in their purchase decision that the product they are buying will perform and last for at least 1 year. Manufacturers that wish to have their solar products tested and certified under the VeraSol quality assurance program are required to offer warranty on their products, and this helps to create product trust with customers and distribution channels. However, it is also common for the distribution channels to not honor the manufacturer's warranty due to the difficulties and costs associated with providing warranties, especially for customers in far-to-reach areas (Lighting Africa, 2013).

PAYG Solar Products#

Electrifying off-grid communities in East and West Africa among others globally is riddled with multiple challenges, many of which are financial or geographical access related. The introduction of digital financing through mobile money services, especially in East Africa, has increased financial inclusion in the area, and, according to a market research report by Lighting Global, it is one of the key trends driving the development of PAYG as an alternative business model for energy access (Alstone et al., 2015). Mobile money allows off-grid customers to store finances and make transactions remotely using mobile phones with different mobile telecom networks. This financial inclusion model has digitalized energy financing by aiding a PAYG business model that allows low-income customers to access and pay for PAYG-enabled off-grid solar products remotely in installments. According to research funded by United Nations Capital Development Fund to assess the correlation between digital financing and energy access in Uganda, over 5 million mobile money transactions were made by PAYG solar customers in the December of 2018 alone (Jain et al., 2020).

Since its introduction in Kenya in early 2010, the PAYG business model for energy access has registered many successes and has since been adopted by several solar energy service providers across several countries that struggle with energy access (Lepicard, et al., 2017). The model is also being adopted for the provision of other energy services such as clean cooking technology and solar appliances (Perros et al., 2021). The model has especially been vital to energy access during the COVID pandemic that put

most businesses in a fully remote operation. According to the 2021 global off-grid solar market report by the global association for the off-grid solar energy industry (GOGLA), over 343,000 units of off-grid solar products were sold via PAYG in the second half of the year, amounting to a 79% increase in PAYG sales relative to the second half of 2019. Globally, out of the 4 million units of off-grid solar products sold in the same period, 1.53 million products were PAYG solar sales (GOGLA, 2021). It is important to note that East and West Africa had a significant contribution to the overall off-grid PAYG solar sales and continue to influence uptake.

While non-PAYG solar products customers can just pay cash to a retailer and go with their products, this upfront cash sales model limits product access for people facing financial poverty. To increase affordability, off-grid PAYG products transactions can be done without requiring a full upfront payment for the product. However, there are extra purchase steps taken to complete the transaction. It is important to note that while the digital transaction process is often similar for most off-grid PAYG solar products between tiers 1-5 (see Table 1 for a description of the tiers), different retailers may require other steps to complete the transaction. Some of the steps may be related to a creditworthiness assessment that differs by the retailer. **Error! Reference source not found.Error! Reference source not found.** below is an example of typical steps that are taken to purchase a PAYG solar product, in this case for a PAYG firm called Angaza.

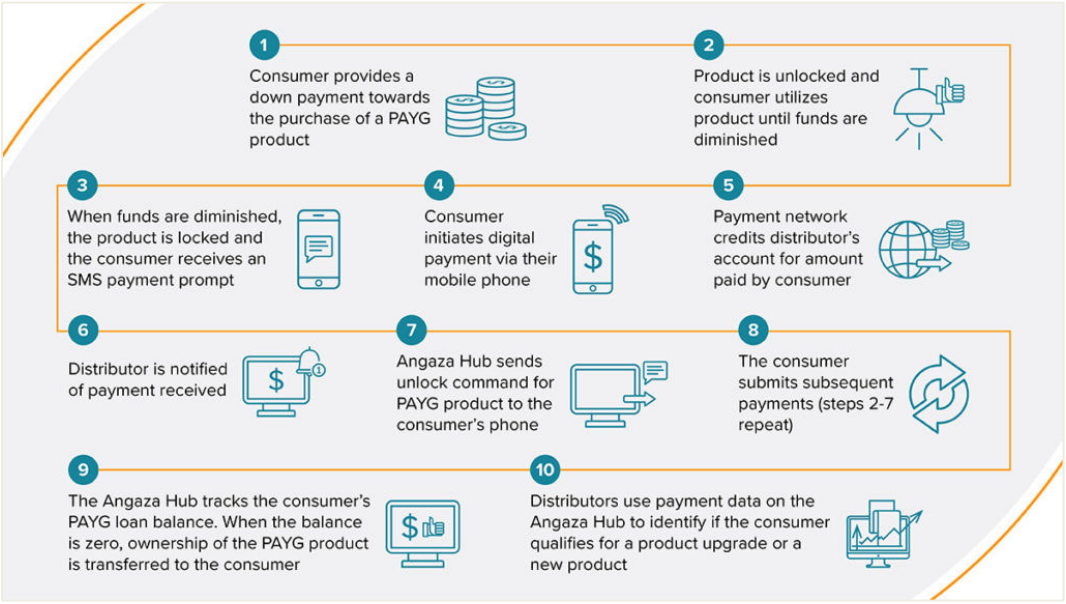

Figure 4. How PAYG works in off-grid solar. (Angaza, 2019)

Addressing Quality in PAYGO products.

As the PAYG business model is expanding rapidly to increase energy access through sales of distributed off-grid solar PAYG products, especially in East and West Africa, among other places globally, it is important to think about the quality of PAYG-enabled off-grid solar products to make the model sustainable in the long term.

Lighting Global, an initiative of the International Finance Corporation and the World Bank, established a global quality assurance framework for off-grid solar products beginning in 2009 (Lighting Global, 2016). In 2020, this program was renamed VeraSol, and it is managed by CLASP and the Schatz Energy Research Center (VeraSol, 2021). Aimed at increasing access to off-grid solar, Lighting Global established quality standards and policy guidelines for distributed off-grid solar products in 2009. These

standards applied to non-PAYG solar products, and they required manufacturers to meet certain product quality standards (Lighting Global, 2014). While some of the requirements for non-PAYG solar products were easily transferable to PAYG-enabled off-grid solar products, in 2015, Lighting Global published modifications of the standards to make them more compatible with PAYG products (Lighting Global, 2015). These revised requirements and policies included approaches that manufacturers of off-grid PAYG solar products could take when a solar product is sold through a PAYG business model.

The program also introduced a PAYG market check testing framework to ensure "…the basic functionality of PAYG features for solar energy kits sold in the intended location of use for the PAYG functionality" (VeraSol, 2020b). The procedures test whether the PAYG features function as intended for the target market before the products reach the end-user. However, a lot happens to the products between the end-user and the retailer/distributor, given the usually unstable road infrastructure and transportation means used to reach last-mile customers. Because of this and many more reasons, quality assurance programs need to establish a robust market surveillance program that samples and tests products at the end-user level to make sure that products that are already quality certified continue to function as intended when they reach the end-user.

A market surveillance program will help strengthen quality assurance and testing procedures to protect end-users, distributors, suppliers as well as the environment, especially with the currently increasing number off-grid PAYG solar companies and

products making waves in Sub-Saharan Africa. The complex nature of off-grid PAYG-enabled solar products puts them in a special position that requires quality standards, testing, and market check policies that are specific to PAYG products. As involved as the PAYG solar product procurement process might seem in Figure 1, above, off-grid PAYG solar products often have features and components that require extra knowledge that users need to understand to use the product correctly. Some of these special features include PAYG operating software for service activation when customers make payments for the product and when service is cut off due to non-payment, the ability to charge via solar PV when services are cut off, PAYG metering accuracy, a keypad to enter action codes when a customer makes a payment, and a PAYG screen that shows the number of days left before the cutoff. Other elements that customers and distributors must navigate to operate a PAYG solar product may include:

- Payment Steps that may involve a scratch card or payments to agents for top-up codes, or mobile money payments using available mobile money network systems, usually from a local telecom company.
- Steps for activating the PAYG solar product when payments are made. This may involve using a manual keypad entry for top-up codes, internal GSM-enabled circuits that send and receive data from remote servers, or a connection with other devices such as smartphones that enable confirmation of payment.
- Metering and enforcement that involves internal circuitry that compares information on payments received and the number of units consumed and disables/enable system operation remotely.

This makes such systems susceptible to wrongful handling on the market, which sometimes compromises the quality and product lifespan. It is important to note that some features for some off-grid PAYG solar products may differ by manufacturer product design.

Challenges Associated with Implementing Quality Standards for PAYG Solar Products

This section of the literature review explores existing information on the challenges associated with implementing quality standards and test methods for PAYG solar products, especially those sold in East and West Africa. It is important to note that this subject in the industry has not been broadly explored in the literature, and there are very few reports and articles previous scholars on this topic. As a result, the information presented is mostly based on personal experience in the industry and my work at Schatz Energy Research Center.

