

The emerging market for pico-scale solar PV systems in Sub-Saharan Africa

FROM DONOR-SUPPORTED NICHES TOWARD
MARKET-BASED RURAL ELECTRIFICATION



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Abstract

The traditional model of rural electrification in Sub-Saharan Africa (SSA) mainly involves donor and government-supported programs. Recently, however, a rapid and significant increase has occurred in the sale of pico-scale solar products throughout SSA. This development is driven by an increasing number of private firms supplying pico-scale solar systems to customers, on a commercial basis, in order to serve their electricity and lighting needs. The system suppliers take advantage of the substantial improvement in the price and efficiency of core technology components, the emergence of smart metering technologies, and the wide-

spread use of mobile phones and mobile payment schemes. Suppliers are, thus, able to target poor customers located mainly in off-grid, rural areas through new pay-as-you-go business models that avoid high upfront costs. With the parallel rise in the costs of conventional sources of electricity and lighting, especially diesel and kerosene, the demand for pico-scale solar appliances has boomed. These factors are driving a remarkable and unprecedented diffusion of pico-scale solar PV products on market terms, which stands in contrast to the donor and government-driven model of rural electrification.

1. Introduction

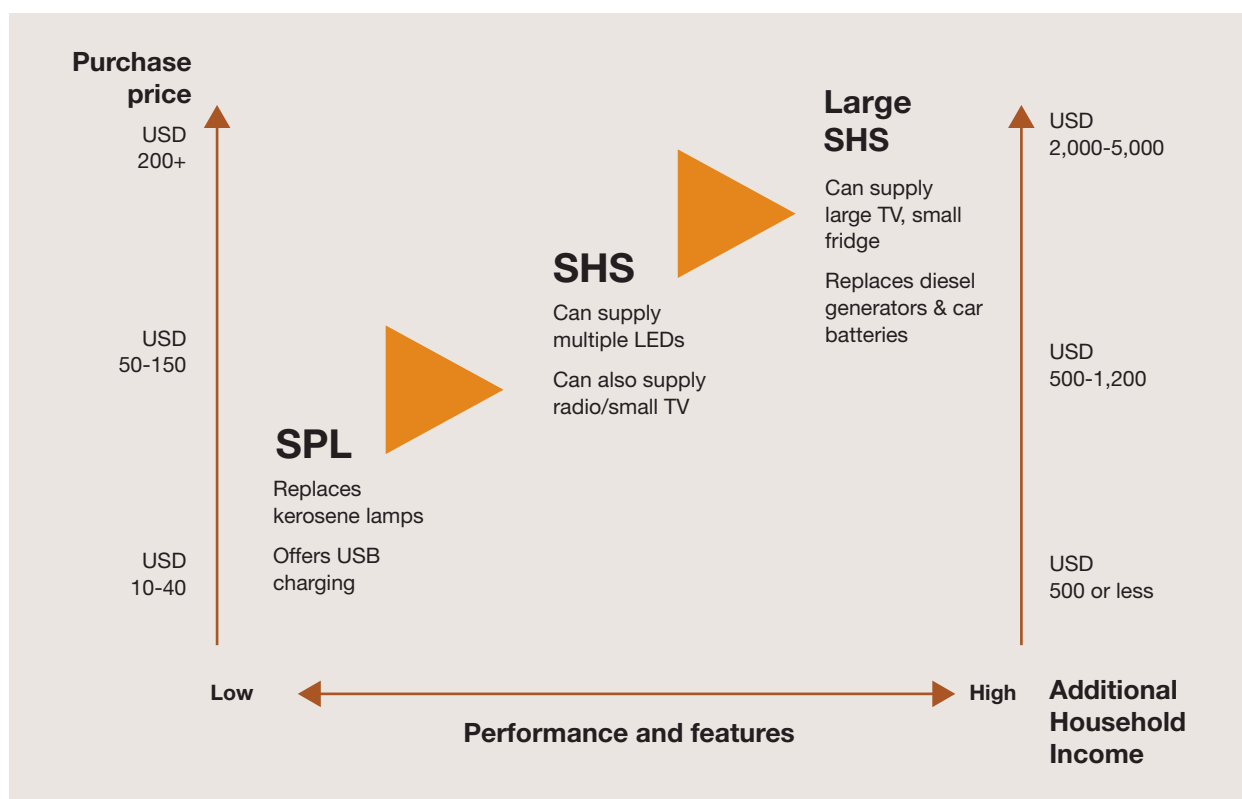
The application of pico-scale solar photovoltaic (PV) appliances is currently becoming increasingly global in nature, and this development is particularly noticeable in Sub-Saharan Africa (SSA). This report aims to shed light on the current and future market of pico-scale solar PV in SSA, and provide tentative suggestions to explain the observed development. The intention is to describe a development that is currently unfolding at an incredible speed and yet continues to occur somewhat below the radar (Kaplinsky, 2011). However, the market for pico-scale solar PV is only expected to increase and spread further across SSA.

This expected growth will have significant implications for the way in which the issue of rural electrification is being approached, and how universal access to modern energy services will be achieved in Africa. The report is based on a review of donor, consultancy and industry reports, media coverage, national and regional market surveys, as well as analysis of journal articles, working and conference papers, undertaken as part of a larger research project on the development and diffusion of solar PV in Africa conducted by the UNEP DTU Partnership (Adomdza et al., 2016).

Photo credit: Frank van der Vleuten



Figure 1. Three categories of solar off-grid lighting products



Source: Hagan et al. (2015) based on A.T. Kearney and GOGLA (2014)

Before proceeding, a demarcation is necessary. This report will focus solely on pico-scale systems to be used by individuals or at the household level (Hansen et al., 2015). Figure 1, above, shows how a small-scale solar PV market can be divided into three different market segments comprising: (i) Solar Portable Lights (SPL) or solar lanterns -- lighting and mobile phone charging applications, (ii) Solar Home Systems (SHS) -- used by households to power multi-light sources and smaller appliances, and (iii) larger SHS, which are able to service higher electricity demands, including fans, televisions, freezers and other household appliances. While this division makes sense, some confusion emerges due to the World Bank Lighting Africa

initiative defining pico-solar systems as systems with an effect below 10 Wp. Early pico-systems were mainly portable lights, but current pico-systems also comprise small SHS with multiple LEDs. In the following, references to pico-systems mean portable lights and SHS with an effect below 10 Wp (Orlandi et al., 2016).