The PAYG model is a key determinant of quality in off-grid solar for end-users among other things and it plays a big role in helping customers make purchase decisions (Jain, 2020). The model gives confidence to customers that products will be of good quality and serviced on time when needed because the full payment is made in installments, incentivizing the companies to make sure that the products keep working at least until the end of the payment period. However, the internal mechanics of an off-grid PAYG solar product are much more complex than that of a non-PAYG solar system. Yet

still, the current quality standard and testing approaches for solar PAYG products are mostly similar to those that are non-PAYG off-grid (VeraSol, 2020c).

The complexity of off-grid PAYG solar products makes it logistically challenging to set quality standards and testing approaches for a comprehensive quality assessment process. PAYG solar product developers are not restricted in how they design and assemble the products in ways that go beyond the standards previously put in place for non-PAYG solar products. As long as the standards are met, PAYG solar designers and manufactures can design the product, including both hardware and software aspects of the product, as they see fit. This means that existing or previous users of PAYG solar products may not fully understand how to use any other PAYG solar product based on experience with products from one manufacturer. For instance, some manufacturers of PAYG solar products prefer to use an inbuilt keypad on the product battery for PAYG code activation, while others use connectable wires that can be connected between a mobile phone and the PAYG solar product for code activation after making installments. Some PAYG solar products have separate external keyboards/pads, among other methods for PAYG activation. This makes it difficult to set quality and testing standards that cut across all different designs. Figure 5 below is an example of PAYG solar products with differences in the keypad design.

Figure 5. "PAYG system A" is an example of PAYG solar system with an inbuilt PAYG activation keypad attached to the battery (Power Solution, 2021). "PAYG system B" is an example of a system with an external keypad that can be attached and detached from the system using a USB cable and port (SolarWorx, 2019).

For end-user management and product monitoring for off-grid PAYG solar products in East and West African, products are monitored and activated using PAYG software that is sometimes supplied to the solar manufacturers by an external software developer (Junio, 2021). Recently, there has been an effort in the sector to decentralize PAYG software, with some PAYG solar manufacturers and distributers designing their own custom made PAYG software to fit their operations and product line with the aim of reaching ambitious sales goals (d.light, 2016). This means that setting quality standards that evaluate all aspects of a PAYG solar system requires understanding not only the varying hardware designs but also the software used. This represents a challenge, as assessing the performance of software can be time consuming and costly.

Solar manufactures and distributes also integrate and partner with local telecom companies to manage mobile money payments. This is intended to provide end-users

with an easy and convenient means of making payments for the products. While this is a great step towards increasing energy access and financial inclusion, PAYG software and mobile money software can differ by country and by telecom company, and there are currently no quality controls related to mobile payments in the existing standards and testing methods for off-grid solar sector. Fully incorporating PAYG aspects in the quality standards and test methods for off-grid solar would require a clear understanding of the integration between PAYG solar companies and telecom companies and the software they each use, which can be challenging based on the differences between the sectors and the quality standards that govern each of them.

As part of the baseline standards for off-grid PAYG solar set by IEC and used by VeraSol, the manufacturer is required to include customer-facing information about the product in a language understandable by the end-user. PAYG solar products are often sold in rural areas where many people are not literate and can only speak their native language (i.e., they cannot speak internationally used languages such as English or French). In some instances, customers might be able to speak the officially recognized language of the country, but they are unable to read it. While manufacturing companies might try to fulfill this requirement by including information in a nationally recognized language, most of their customers are unable to read and understand the information on the product which could potentially lead to product mishandling. Additionally, some manufacturers sell the same product in different regions of the same country, and African countries in East and West Africa are known for having multiple languages spoken in

different regions. This makes it hard to set a standard that caters to all these language needs.

Products are used in varying weather conditions across countries where these products are sold. While market research can help manufacturers and standards organizations come up with quality standards and test methods based on the expected environmental conditions the products may experience, the weather can differ significantly by region, even within a given country. This makes it hard to design products for all the different weather conditions where they may be used while keeping the cost of the products low to enable affordability.

Government policies and regulations are also limiting factors when it comes to setting quality standards for off-grid PAYG solar products. While some countries have some set quality standards for off-grid PAYG solar, primarily through adoption of the IEC set standards, the majority of countries do not have any regulations or policies governing quality in off-grid PAYG solar. Many countries in East and West Africa still have the majority of their population not connected to the grid and are looking to off-grid solar to cover that gap. By so doing, restrictions on solar products that can be sold in the country are loose, which enables private solar companies to distribute off-grid solar products. And with much of the population in such countries being financially poor, PAYG is the most financially viable approach for many countries in East and West Africa to electrify these populations, hence keeping the policies and regulations on quality relaxed to allow more investment into the industry. This makes it difficult for

external quality assurance bodies to broaden and implement quality standards for off-grid PAYG solar products.

The International Electrotechnical Commission (IEC) battery technology standards and quality certificates do not consider PAYG functionality in off-grid solar products. IEC 60086 is an international standard that encourages battery manufacturers to ensure that their batteries are interchangeable according to standard form, fit, and function, but it is not specific to PAYG solar products. Many solar products use lithium-ion batteries to store energy, but batteries can easily drain when left unused and require charging. When customers for off-grid PAYG products fail to pay the required minimum cost to keep the lights on, the product ceases to work, and in some cases, the battery is unable to charge because the connection to the solar module is switched off. In some cases, the battery is unable to work due to product programming and in others, the customer is not incentivized enough to keep charging a product that is no longer useful to them. While both IEC and VeraSol have battery quality standards in place, there haven't been any requirements for manufacturers and distributors of off-grid PAYG products to encourage the user to continue charging their product battery even when it cannot provide the full services they require from it.

The communities where PAYG products are sold are ignorant about quality standards for PAYG and the associated certification bodies. As such, instead of looking out for products that are certified to meet standards before making the decision to buy, they look for affordability and flexibility from the seller as key determinants in their

purchase decision. This leaves room for consumers to buy substandard PAYG products if they can get them cheaply or on credit.

As the off-grid PAYG solar industry expands with more investors and manufacturers coming on board, it is easy to attract substandard and copy-cat products if they sell on a PAYG basis. While a PAYG-centric quality testing and certification approach is helping to guide manufacturers on basic quality standards, a robust market surveillance program focused on PAYG solar products can help ensure that the users and distributors are receiving the tested and certified quality products and can help weed out substandard products and copy-cats.

CHAPTER 3. METHODS

This chapter details the data collection process, analysis, and data utilization for this research. The challenges faced during the data collection process are also presented in this chapter. Key resources for this research include data sets from previous research on off-grid solar product quality, along with information from test laboratories and distributors of off-grid PAYG solar products in East and West Africa. Given the COVID 19 pandemic, information sessions held with solar manufacturers and distributors were done via Zoom calls in which company representatives especially from the product development and customer experience departments shared their experiences with product failures experienced on the market based on the company's product line.

Data Collection and Sampling

As it is a key player in off-grid solar quality standards, testing, and certification, this research utilizes data from the VeraSol quality assurance program to understand the common product failures both in the market at the end-user level and through testing at the laboratory level. This data was made available through the Schatz Energy Research Center, where I have worked on the quality certification process and off-grid solar policies through the VeraSol initiative.

Kenya Data on Product Functionality

This research utilized VeraSol data collected from previous research on off-grid PAYG solar product functionality in the Kenya solar market (VeraSol, 2021). Kenya has the largest number of off-grid PAYG solar products in use in the East African region. It is also a pioneer of the PAYG model in off-grid solar, making it a viable source for information on product failure in the off-grid PAYG solar market.

Data from Quality Testing

The study also utilized product failure information from laboratory testing of PAYG solar products during renewal testing conducted through the VeraSol program. This data is used to understand the types of product failures identified in the renewal process for products that were previously certified. Additionally, this data helps to understand how solar manufacturers have sometimes made changes or updates to their products post-certification to keep up with sector innovations and how these changes affect product quality. Note that the certification status of products should be renewed every two years according to requirements in the international standards in IEC 62257-9-8:2020.

Information from PAYG Solar Manufacturers and Distributors

To supplement the two sets of data from VeraSol, this research used information from conversations with PAYG solar manufacturers and distributors in which they shared the most common product failures they observe in products that come back for service from end-users and warehouses on the market. Participants for this category of contributors were selected based on the choice of market for their off-grid PAYG solar products i.e., East and West Africa. However, it is important to note that all of the manufacturers and distributors that were spoken with had their products manufactured and designed in places other than East and West Africa.

With some already established contacts in the sector from previous and current work engagements, all participants that contributed to this research to provide information and data on off-grid PAYG solar product failure were opportunistically selected among the contacts in my energy sector network. This also includes some people representing organizations that directly participate in the VeraSol quality assurance program.

Selection of participants as off-grid PAYG solar manufacturers and distributors was based on the following criteria.

- Manufacturers and distributors had to be off-grid PAYG solar distributors, either as a company that focuses on product distribution/retailing or a solar product manufacturer that is also doing their distribution/retailing with a solid establishment in East and/or West Africa.

- Participants were picked based on the legal status of the business in the country of operation in the region/s of choice. That is, they had to be legally registered distribution companies in the country of operation with an established after-sales service team in the country.
- Companies had to have the ability to offer and honor customer warranties. This was important to ensure that they could provide information regarding how off-grid PAYG solar companies address aftersales services.
- Participants had to have the ability to document after-sales services offered to end-user customers in terms of product repair or product replacement for products under warranty.
- Manufacturers and distributors had to be dealing VeraSol/Lighting Global certified off-grid PAYG solar brands. Information about product failures for certified products was used to help develop suggestions for improvements in the quality standards certification process and the design of market surveillance programs.

Data Analysis and Presentation

Data analysis for this research was conducted using Excel data analysis tools, and the finding are presented in a graphic and narrative format. Due to confidentiality, individual brand names and the names of the distribution companies that were part of this research are not disclosed in this report. However, should any participating company

wish to learn about findings related to its product brand, a request can be made in writing following the guidelines on formal protocols for information disclosure in Appendix A.

Data Utilization

To inform the recommendations for formulating guidelines for designing a robust market surveillance program that effectively tracks quality standards for off-grid solar products, the research analyzes common product failures in off-grid PAYG solar products as an initial step in the analysis. The study analyzed data from a survey conducted in Kenya by VeraSol to understand quality in the Off-Grid Solar Market (Verasol, 2021), data from 2019 to 2021 on the outcomes of laboratory testing from VeraSol product renewal tests, and information from industry practitioners. Furthermore, the study examines current market surveillance efforts by VeraSol, including market check testing and product renewal testing procedures. An output of this assessment is a set of recommendations on approaches and considerations for designing a robust market surveillance program that addresses common PAYG solar product failures observed in the market.

Key Variables from the Kenya Data

Given that Kenya is the country with the largest sales of PAYG off-grid solar products, the study uses data from the VeraSol end-user product survey that was conducted in Kenya in 2021 as a key variable in the analysis of the common failures in off-grid PAYG solar in the East African market (Verasol, 2021). It is important to note

that similar products that were considered in this evaluation are among the products sold in West Africa as well as other regions globally. To understand the common failures in off-grid PAYG solar in East Africa and West Africa, the study analyzed a sample of 297 off-grid solar products, classified as Tier 1 and Tier 2 according to the Sustainable Energy for All Multi-Tier product framework, which includes energy systems that can provide power between 4 hours to 8 hours a day and between 1 hour to 3 hours in the evening, respectively (Rysankova et al., 2016). The analyzed products were reported to have been purchased on a payment plan between the years 2016 and 2019. See Table 2 for product classification. These off-grid solar products include VeraSol quality certified products and non-quality certified products that were reported to have been purchased on a payment plan. While the analyzed products were all sold on a payment plan basis, 73% of the total products analyzed in the study were sold as off-grid PAYG solar products and 27% were sold on installment plans that were non-PAYG as shown in the Table 2 below.

Table 2. Total sample of products used for the study, classified by payment plan type. (VeraSol, 2021) n=297

Payment Plan	**Totals Products Per plan**	**%**
PAYG	218	73%
Non – PAYG (Payment Plan)	79	27%
Total Sample Products (n=297)	**297**	**100%**

While both the PAYG and non-PAYG Off-grid solar products that were used for this analysis were sold on an installment payment plan, products sold under PAYG often have more formal procedures that companies and customers follow during the product purchase for accountability purposes between the two parties. Table 2, above, classifies

the products in the sample used for the analysis as PAYG and non-PAYG to help understand the difference between product failures that are encountered on products that are sold on the PAYG basis and those that are sold on a payment plan that is non-PAYG.

Consumer Demographic by the Source of Income

While there are some differences in typical weather conditions between Eastern and Western Africa, the user demographic remains relatively similar, where the majority are farmers and casual laborers often living in peri-urban and rural areas. This implies that the findings of this data may be applicable to both East and West Africa, with some potential for difference in failure types that occur as a result of weather impact. Table 3 below shows the main ways that product customers source their incomes.

Table 3. The main income source for the customers using the products that were analyzed. (VeraSol, 2021)

Users by grouping	**Total per year**	**%**
Casual Laborers	125	42%
Formal Employees	23	8%
Farmers	147	49%
Unemployed	2	1%
Total	**297**	**100%**

Based on the demographic analysis above, most of the products used for the study analysis were bought by households that included farmers (49%) and casual laborers (42%). With this in mind, we can assume that the majority of products assessed in the analysis were sold to low-income earners that require much protection when it comes to the quality of off-grid PAYG solar products.

Annual Product Sample

While the survey collected data from products bought between 2012 and 2021, for the purpose of this study, only products that were bought between 2016 and 2020 were considered for the analysis as shown in Table 4, below. This is because products purchased during this period are assumed to still be in the product functionality window of the battery life span and are expected to still be functioning. It should, however, be noted that there are products that were considered for the analysis where customers did not remember the date of purchase, and these are marked as "others" in Table 4. Products were also categorized based on the type of products purchased for each year. This includes solar lanterns (SL), which are a type of Pico-PV system that consists of a standalone single solar lamp with or without phone charging, solar kits (SK), which are a type of Pico-PV system with multiple lamps that can be connected permanently in the house, and solar home systems (SHS), which are have solar modules larger than 11 watts and are often characterized by having several lighting points and the ability to power multiple appliances. This was done to help understand the types of failure encountered for each product category.

Table 4. Products sampled for each year from 2016 to 2020. (VeraSol, 2021)

Product Category	**2016**	**2017**	**2018**	**2019**	**2020**	**Others (Forgotten Dates)**	**Total Products**
Solar lanterns (SL)	2	0	2	10	13	9	36
Solar kits (SK)	3	10	11	16	34	26	100
Solar home system (SHS)	9	12	17	29	64	30	161
Total per year	**14**	**22**	**30**	**55**	**111**	**65**	**297**

Out of the total 297 products that were used for the analysis, 54% of the products were SHS sales, 34% were solar kits, and 12% were solar lanterns. It should however be

noted that the total sample in each product category does not necessarily reflect the ratio of off-grid solar products sold on the market. In practice, there are more solar lanterns sold each year in Kenya compared to solar kits and solar home systems. However, for the purpose of this research, only products that were sold on PAYG or any other payment plan other than PAYG were considered, and it is more common for solar lanterns to be sold on a cash basis. Additionally, the products in the sample are those that end-users reported having a problem or having had a failure at one point. It is possible that some categories of products sold on a payment plan had a larger prevalence of problems than others, and this would also influence the numbers in the study sample. Finally, it is also important to note that many of the products used in the analysis were sold in 2020, which implies that they had only been in use for 1.5 years or less at the time of the survey.

The Two-Year Analysis

As part of the quality standards, VeraSol quality-certified products are required to have at least a 1-year warranty for Pico-PV products and 2-year warranty for solar home systems. The warranty is to be extended to the end-user at the time of product purchase. However, the offered warranty on products that are sold on a payment plan often varies between 1-2 years. Some VeraSol quality-certified products offer up to a 2-year end-user warranty on their products. The 2-year warranty is sometimes offered on the full product with its components or on some components of the product. To understand the impact of warranty and quality certification on the common failures of PAYG solar products, the study analyzed data for products sold between 2019 and 2020 in Table 5 below.

Table 5. The two-year product analysis for common failures in the early stages of the product for the years 2019 and 2020. (Source: VeraSol, 2021).

Type of product owned	SL	SK	SHS	Total Products Sold
Total # of products bought in 2019 and 2020	23	50	93	166
Total QV Products	22	48	89	159
Total Non-QV	1	2	4	7
QV Products that are PAYG	6	41	50	97

Based on the available data, 56% of the 297 products analyzed were sold between 2019 and 2020, and, of those, 96% were VeraSol quality certified, and 4% per not quality certified but sold under a payment plan. Out of the total VeraSol-certified solar products in the analysis, 61% were sold on a PAYG basis. Considering the requirement in the quality standards used by VeraSol that Pico-PV products must include a one-year warranty and solar home system kits must have a two-year warranty, some of the products in the two-year analysis, especially those sold in 2019, could be assumed to have been out of warranty or to have had a small amount of time left on their warranty. However, the five-year analysis shows that most products in the overall analysis were sold in 2020. Based on this, we can assume that 2020 had the highest contribution to the products analyzed in the two-year analysis, i.e., 2019 and 2020. With this assumption, we can further assume that majority of the products in the two-year analysis still had at least 6 months remaining on their product warranty.