The report is structured as follows. Section two provides a short overview of the state of the market for pico-scale solar in SSA. Section three follows with a description of the main factors appearing to have enabled the development of the market. Finally, the conclusions are presented and discussed in Section four.

2. Market status for pico-scale solar in Sub-Saharan Africa

With support from various government and donor-funded programs and NGO projects, as well as private over-the-counter sales of products and appliances, the market for small-scale solar appliances has existed for many years in SSA. Recently, however, the sale of pico-scale PV appliances to private consumers has seen tremendous and unprecedented growth, which has been left largely unnoticed by the general public. As shown in Figure 2, below, the total annual sale of pico-solar products in Africa has been estimated by Orlandi et al. (2016) to have increased from less than 100,000

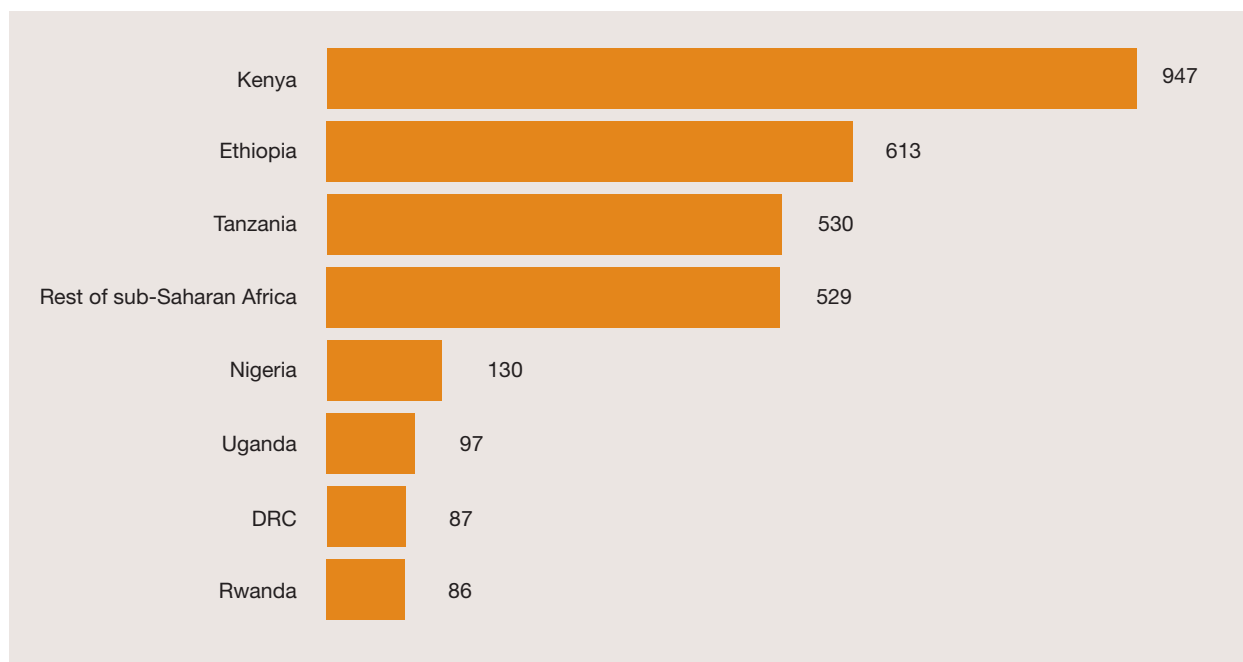
per year in 2010 to more than 4 million units sold in 2014. Available forecasts suggest that this growth rate is expected to continue in the coming years. With a current market penetration of only 3% in a continent with roughly 600 million people living without access to electricity, of which the IEA estimates 20% will most optimally be served by off-grid solar solutions, the potential for further market growth certainly exists. Under favourable conditions, it is forecasted that sales of quality-certified SHS could grow to as much as 17 million units per year by 2030 (Scott and Miller, 2016). An even lar-

Figure 2. Sales of branded pico-solar lighting products in Africa (million of units)*



Source: Orlandi et al. (2016). (*) 'branded' refers to products sold by well-known brand names

Figure 3. Sales of Pico-solar products in Africa in 2014-2015 (thousands of units)



Source: Orlandi et al. (2016)

ger market may exist due to the sale of so-called generic products, such as no-name products, copycats and counterfeits, which according to Orlandi et al. (2016) account for at least half of all pico-solar sales. Interestingly, the sale of pico-solar products are mainly in East Africa, in particular Kenya, Ethiopia and Tanzania, who account for two-thirds of total sales, as seen in Figure 3. The markets in Rwanda and Uganda are still comparatively small, but are expected to be the next to grow rapidly since many private companies have been entering over the past two years (Scott and Miller, 2016).

A few years ago, pico-solar products were mainly Solar Portable Lights, but due to the emergence of energy efficient lighting alternatives, especially the Light Emitting Diodes (LED) lamps and energy efficient LED-based television sets, there are currently a number of small SHS on the market in the range of pico-systems (5-10 Wp), which are providing the same services as the much larger solar home systems did only 10 years ago (Hansen et al., 2015; Orlandi et al., 2016). This means that while

these Pico products are generally smaller compared to SHS, offering mainly the service of lighting and battery charging, pico-systems are increasingly sold as larger integrated kits, combining lighting, mobile charging and electricity services for small appliances -- e.g. radios. Surveys conducted in a number of SSA countries reveal how a vast majority of the customers buying pico-solar products show interest in either purchasing a second light or upgrading their system to have increased capacity and functionality (Scott and Miller, 2016). The market for SHS is also experiencing a movement towards larger systems that can accommodate multiple devices such as televisions, fans and small refrigerators. As an example of the fast development, one of the leading suppliers of Pico and SHS products from Kenya, called M-KOPA, started in 2012 and has since managed to install more than 300,000 units in Kenya, Tanzania and Uganda. In comparison, prior to 2012 around 320,000 SHS had been installed in total in Kenya over the past 30 years (Hansen et al., 2015).