Quality Certification Status of the Sample Products.

To further understand the impact that quality verification and certification have on product failure at the end-user and at the market level, the study classified the total sample products into quality-verified/certified (QV) and non-quality verified (non-QV). These are products that were either VeraSol quality certified or non-VeraSol quality

certified products, respectively. Table 6, below, shows the number of products that were QV and Non-QV.

Table 6. Product classification by quality certification/verification status. (VeraSol, 2021)

QV Status	Sample Number	%
QV	276	93%
Non-QV	21	7%
Total Products	**297**	**100%**

Kenya has the highest uptake for off-grid solar products in Africa, and the market is increasingly keen on quality since the country adopted international standards that are equivalent to the standards used by the VeraSol certification program. This and many other reasons can be used to understand why 93% of the overall products in the sample were VeraSol quality-certified products and 7% were non-quality verified.

Quality Certification and PAYG Status

Some of the VeraSol quality certified products (QV) that were used for the analysis were sold on PAYG and others were sold under payment plans other than PAYG. Additionally, there were products sold on PAYG but not VeraSol quality certified and others that were neither QV nor PAYG but were sold on a payment plan. Understanding the quality verification and PAYG status of the sample data helps to highlight the and focus the failures experienced in quality verified PAYG products so as to recommend suitable solutions to solving the products and help improve quality standards and test methos for PAYG products on the market. To understand how these variations affect the failure of the product on the market, the sample was further classified into those specific categories as shown in Table 7, below.

Table 7. The total number of products evaluated based on quality certification and PAYG status. (VeraSol, 2021)

	QV & PAYG	QV but non-PAYG	Non-QV but PAYG	Non-QV & Non-PAYG (sold on a pay plan other than PAYG)	Total Sample
Evaluated Products by Classification	199	77	19	2	297
%	**67%**	**26%**	**6%**	**1%**	**100%**

Information from VeraSol Renewal Test Data

To understand the common failures that occur during renewal tests for quality certification, the study analyzed data from VeraSol renewal tests for off-grid solar products recorded between 2019 and 2021. The quality testing renewal procedure focuses on products that were previously certified by VeraSol and have already been on the market but are seeking to update their quality certification status after expiration of their original test report (which occurs after two years) or after making some changes to the product. The analysis of common failure modes observed during renewal testing was done by evaluating results from products tested through the VeraSol program.

The results are classified into categories, including the following: (i) a straight pass where the product directly meets the quality standards and is certified on the first test, (ii) a pass after correction where quality gaps as per international quality standards are discovered in the products after the first evaluation, and manufacturers are required to make the changes before the product is certified, (iii) a pass after clarification where the manufacturer is required to clarify some things with the test laboratory, usually language

on the packaging or user manual, before a pass is granted, or (iv) a fail which happens when the product does not meet the quality standards.

For this study, the analysis involved 103 results for products tested between 2019 and 2021, out of which 24% were straight passes, 57% were conditional passes that required correction from the manufacturer, 3% were conditional passes that required clarification, and 16% were fails. Figure 6 below, shows the percentage results by category.

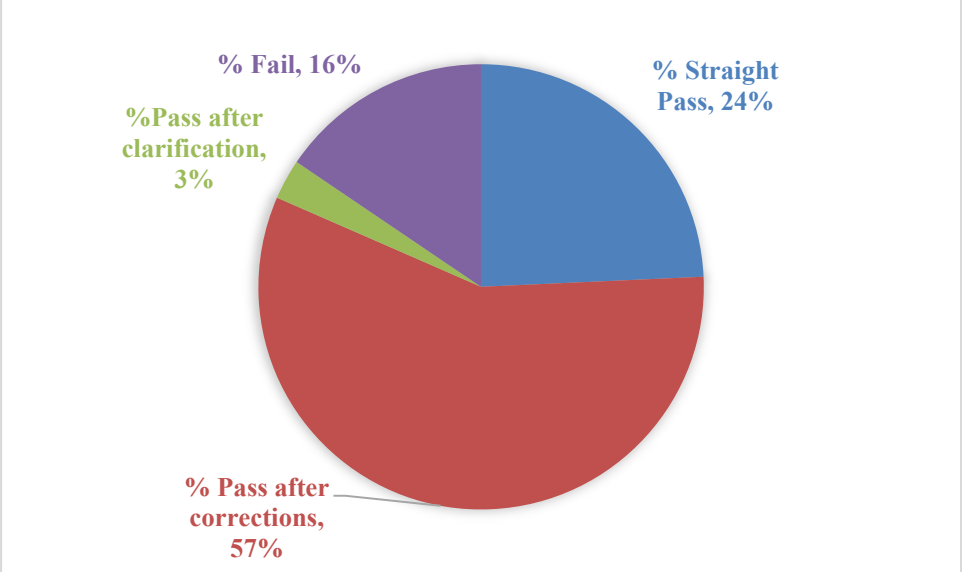

Figure 6. Percentage test results for Tier 1 and 2 solar products tested between 2019 and 2021. (VeraSol, 2021)

The IEC test procedures used by the VeraSol quality assurance program focus on a wide range of functionality in off-grid products, based on the set standards for quality certification. Similarly, failures are categorized based on the established quality standards, and products fail for different reasons. It is possible for one product to fail for

more than one reason. To understand the common failures in off-grid PAYG solar products at test renewal, the study analyzed 173 failures that were reported from the tests conducted between 2019 and 2021 using failure types categorized by VeraSol. One failure category is related to truth-in-advertising (TiA). According to this requirement in the standards, all advertised features associated with a product must be clear, true, and accurate. Relevant parameters for TiA include solar runtime (i.e., operational time after a day of solar charging), full battery runtime, daily energy service, and others. In addition to TiA, some other failure categories include inclusion of customer-facing information, performance reporting, ingress protection, battery durability, and documentation, among others.

Out of all the reported renewal test results reported from 2019 to 2021, 39% were from 2020, with 2019 and 2021 contributing 33% and 28% of the overall results, respectively. Even though most test results were reported in 2020, the highest contribution to the total failures recorded in the data was from tests conducted in 2019, at 38% out of the 173 recorded failures during the three years. The years 2020 and 2021 contributed 29% and 33% of the total failures discovered during product renewal, respectively. Figure 7 below, shows the total number of failures contributed by each year.

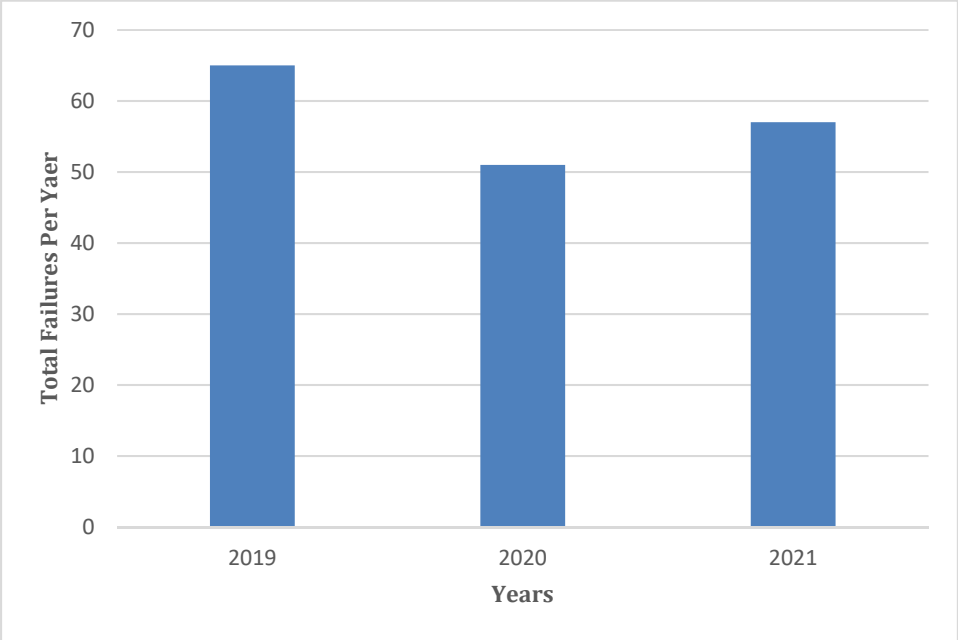

Figure 7. Annual total product failures reported during renewal tests between 2019 and 2021 (data courtesy of VeraSol).

Information Gathered from PAYG Solar Distributors and Manufacturers.