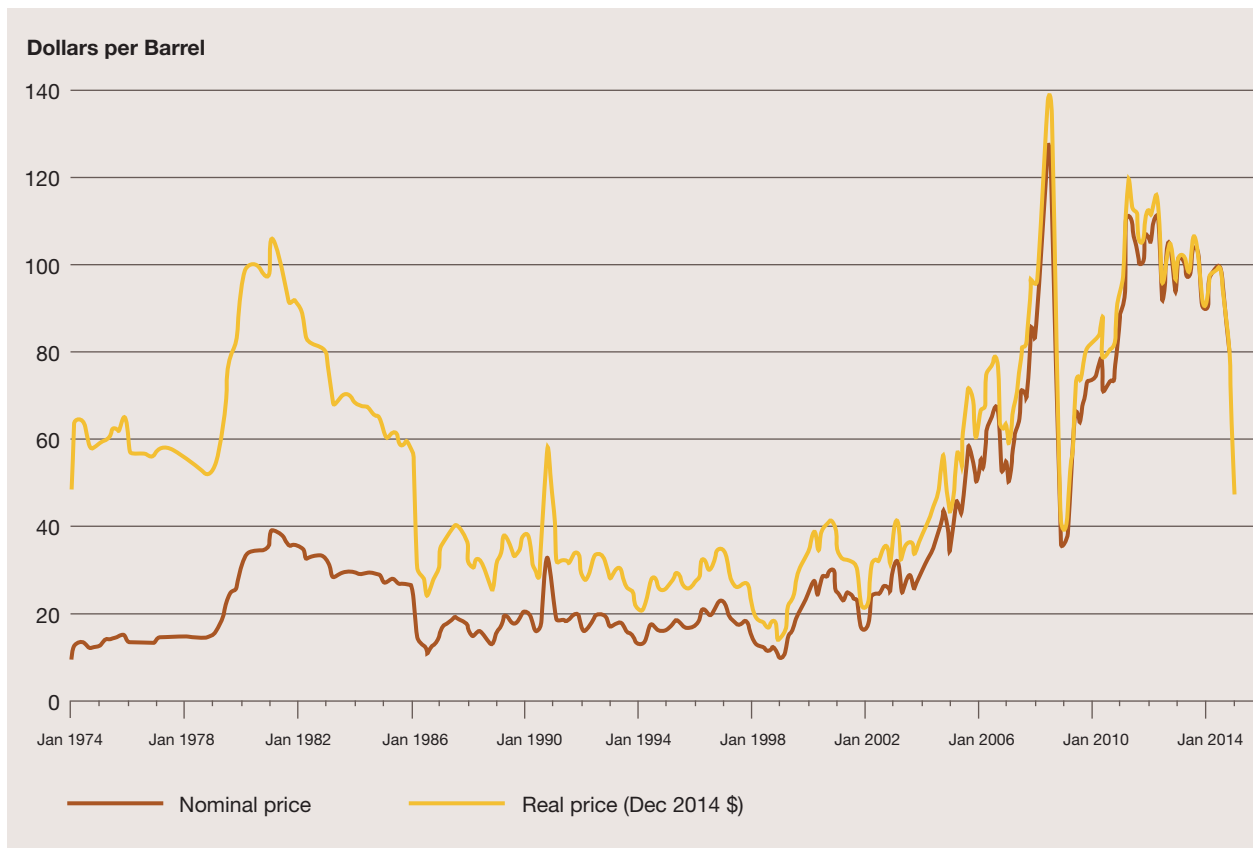
3. Critical elements enabling the development of the market for pico-scale solar in SSA

The following section will provide a number of decisive elements that seem to have coincided to enable the development of the market for pico-scale solar PV systems in SSA, as described above. The four elements, which will be addressed, are: (i) the general increase in the price of oil and derived products; (ii) the improvement in the price and efficiency of core components; (iii) the emergence of new pay-as-you-go business and delivery models; and (iv) the introduction of a global product quality certification system.

3.1. INCREASE IN THE PRICE OF OIL AND DERIVED PRODUCTS

As shown in Figure 4, the price of oil was relatively stable, approximately 20-40 USD per barrel, from around 1986 until the end of the 1990s. Since then, however, the oil price has gradually increased and reached an average level of 100 USD per barrel, for the period of 2007-2015 -- which is more than double the previous period. The oil price has been highly fluctuating in recent years, and currently stands at almost 50 USD per barrel.

Figure 4. Monthly imported crude oil prices (USD per barrel) 1974-2015



Source: Gongloff (2015)

The long period of rising and high oil prices has meant that the price of derived products, such as diesel oil and kerosene, which are widely used for electricity generation and lighting purposes throughout SSA, has increased accordingly. This is reflected in the increasing government spending on subsidies to level out the difference between rising world market prices of diesel and kerosene, and the price paid by domestic consumers in many SSA countries. In Nigeria, for example, government subsidies on kerosene amount to more than those for security, critical infrastructure, human capital development, and land and food security combined (UNEP, 2014). Price increases, however, have been unavoidable in many countries. In Kenya, for example, as shown in Figure 5 below, the price of kerosene paid by customers at local gas stations has generally increased and fluctuated in parallel with the general upward trend in global oil prices. With the resulting increase in household spending on kerosene and diesel, a demand for alternative and lower cost sources of fuel and electricity, including solar PV, has emerged, especially from the rural

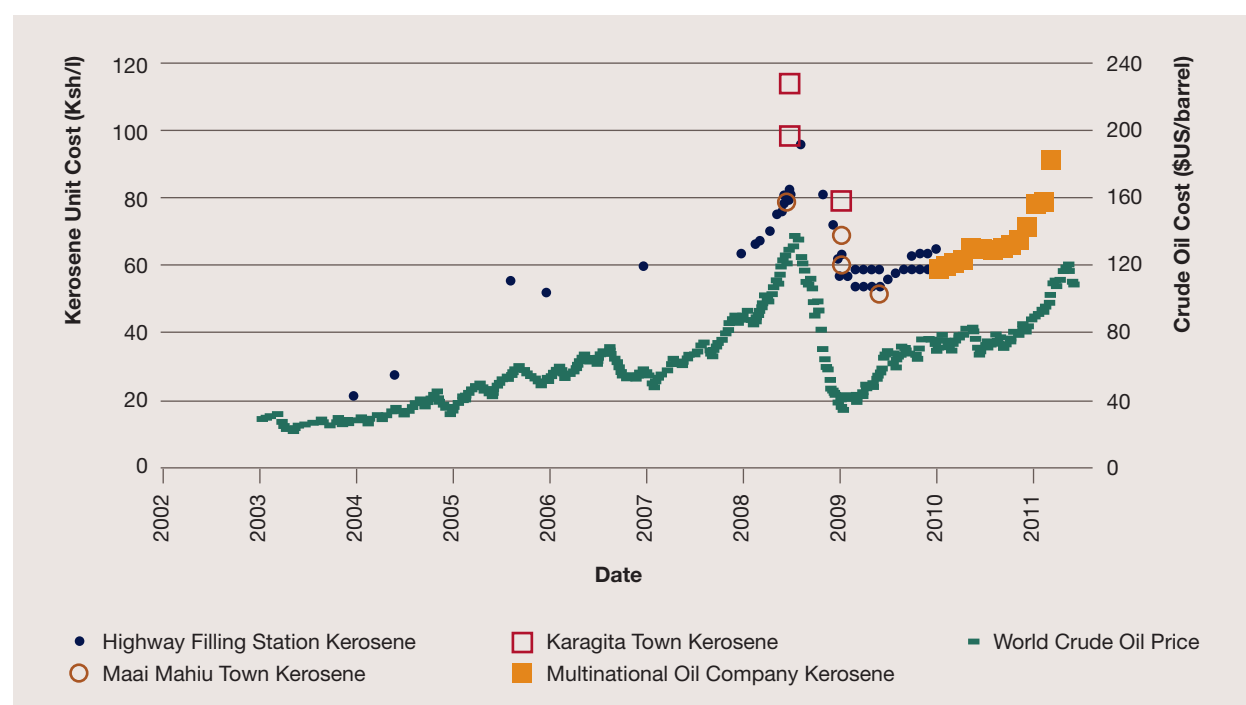
population. This demand seems to have encouraged the development of the market for solar Pico and SHS in SSA (Tracy and Jacobson, 2012).

3.2. IMPROVEMENTS IN THE PRICE AND EFFICIENCY OF CORE TECHNOLOGY

The potential for generating power through solar PV has been known and recognized for a long time. However, it was not until recently that solar PV developed to a state where, under favourable conditions, it reached grid parity (Bazilian et al., 2013). As can be seen from Figure 6, the price of solar PV modules has been continuously reduced since the beginning of the 1990s. From 2003 to 2008 minor price increases occurred, but since 2008 prices have declined rapidly and are expected to continue doing so in the foreseeable future.

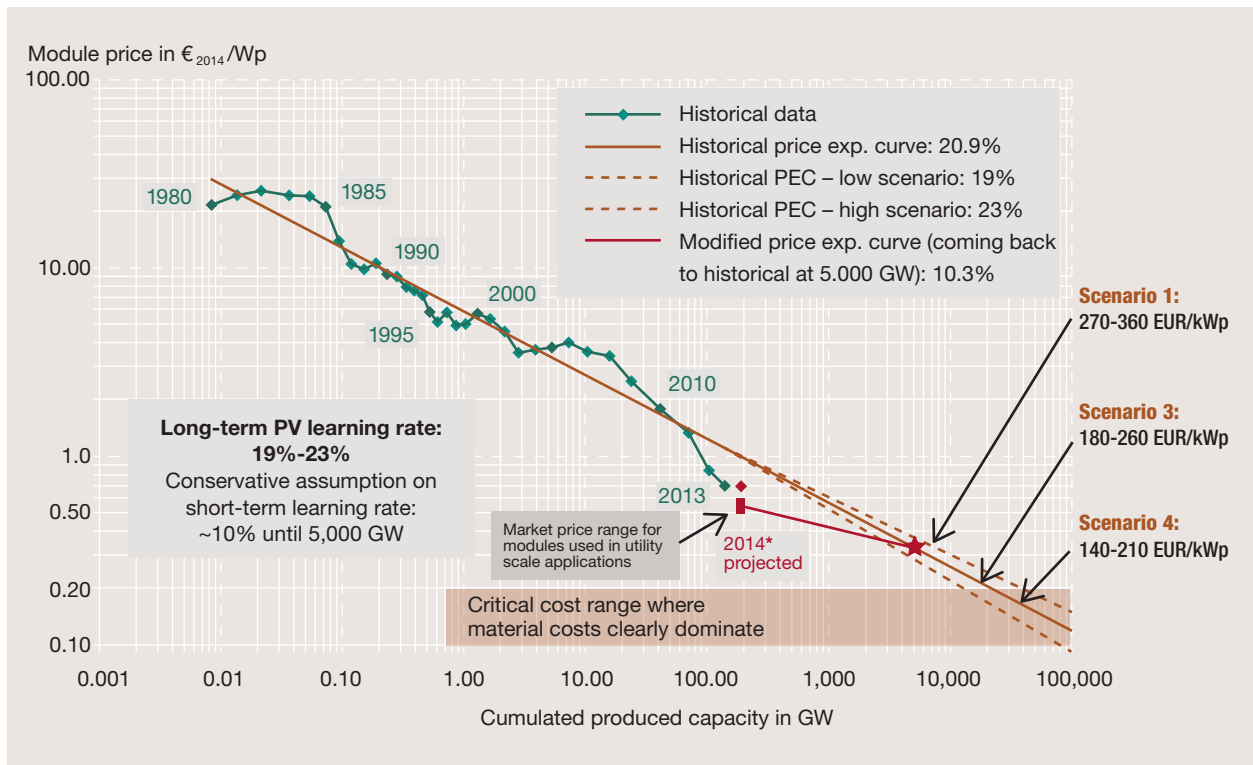
The decrease in unit prices has been brought about by a general expansion in the production and installed capacity of solar PV during that