To corroborate the information gathered from the VeraSol data regarding common failures in off-grid PAYG solar products, the study used information shared by a total of 6 distributors and manufacturers of off-grid PAYG solar products to understand the types of product failures that are often reported by end-user and distribution channels in the market. While none of the companies agreed to share their aggregated after-sales service data, the companies were able to provide a contact person who shared some of the company's experiences with off-grid PAYG solar product failure. The people who shared information on behalf of the companies were either senior managers or high-ranking personnel working in product management, after-sales/customer care, or technical/repair and maintenance. All contributions are from PAYG solar companies that are directly or

indirectly selling off-grid PAYG products in East and West Africa. Contributors were categorized into the following: (i) manufacturers i.e., they manufacture off-grid PAYG products and supply distributors/retailers in East and West Africa; (ii) distributing manufacturers i.e., solar manufacturing companies that have direct distribution channels for off-grid PAYG solar products established in East and/or West Africa; and (iii) distributors that buy and sell PAYG solar products in East and West Africa (but do not manufacture the products themselves). Of those who participated in the study, 33% of the representatives were distributing manufacturers, 50% were distributors, and 17% were manufacturers. It is also important to note that all contributors were selling products that are VeraSol certified.

Contributors were asked to share their experiences with respect to failures in relation to specific aspects of off-grid PAYG products, such as the battery, PAYG keypad, software compatibility, overall product user-friendliness, lights, PV cells, connection ports, wiring, and mobile network compatibility with the software operation. However, they were not limited to just the provided options. They were also able to share other PAYG solar product failure challenges that they face on the market, including solar waste management, export of non-functional products, and many others.

CHAPTER 4. RESULTS

This section of the chapter presents the findings from the analysis conducted on the data from VeraSol, as well as the information gathered during conversations with off-grid PAYG solar distributors and manufacturers regarding common failures in off-grid PAYG products on the market. The findings in this section will provide a basis for the recommendations on designing a robust market surveillance program that focuses on improving quality standards and testing procedures for the problematic areas to help strengthen quality assurance approaches for off-grid PAYG solar products on the market.

Common Failures in Off-grid PAYG Solar Products Sold in East and West Africa: Findings from the Kenya study

Out of the sample of 297 off-grid solar products that were sold on a payment plan, 21% reported failures at the time of the interview and 79% were functional. Considering that a large fraction of the products sampled were VeraSol quality certified and PAYG enabled, it is not surprising that 73% of the failures were reported in products that were VeraSol certified and PAYG enabled. Table 8, below, includes information about product functionality based on quality certification and PAYG status.

Table 8. Overall number of products that have had problems categorized by functionality, quality certification, and PAYG status. (VeraSol, 2021)

Criteria	QV & PAYG	QV but non-PAYG	Non-QV but PAYG	Non-QV & Non-PAYG	Total Products	% of Total Products
Products with problems	46	12	4	1	63	21%
Products without a problem	153	65	15	1	234	79%
Total products evaluated	**199**	**77**	**19**	**2**	**297**	**100%**

Of the 199 total quality-certified and PAYG-enabled products, 23% reported failures at the time of the survey while 15% of the 77 quality verified non-PAYG products had functionality problems. As the market continues to embrace quality, non-quality certified products are becoming less common on the market, especially in East Africa. The quality assurance and certification processes need to be strengthened to decrease the number of product failures in off-grid PAYG products that are quality certified.

The failures were further categorized by the type of product being used by the end-user i.e., solar lantern, solar kit, and solar home system. Tier 1 and Tier 2 category products are the commonly purchased products for household use in East and West Africa, and with East Africa, specifically Kenya reporting high numbers of VeraSol quality certified products. Understanding the common failures by product type can help target the improvement in the quality assurance process given that each product serves different needs.

Solar home systems and solar lighting kits often have multiple lighting points. On a full battery charge, they can power other small appliances such as radios, torches, television, fan, and many more. Some manufacturers include the appliances that can be powered by the system as a full kit, with a limit on how much can be powered at a time, while others leave the choice of extra appliances to the end-user with an indication of the system capacity. The systems can also be used for phone charging domestically. But in some cases, especially in remote areas with limited or no access to a stable grid connection, end-users provide cell phone charging as a paid service using their solar system, especially for products bought on a payment plan. With all these different ways for end-users to utilize the energy stored in the system battery, batteries become one of the most vulnerable parts of a PAYG solar product and can easily be subjected to misuses such as overloading. This is especially true if the system is not well-sized for the application and the information provided to the end-user is not sufficient or well explained. Table 9, below shows different identified product failures by product type.

Table 9. Total number of failures identified in each product type. (VeraSol, 2021)

Problem type	Solar lanterns	Solar kits	Solar home system	Total problems
Battery Charge	1	19	14	34
Lighting	4	4	18	26
Non-Functional	1	-	-	1
Switch	-	1	-	1
Other	-	-	1	1
Total failures	**6**	**24**	**33**	**63**

Out of the 33 product problems reported in solar home systems, 55% were light related and 42% were issues with the battery. Solar kits reported 79% battery related failures and 17% light related issues out of the 24 common identified product problems as shown in Figure 8 and Figure 9 below.

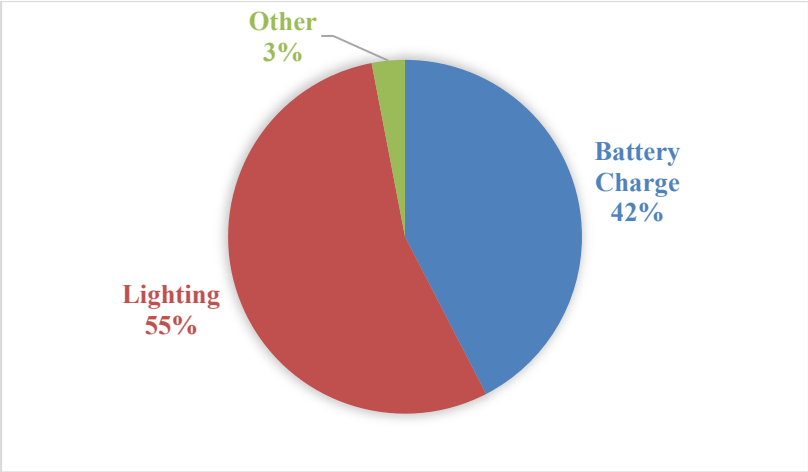

Figure 8. Percentage of common failures identified in solar home systems. (VeraSol, 2020).

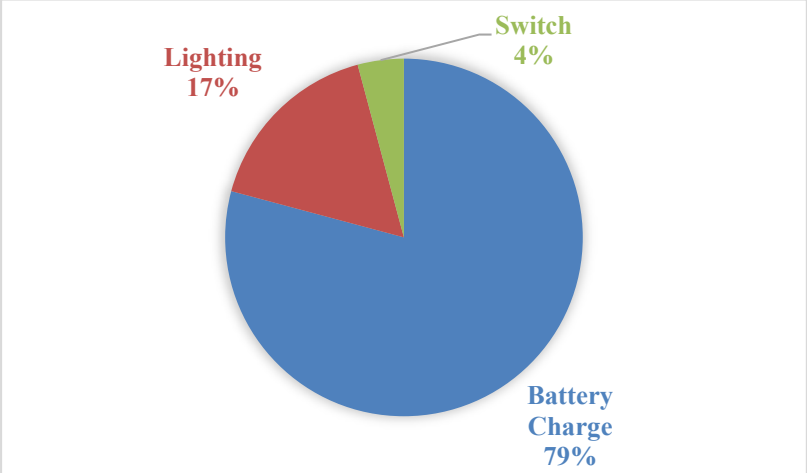

Figure 9. Percentage of common failures identified in solar kits. (VeraSol, 2020).

It is also important to note that the numbers reflected in the sample do not necessary reflect the market share of each of the product category on the market in terms of sales volumes. Solar lanterns have a significantly bigger market share especially in East and West Africa given their relatively lower initial cost compared to solar kits and solar home systems, making it easier to purchase them on cash instead of a payment plan or PAYG. This study is more focused on product failures in PAYG products, including products bought on non-specified payment plans other than PAYG. Products sold on a payment plan are usually have a significantly higher initial cost such as solar kits and solar home systems. In some markets, the ability to sell products on a payment plan or PAYG model symbolizes quality in the product. This assumption can be used to explain the disproportion is sample numbers by product type compared to their market share. Other failures reported from the Kenya market study were switch related and some customers had products that were non-functional.

When asked about the common failures that end users usually face with off-grid PAYG solar products, some users that did not have product problems at the time of the interview indicated they had experienced problems in the past with wiring, especially for the solar home systems and solar kits. Prior problems with switches, lights, batteries, and solar PV modules were also mentioned. End users that experienced battery failures reported their battery not being able to keep a charge for as long as it had in the first few months of operation. In most cases, the interviews occurred 6 months to two years after the product was purchased. Others reported their batteries not being able to charge as fast

in comparison to the first couple of months after purchase, regardless of whether there was sunny weather. End-users that reported problems with lights mentioned issues with flickering lights, lights that were dimmer than they used to be when the product was first purchased, and issues with lights going off abruptly even though their PAYG subscription was still sufficient. Table 10, below, categorizes the different types of product failures reported by quality verification and PAYG status.