Figure 5. Historical unit prices of Kenyan kerosene and world crude oil from 2003 to 2011



Source: Tracy and Jacobson (2012). Note: kerosene prices are typically higher in rural areas compared to urban centres

Figure 6. The PV module price 'learning curve' for crystalline silicon modules

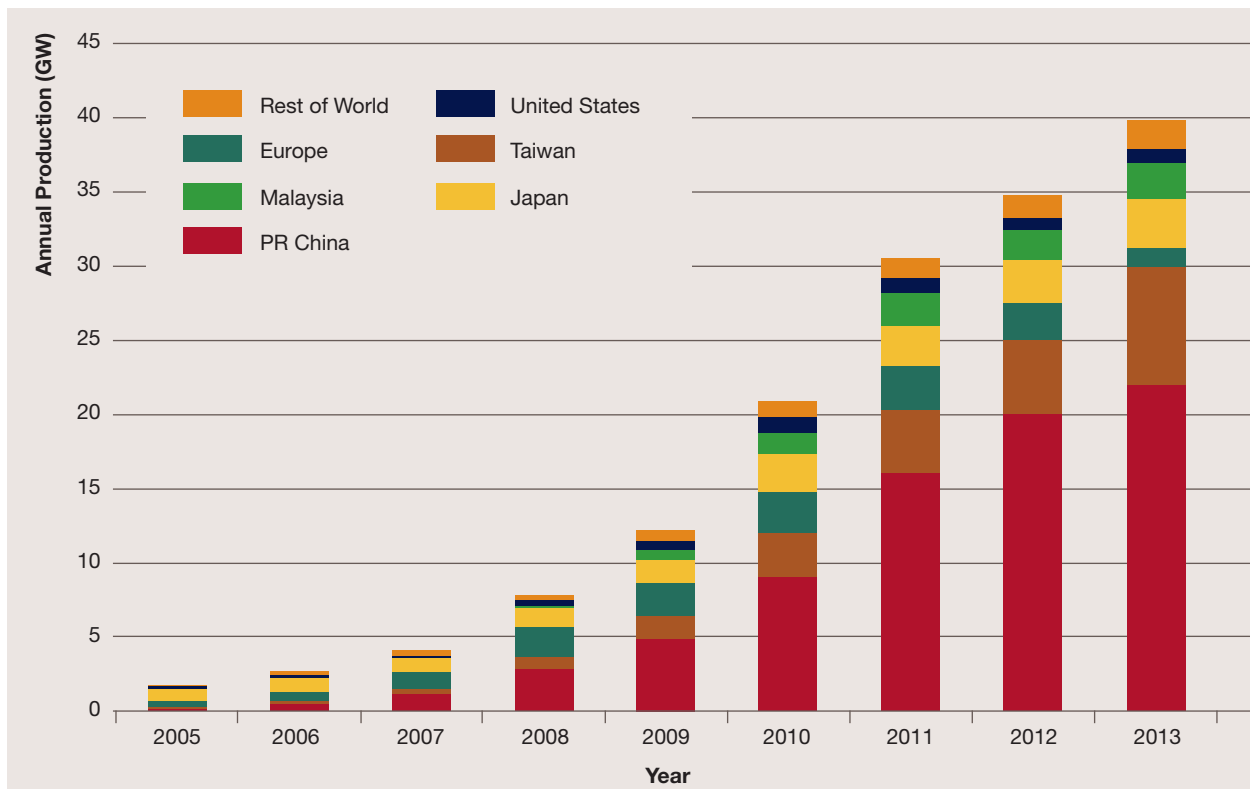


Source: Fraunhofer (2015)



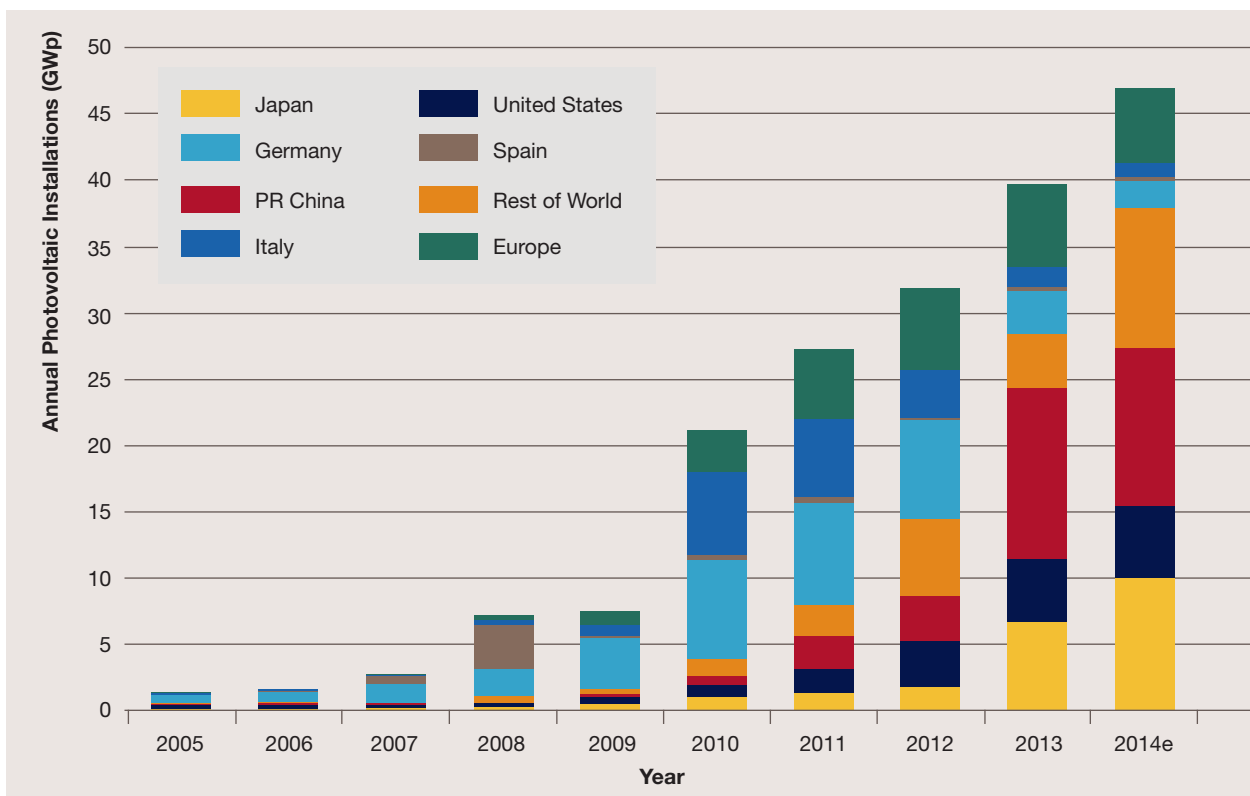
Photo credit: DTU Energy

Figure 7. Global annual PV production (GWp) by country and region 2005-2013



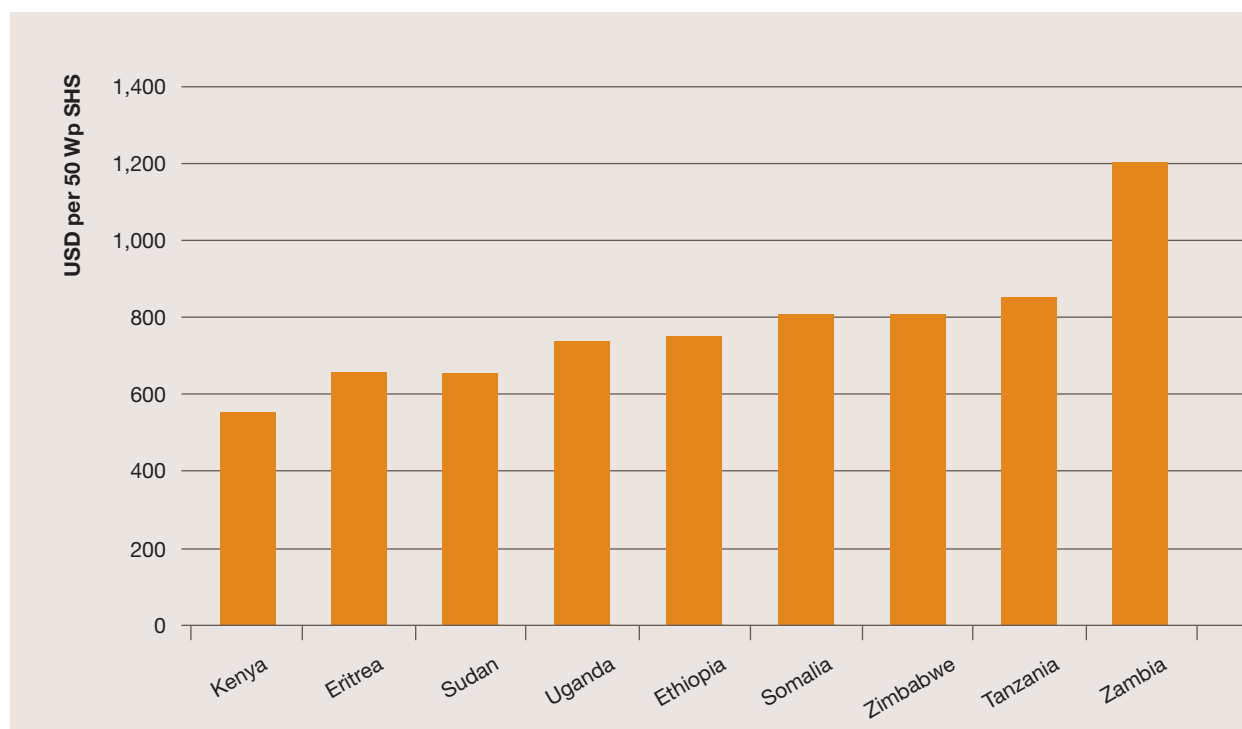
Source: Jäger-Waldau (2014)

Figure 8. Annual PV installations (GWp) by country and region 2000-2014



Source: Jäger-Waldau (2014)

Figure 9. Retail prices of a 50 Wp SHS (incl. panel, four lights, charge controller and installation) in the period 2001-2003



Source: Nygaard (2009) based on Moner-Girona et al. (2006)