Table 10. Identified common product failures by quality verification and PAYG status. (Verasol, 2021)

Type of Problem	QV & PAYG	QV but non-PAYG	Non-QV but PAYG	Non-QV & Non-PAYG	Total Failures	%
Battery Charge	22	8	3	1	34	54%
Lighting	21	4	1	0	26	41%
Non-Functional	1	0	0	0	1	2%
Switch	1	0	0	0	1	2%
Other	1	0	0	0	1	2%
Total failures	**46**	**12**	**4**	**1**	**63**	**100%**

The first two years of the product are very crucial for client satisfaction, especially for PAYG solar clients that could sometimes have 6–24-month payment plans. This is also true for solar distributors and manufacturers, as it is crucial for building the company brand in terms of product quality, customer loyalty, and the Net Promoter Score, which measures the number of existing customers that would be willing to recommend the same products or services based on previous experiences with the company. The two-year data analysis for product failure analyzed 166 products out of the 297 sample products for this study. This represents 56% of the overall sample of products analyzed for reported product failures.

From the overall number of customers that bought products in 2019 and 2020, 87% were new end-users experiencing quality-certified solar products on a payment plan for the first time, and 13% were returning customers that had prior experience using quality certified solar products sold on a payment plan basis but not necessarily PAYG. First impressions and experiences are key in shaping customer loyalty. As such, it is important that customers using a product for the first time do not experience problems with the product. The analysis also shows that out of the 166 products sold in 2019 and 2020, 58% of them were being used by end-users who were experiencing quality certified solar PAYG products for the first time. In the sample used for the study, 65% of the products sold in 2019 and 2020 were quality-verified products that were bought on PAYG either by a returning customer (10%) or a new user (90%).

The data for products bought between 2019 and 2020 show that 17% of the products experienced problems, including issues with batteries, switches, and lighting. This means that 20% of the end-users that were experiencing quality-certified products on a payment plan for the first time had a problem with their product. As noted previously, batteries and lights accounted for the most failure points on the products. It is important to note that out of the two-year sample data, none of the products were reported to be non-functional.

It is important to note that the number of products that were both quality verified and PAYG in the sample were high compared to others. This is mostly because more people are buying more quality verified products on PAYG especially solar home kits

and solar home systems. However, some of the failures reported in quality verified products can also be found on non-quality verified and non-PAYG products and vice versa.

Common Failures in Off-grid PAYG Solar Products Sold in East and West Africa: Findings from the VeraSol Test Renewal Data

There were six major failure categories that contributed highly to the 173 failures recorded from the 103 renewal tests conducted by VeraSol between 2019 to 2021. This is mostly because a product can record more than one failure during quality testing. Some of the common failures include issues related to Truth-in-Advertising as per Energy Service Calculations (TIA-ESC), consumer-facing information, performance, ingress protection, warranty, ports, and battery documentation. See Figure 10, below, for product failure information by category.

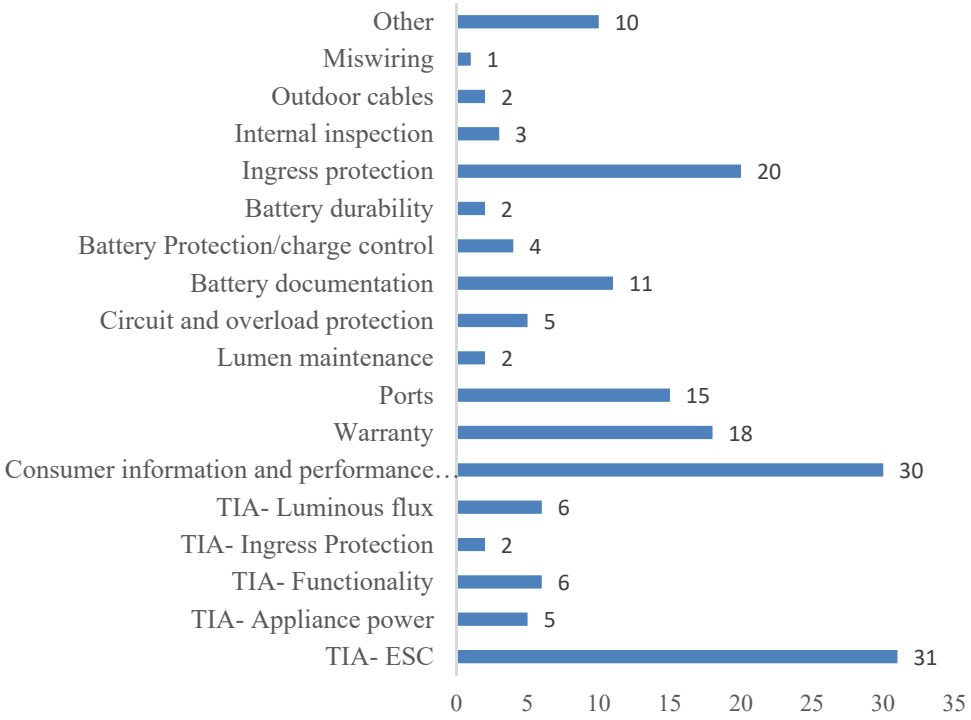

Figure 10. Failures from the 2019/2021 renewal test data from VeraSol quality certification program. (VeraSol QA test data, 2021)

The results in Figure 10 show that Truth-in-Adverting (TiA) accounted for the most failures during renewal tests at 18% of the total. While the statistics in Figure 10 above are more focused on PAYG products, it is important to note that VeraSol also certifies solar products that are non PAYG. As per the quality standards followed by VeraSol, TiA is applied to metrics such as the daily solar run time, full battery run time, battery charging time, and daily energy service in watt-hours per day (this latter metric is assessed using a defined set of Energy Service Calculations, or ESC). Many products evaluated during renewal testing showed a discrepancy between the test results from the ESC and what manufacturers indicate in the product specifications.

Out of the 173 failures registered, customer information and performance reporting represented 17% of the total failures, with 12% and 10% for ingress protection and warranty issues, respectively. Based on the customer information and performance reporting standards set by VeraSol quality assurance program, "all manufacturers are required to accurately present performance metrics on product packaging and other relevant consumer-facing materials to enable retail buyers and distributors to compare products and make educated choices" for the product to pass the test. Accuracy in customer-facing information and performance reporting is also necessary for the proper usage of the products to avoid over and underutilization of the product. It also helps the customer to identify and set expectations for what is inside the product packaging.

The level of ingress protection in off-grid PAYG solar products is a crucial determinant of product durability on the market, especially for products that require outdoor connectivity or those that can be used outside. VeraSol assesses three aspects of ingress protection based on product type. These include enclosure only,[2] the technical level of water protection,[3] and the overall level of water protection.[4] Because products are used in places that are subjected to different weather conditions, all off-grid solar

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[2]Enclosure only: In this case, product manufacturers design the enclosure of the product to prevent ingress of physical objects and water to the specified level. These are hardware related measures.

[3]Technical level of water protection: This approach allows companies to use a combination of the design of the enclosure and additional technical approaches, such as conformal coatings on the circuit board, to protect electrical and electronic components from damage by water.

[4] Overall level of water protection: This approach allows companies to use a combination of measures, including enclosure design, additional technical approaches, and warning labels to address issues related to water ingress. Warning label examples are presented in **Error! Reference source not found.**.

products must meet a certain level of water protection to ensure their life span during use in the field. Some of the things that are tested for under ingress protection include, but are not limited to, the level of protection from occasional and frequent rain, protection from permanent outdoor exposure, and rooftop PV module protection. Manufacturers may include this information on the product packaging, user manual, or on the product itself. See Figure 11 below, for an example of one of the ways that manufacturers indicate water protection warnings to caution consumers and distributors.

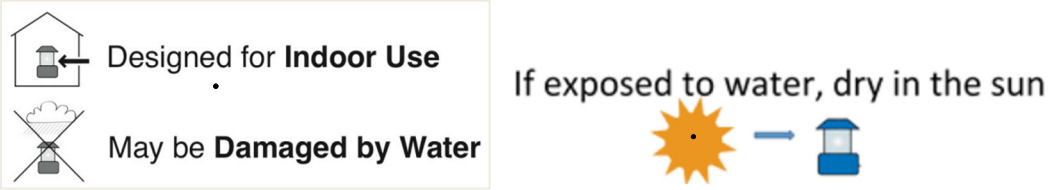

Figure 11. Example of ingress protection caution labeling on off-grid solar products (VeraSol, 2020b).

Manufacturers are also required to communicate this information and all customer-facing information in a language understandable by the end-users and distributors of the products in the place where the products are intended to be distributed.