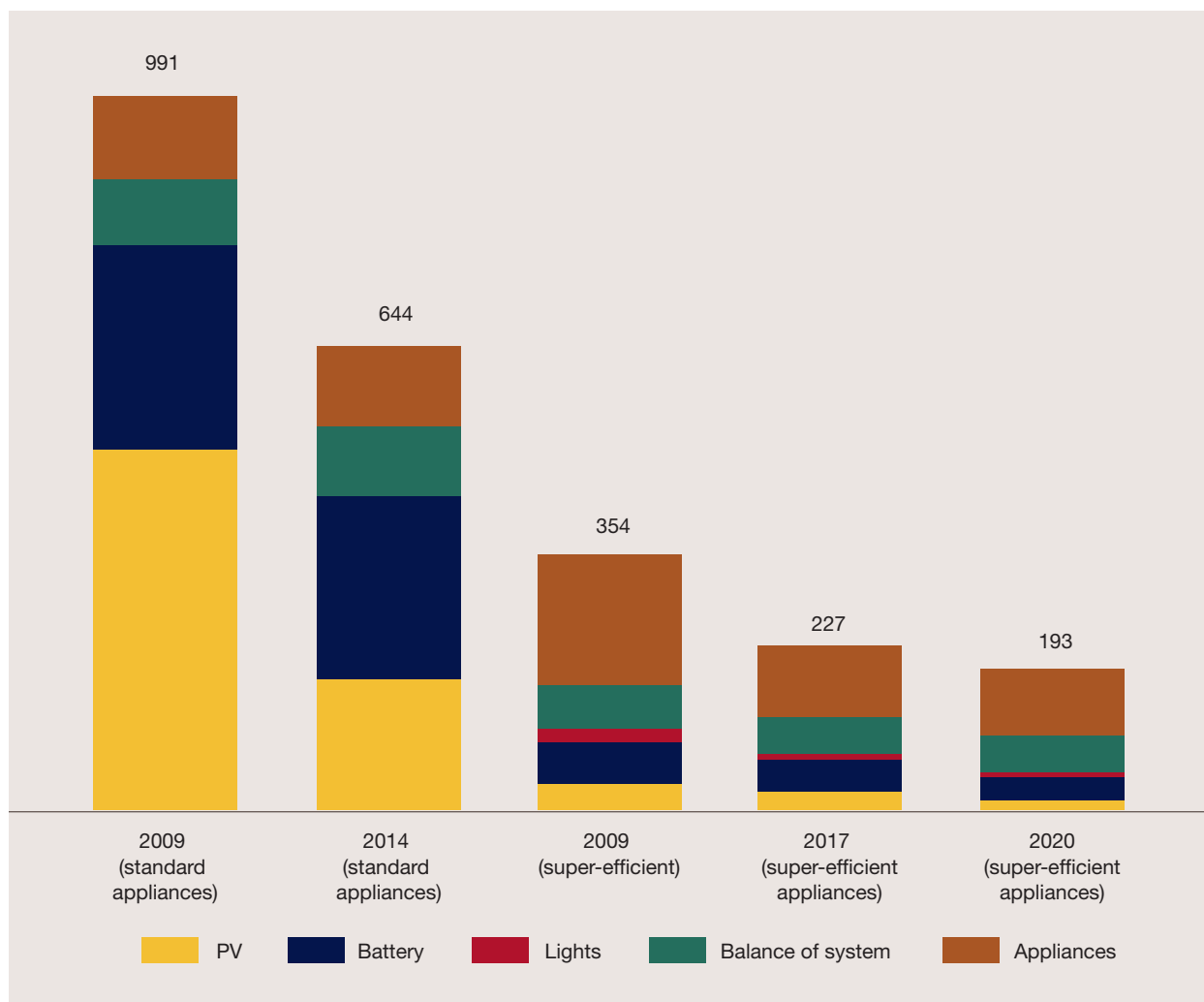
period (see Figures 7 and 8). On the production side, process efficiency improvements and economies of scale have enabled reduced costs of manufacturing cells and modules -- a trend that has been particularly noticeable in China and Taiwan (Jäger-Waldau, 2013). The price increases from the early 2000s to 2008 were partly caused by a shortage of polycrystalline silicon. This lack of supply encouraged a significant increase in investments in polycrystalline silicon and PV production capacity, again, mainly observed in China. Nevertheless, following the global financial crisis in 2008, the demand for solar PV slowed and various support programs, such as the Spanish feed-in tariff program, were put on hold or closed entirely (Bazilian et al., 2013). Consequently, the earlier investments in expanding production capacity resulted in the industry witnessing considerable excess production capacity. This, in turn, led to the emergence of significant price pressure throughout the value chain as suppliers entered into fierce competition in order

to survive (REN21, 2013). This development was a major cause of the decreases in solar PV prices, and although the rate of decline will most likely be slower, prices are expected to continue declining in the near future, as seen in Figure 6.

At the beginning of the 2000s, prices of SHS in SSA were higher than in other parts of the world mainly due to high taxes and transportation costs. As Figure 9 shows, even within SSA there were considerable price differences between countries due to varying tax levels, sales volumes and retail market structures. Since then, price differences have been reduced.

In parallel with the declining price of solar panels, their efficiency and performance levels have increased concomitantly (Alstone et al., 2015; Orlandi et al., 2016). To illustrate this price/performance ratio improvement of solar panels, the Kenyan solar energy company M-KOPA currently offers a Pico SHS with an 8 Wp panel, which outperforms a 50 W SHS from the beginning of the

Figure 10. Retail prices of SHS with 19" TV, radio and lights (USD/unit)



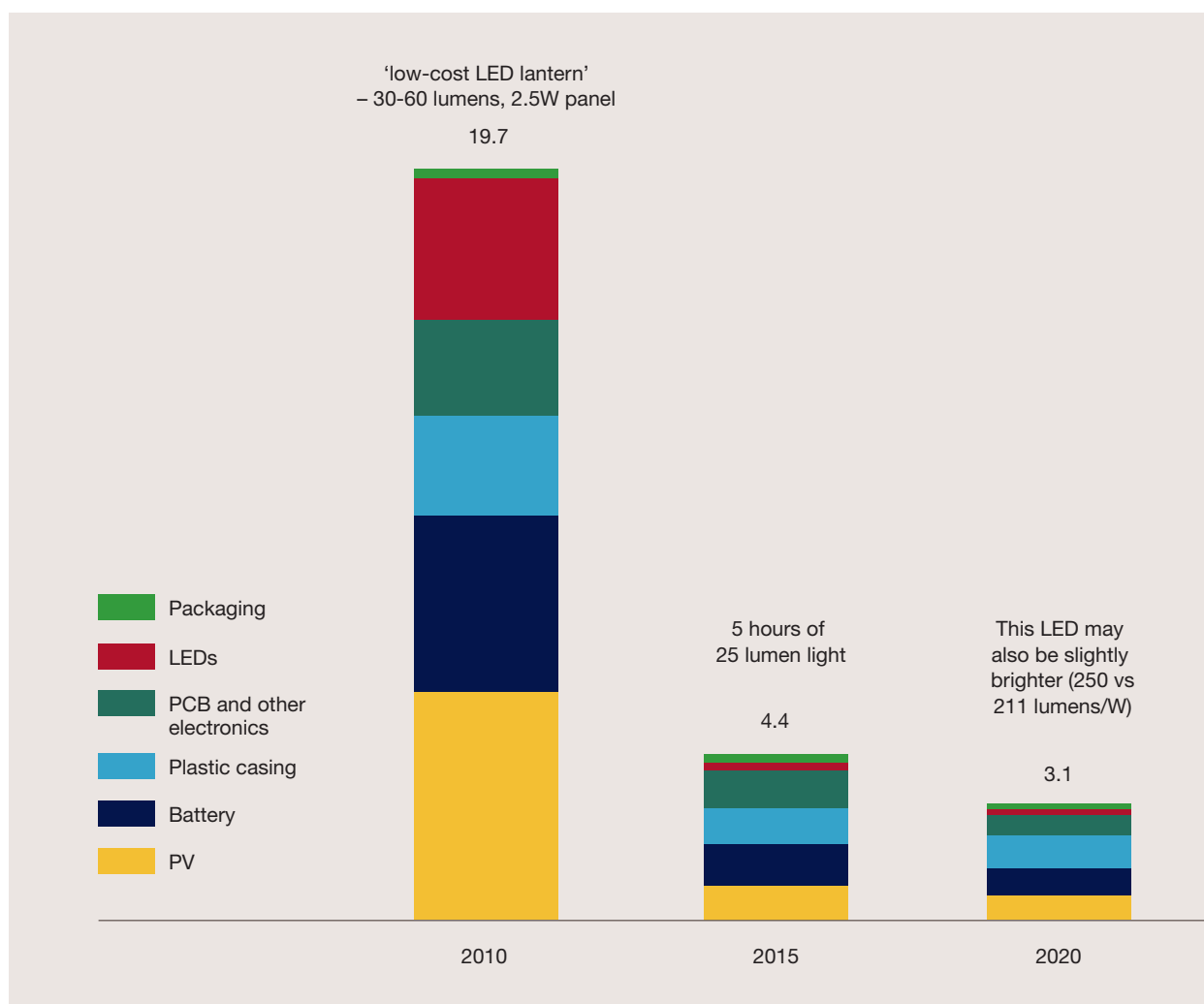
Source: Orlandi et al. (2016)