Since PAYG products are expected to be paid for in installments over a period of time, it is important to ensure that all aspects of the products are functioning as expected at the end user and as such, it is important to have a mechanism in place that tracks product functionality on the market to monitor quality and understand common failures on the market so as to come up with measures of addressing the failures in quality testing and verification of PAYG products.

Common Failures in Off-grid PAYG Solar Products Sold in East and West Africa: Findings from the Information Provided by PAYG Solar Manufacturers and Distributors

From the information gathered from conversations with PAYG solar distributors and manufacturers, problems associated with batteries, lighting, wiring, and connection ports are the main failures that end-users report when returning products. All study participants indicated that these were common failure types reported by customers. In addition, 33% and 83% of the participating companies indicated that customers reported having problems with PV cells and mobile network connections, respectively.

Battery Issues

Under batteries, manufacturers and distributing manufacturers indicated battery discharge during the shipment transit and warehousing as one of the key problems that they were facing. Since nearly all PAYG solar products sold in East and West Africa are manufactured outside of the African continent, manufacturers and distributors must ship the products to the markets in East and West Africa where they are sold. As per the shipping requirements related to safety, batteries are only allowed to have a 30% charge at the time they are shipped. Unfortunately, this sometimes ends up being insufficient to ensure that the battery is delivered to the end user in good condition, especially when there are delays in product arrival or clearance when they are enroute. The delays cause batteries to fully discharge, which can compromise the battery's durability and, in some cases, requires the batteries to be jumpstarted using grid electricity before the distributors can sell them to the end-user.

Many of the distributors contacted reported receiving service cases from end-users with battery charging problems. All the distributors spoken with said that they receive complaints regarding battery charging where customers are unable to charge their battery because the battery cannot charge or no longer holds the charge for long. Some distributors had cases where PAYG solar users reported their batteries not being able to charge during service cut-off when their PAYG subscription expires, and others had brought back service cases in the past where the battery could not charge regardless of whether they had a running subscription for PAYG or not.

In some cases, customers add other appliances and components to the system that over-drain the battery and as a result affect the battery's durability and cycle life. This is a problem that some distributors and manufacturers of solar home systems reported facing. Because actions from the end-users in terms of product handling violate the warranty terms of the product, distributors are then forced to exchange the nonfunctioning battery for a new battery at a cost and end up keeping the nonfunctioning battery, which eventually accumulates waste at the distribution point as such failures become common.

Some distributors shared incidences where customers reported batteries that caught fire. While these are rare incidences, those that have happened were reported in solar home systems above 11 watts. Some customers that experienced such horror were either forced by the circumstance to go back to the same old ways of providing light in their homes using kerosene lamps even though they were offered replacement batteries.

Others choose to take the replacement and continue using the system but with extra caution.

Lighting Failures

The information gathered from talking to companies showed that 67% of the participants received repair and service cases from end-users involving lighting-related problems. Some of the problems mentioned were flickering lights and situations where the lights did not work anymore even when the battery is fully charged. Distributors reported that these service cases often occur after about 2-3 years of the product being used.

Wiring Failure

All participating companies reported having wiring problems as one of the most common failures they receive from the end-users. While some of the wiring issues reported were non-technical i.e., rodents chewing the wires or end-users cutting the wires for one reason or another, there were situations reported where some wires were overstretched and broken during installation. Another wiring problem that is commonly reported to distribution centers from end-users is the broken gooseneck due to strain over time.

Charging Ports Failure

Corrosion of the connection ports for the battery and connection wires was another problem that all participants reported having, especially for products sold in West African countries such as Cameroon, Nigeria, and Sierra Leone. This may occur due to the high levels of humidity in most West African countries. There were also a few cases

of corrosion reported for products that are sold in East Africa, but cases for East Africa were commonly experienced during the rainy season or in some parts of Kenya that are near the coast.

Keypad Problems

The most common keypad problem is faced in PAYG solar products that have a PAYG code activation keypad that is separate from the system i.e., sold with the system but as a component rather than an inbuilt keypad. End-users misplace the keypad, and they are unable to activate their tokens after making payments. The other problem that was mentioned by some distributors was related to loose keys on the keypad, especially for products that are sold on a payment plan of 1-2 years. This is especially common in products that have the keypad inbuilt in the system battery, which is particularly prevalent in solar home systems.

Solar PV Cells

Information provided by the participating companies shows that 50% indicated having solar PV-related service cases from their end-users, especially those that buy/use solar lanterns. Some distributors and manufacturers, especially those that outsource solar panels from other manufacturers, recorded a significant number of service cases for solar panels that are brought back from end-users when they are broken. Moreover, some PV modules break in transit to the end-users due to the rough terrain that products must travel to reach the end-user and remote distributions centers. Transit damage was also reported to be common in solar appliances that are powered by off-grid PAYG and non-

PAYG solar products. Some of the products that are damaged in transit include but are not limited to televisions, fans, fridges, and others.

Network Challenges

While not technically directly related to the product, distributors have had end-users bring their PAYG solar products back out of frustration from having trouble receiving activation codes on their mobile phones due to network connection failure. While this is not usually a common problem, some distributors expressed concern about losing clients, and some have had their customers return to using kerosene in cases where they were not able to pay out the product to avoid frustrations. Some customers just neglect the product and stop paying the installments and go back to using kerosene or buy a low-quality substitute on the open market that they can afford in cash to avoid inconveniences.

CHAPTER 5. DISCUSSION

There is no doubt that off-grid PAYG solar has the potential to electrify and empower off-grid communities and that many people are already benefiting from its wide adaption. PAYG solar systems are used to provide electricity beyond just lighting. Currently, the approach is being implemented at the individual household level and at a broader community lever for lighting, powering appliances, small businesses, and other productive uses. However, the results from the analysis show that quality testing and monitoring need to be strengthened to reduce the number of failures experienced by end-users. As new innovations in the off-grid PAYG solar market increase and become more affordable, quality testing and monitoring for these products need to be extended down to the markets where the products are being used. Moreover, the focus for quality testing and field testing can be directed towards the common areas of concern, which may vary by country or region. For instance, issues with ingress protection might vary depending on the weather conditions experienced by region and how products are being used in different areas. Same might apply for battery issues where solar products are more used to power appliances in some regions more than others. The results from the analysis of renewal testing failures indicate a similar set of problems to the issues identified from the field study of the Kenya market and the information shared by manufacturers and distributors.

The fact that the test results show more products failing the quality renewal testing for truth-in-advertisement, customer information, and performance reporting shows that there might be some aspects of the products that change after the initial quality certificate has been granted. This also explains why failures reported from the field data are commonly performance related. A well-designed market surveillance program that focuses on testing the products on the market to make sure that they are performing as advertised can help strengthen the quality of off-grid PAYG solar products and other quality-certified non-PAYG solar products.

Many consumers of off-grid PAYG products are looking to get more than just lighting out of the industry and, as such, the market for solar home systems that come with multiple lighting points and appliances with an option to upgrade is growing rapidly even in the rural communities where most customers are low-income earners. PAYG makes it easy for low-income earners to afford solar home systems and upgrades with multiple appliances. However, when the customer-facing performance information provided for the product is misleading, the product will not perform per consumer expectations and will be prone to failure. Rural markets are often isolated from easy access to after-sales services, and distributors are not motivated enough to establish service points in such areas. When they do, they often have to incur a high cost to provide after-sales services such as repair when needed. In some cases, once products are sold, it is hard for the distributors to find ways of providing after-sales services. In such cases, the customer is left with a problematic product that cannot perform to the approved

standards. This is even more so when the product has completed the payment plan or is out of warranty. Extending the quality assurance program to protect end users through market surveillance programs can help flag such products, and advocate for the consumers and distributors.

Despite improvements in battery technology, there is still a lot that is lacking, including in the PAYG solar industry. Battery performance is highly affected by the weather and time spent idling (i.e. without being charged). The difference between the environmental conditions (i.e. weather) where products are manufactured and conditions for which it was designed and tested can result in variations in battery durability and performance relative to expectations. Even when the testing conditions are manipulated to mimic the weather at the point of use, use patterns in the field can vary significantly from those assumed by product designers. As for PAYG solar products whose performance is metered based on the client subscription, customers may not pay close attention to the battery charge when their products have been remotely switched off when their subscription expires. And in some cases, batteries cannot be charged when the system is switched off. Since most PAYG solar products are used in low-income communities, some customers take a while before they can make their next subscription payment, which sometimes leaves the battery uncharged for a long time and this can affect future performance.

Switches are some of the most used parts of PAYG solar products and any other off-grid solar system. Just like batteries, it is hard to fully test switches in the same way that they will be used in the field, as their use is mostly dependent on the information passed on by the installing technician. It is even harder for customers to use the switch well for plug-and-play products that they install themselves, especially if the customer information provided to them to explain how the product is used is not understandable to the customer. It is important to standardize the quality of switches for off-grid PAYG solar so that they are appropriate for the use conditions in the field.

Keypads are an essential part of off-grid PAYG solar products, especially those that require customer interaction with the product for PAYG activation. However, there are no standard quality requirements that are specific to the PAYG activation keypads and code format. PAYG solar customers often live in small spaces that are shared with many other family members that include children, which makes it difficult to keep the keypad safe. Keypads that are not attached to the battery enclosure of the PAYG product are often lost, misplaced, or exposed to children, which may lead to tampering or damage.

The issues identified in ingress protection and ports from the renewal test data in the context of the VeraSol quality certification program also correlate with some of the failures identified in the data from the Kenya study. For instance, batteries may fail because they cannot be charged after some time due to water damage to the charging port. Water damage to connection ports for appliances can also lead to corrosion that reduces the functionality of products. These problems can happen when the system/ports are not well protected from water and humidity.

Warranty is an important aspect of the off-grid sector especially when it comes to ensuring quality, protecting the end-user, and the industry at large from substandard products. The current quality standards for off-grid solar address warranty at the manufacturer level by requiring that products offer a warranty (either one or two years, depending on the product size) in a way that is evident to the consumer at the time of purchase. However, even with this requirement in place, there are challenges associated with effective implementation of warranty requirements on the market level in the context of a quality assurance program.

With the current approach, quality assurance programs only have leverage over manufacturers during the product certification process to ensure that off-grid solar products offer the requisite warranties. These terms, however, do not necessarily transfer down to the distributors and retailers who sometimes reduce the warranty period or eliminate it altogether for products and appliances as they see fit. As a result, some end-users are unable to claim the full warranty period of the product from the distributor or

retailer as advertised on the standards-compliant customer facing information (which may communicate through the product packaging, or a warranty card included in the package by the manufacturer). Some distributors and retailers that extend the full certified warranty period i.e., 1 to 2 years, to the end user are those that sell off-grid PAYG products with payment plan that is 1 to 2 years in length. This approach is used as a customer incentive to minimize default rates, as it ensures that the customers receive aftersales services within the payment plan period (which is aligned with the warranty period). The idea is that customers will continue paying for their products within the payment period with minimal service inconveniences. Some distributers and retailers extend the certified warranty period out of honesty, and faithfulness to their customers. In some cases, the warranty offering is dependent on the distribution agreement they have with the manufacturer. As companies that provide products that meet standards and have products listed through certification programs, manufacturers need to ensure that all their distributers and retailers are held accountable for delivering the stipulated warranty for the entire period that is advertised when the product is purchased.

CHAPTER 6. RECOMMENDATIONS

Quality standards and certification programs are important for manufacturers, as they ensure a level playing field in the market. They also help manufacturers secure investment, participate in incentive programs, and access other sources of funding. As solar companies adopt quality standards and testing procedures set by quality certification bodies such as VeraSol, it is increasingly becoming important for quality certification bodies to ensure that the approved and certified quality for products continues over time as products are delivered to the market. The analysis of the data used for this study indicates that there are still quality gaps in products that have been certified when they reach the market.

To bridge these gaps, quality certification programs need to aggressively continue checking the certified products on the market to make sure that they still meet the quality requirements, and this should be done at the distribution and end-user levels. By identifying and understanding the common product failures that occur at the distribution and end-user levels in quality-certified products, quality certification bodies can design market surveillance programs that focus on testing and improving quality standards in off-grid PAYG solar products, targeting the key points of product failure to further emphasize and assure quality for off-grid solar products on the market and to protect distributors and consumers. The below suggestions for approaches to designing an efficient and effective market surveillance program aim at addressing the identified

common failures in off-grid PAYG solar products with the goal of improving quality and sustainability in the solar energy sector.

Based on the study results, batteries were identified as one of the key points of failure in off-grid PAYG solar on the market. While the current testing and certification standards for off-grid solar products emphasize the importance of battery safety, performance, and durability, battery failures remain an important challenge. Expanded market surveillance efforts that aim at testing the performance of batteries in quality certified PAYG solar on the market level would be beneficial and can be adopted across all solar products including non PAYG solar products. These efforts should include a focus on identifying the specific types of battery failure that are being experienced in the market. Data collected through such an effort can help inform improvements to test methods and standards for batteries. This could help increase battery performance for off-grid solar products at the end-user and distribution level, by ensuring that PAYG solar batteries perform to the estimated full cycle and reduce the quantity of toxic waste from batteries entering the waste stream, thereby making the off-grid PAYG solar industry more sustainable.

Solar lighting and battery technology have tremendously improved since the introduction of off-grid PAYG solar in Sub-Saharan Africa. However, as innovations in the industry increase to maximize the benefits of off-grid PAYG solar to the market, accurate customer-facing information and guidelines regarding product capacity and performance are needed at or before the time of purchase. The topic of consumer information requires more attention to avoid end-user disappointment when the product cannot support additional components to the system and fails to work to end-user expectations. The end user data analysis from the Kenya study indicates that many end-users report lighting and battery failures in off-grid PAYG products, while the test renewal data reported many failures with truth in advertising, especially with reported product performance. A field-oriented market surveillance program that focuses on testing product performance for quality certified products at the end user level can help ensure that the same initially quality certified product performance standards continue to the market. This will help protect the end-users and distributors from product failures and strengthen quality in off-grid PAYG solar. The same approach is applicable for non-PAYG solar products to strengthen quality in the solar sector and reduce waste.

Warranties are a key determinant for quality in the off-grid solar sector, and they are highly necessary for PAYG solar products. Results from the Kenya data indicated a variation between warranty periods for solar products, where the product warranty set by the manufacturers and certified during the quality certification process is not honored by the distributors and/or retailers at the market level. Warranty challenges at quality

certification during qualification and renewal testing can easily be remedied by withholding the quality certification until the manufacturer has met the required standards for advertising warranties. The issues that arise with warranty service being honored at the market level, on the other hand, are much more complex. This is especially true in situations where it involves third-party distributers or retailers. This is mostly because the quality certification standards and processes for off-grid solar can only hold manufacturers accountable for the acceptable standard warranty terms during quality certification processes. Presently, there are no mechanisms in the quality standards certification process that ensure distributors and retailers provide warranty service to the end user. As a result, effective quality certified warranty services and implementation on the market level is left to distributers or retailers' good faith participation. Similarly, the current quality certification programs are not mandated to regulate the distribution or retailing contracts between manufacturers and distributers or manufacturers and retailers, which makes it hard to understand the terms of warranty implementation at the market level.

Additional research into the subject is required for quality standard programs to understand the terms of operation between manufacturers and distributers or retailers regarding warranty implementation on the market to better protect end users. The information from future research on warranty implementation could be used to design an expanded market surveillance program that monitors quality standards at the market. However, it is important to note that there might be other challenging factors to be considered in relation to warranty enforcement. These may include funding, development of the human capacity to successfully monitor warranty implementation in markets around the world, the degree of interests by country governments to engage in these types of consumer protection issues, and others.

There are also country-specific PAYG challenges that should be considered when designing an effective market surveillance program to support quality in off-grid PAYG solar markets. These include PAYG solar enabling technologies such as telecom networks and monitoring systems that support PAYG transactions among others. These are important in ensuring PAYG product functionality on the market. However, addressing identified issues for such enabling technologies might require working with other quality assurance bodies for technology or country-specific technology standards for software application.

CHAPTER 7. CONCLUSION

Quality assurance programs in the off-grid solar sector aim at protecting the market from substandard and copy-cat products. By emphasizing quality at the manufacturing level, these programs act as the voice for end-users and distributors. They are also key in informing the industry, especially when it comes to industry financing. However, without close attention to product performance on the market, quality can be compromised, which disregards the purpose of quality assurance programs. By extending quality assurance and monitoring programs to the market, especially to the end user, quality assurance programs can support a sustainable solar industry that protects the market and reduces solar waste on the market.

Market surveillance programs and market check tests that aim at ensuring product quality and performance at the end-user and distribution level are key to ensuring a sustainable solar industry. As off-grid PAYG solar dominates the market and the majority of countries especially in Sub-Saharan Africa adapt to the widely accepted international quality standards for off-grid solar, it is important that quality assurance programs work with local governments to implement effective market surveillance programs that monitor quality in solar products that have been quality certified by international quality certification bodies. And because off-grid PAYG solar operations involve aspects that are only applicable to a specific country of operation, quality certification programs should work closely with local governments and solar manufacturers to design market

surveillance and quality assurance programs that target product standards and make product improvements in specified countries based on the common failures identified or faced by off-grid PAYG solar customers.

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