millennium at only a third of the price -- taking inflation into account. Similar price and efficiency improvements have taken place over the past decade in the other core technologies used in Pico and SHS products sold throughout SSA, in particular: (i) small lithium-ion batteries; (ii) energy efficient lighting alternatives, especially Light Emitting Diodes (LED); and (iii) balance of system components (BOS) -- e.g. inverters, charge controllers and cables and wires. In combination with the continuously decreasing cost of solar panels, the overall cost for SHS, including lamps, a radio and a television, have declined by 64% from 991 USD in 2009 to 354 USD in 2014 (see Figure 10) (Orlandi et al., 2016).

The price for such a system is expected to decrease further by 50% over the next five years. Overall, however, solar panels in the range of 3-50 Wp are witnessing a slower decrease in price compared to larger, grid-connected systems simply because there is a minimum component unit price, which is independent of the size of the panel.

A similar trend can be observed for pico-systems. The retail price of pico-systems varies across countries depending on competition and volume in the market, as well as the type of product being sold. While 59% of all pico-solar units are priced below 20 USD, the price can go as low as 5 USD for a system. In Tanzania, mainly simple lanterns

Figure 11. Pico-solar lantern cost development (USD/unit)



Source: Orlandi et al. (2016)

are sold, resulting in a considerably lower average retail price compared to Kenya where higher end products below 10 Wp are dominating demand (see Figure 11).

In summary, the pico-scale solar products offered to customers in SSA are now available at significantly lower costs and with higher levels of efficiency, compared to six to eight years ago, which appears to be a key factor in driving the increased interest in investments.

3.3. THE EMERGENCE OF A NEW AND INNOVATIVE BUSINESS AND DELIVERY MODEL

Within the past 10 years a new and innovative business model has emerged, which has greatly contributed to the diffusion of pico-solar and SHS among lower income groups of society in SSA. This model has come to be known as the Pay-As-You-Go (PAYG) model where consumers are able to purchase smaller amounts of electricity based on their needs, instead of investing a considerable sum of money on purchasing the equipment up front. The PAYG model requires that a company, donor or



Photo credit: DFID – UK Department for International Development

utility owns and operates the equipment while servicing the local household's electricity needs. The household, in turn, pays for the service in smaller instalments over a period of 12-36 months (Rolffs et al., 2015).

The emergence of the modern PAYG model has been enabled by two crucial preconditions. The first relates to the diffusion of mobile phones and the spread of mobile payment schemes, initially developed in Kenya in 2007. The second is related to the introduction of new metering and monitoring technologies, which enable instant monitoring and regulation of electricity use. In combination, the widespread use of mobile phones, availability of mobile payment schemes and new metering technologies allow suppliers of Pico and SHS systems to monitor and regulate consumption remotely (Faris, 2015; Fox, 2015). Equipment use can be monitored in real-time by means of a telephone chip, and electricity will only be provided as long as the consumer is in advance of the payment agreement. Furthermore, mobile payments allow companies to collect large amounts of data on consumption patterns in order to optimize energy use for the consumer. While the current availability of PAYG lighting services in Africa is mainly concentrated in East

Africa, leading providers of PAYG solar systems are expanding their operations into other African countries. This regional expansion of small-scale solar products offered via PAYG systems is expected to continue in the coming years.

Currently, the companies with the highest market shares in East Africa providing Pico and SHS products via the PAYG model include: M-KOPA, Mobisol, Azuri Technologies, BBOXX and Solar-Now (Rolffs et al., 2015; Alstone et al., 2015).

Table 1 provides a description of Azuri Technologies to illustrate how the PAYG model forms an integrative part of the business model and activities of one of these firms.

3.4. THE INTRODUCTION OF A GLOBAL PRODUCT QUALITY CERTIFICATION SYSTEM

In 2010, a global certification scheme for pico-scale solar products was established by the World Bank's program entitled Lighting Africa. The program ran its first pilot projects in Ghana and Kenya, but is currently operating in 11 countries across Africa, and is planning to further expand on the African

Table 1. Key characteristics of Azuri Technologies

| Background and business model |
|---|
| <p>Azuri Technologies, with headquarters in Cambridge, UK, is currently the provider of SHS in SSA with the widest reach. It has operations in 11 different countries and staff based in Kenya, Uganda, Ghana, Ethiopia and Tanzania. Like other providers, Azuri is applying the PAYG business model to service rural, off-grid customers with solar energy. Customers can purchase credit either through SMS or mobile money to top up their unit for a given amount of time, and buy as much or as little as they want at any given time. Azuri engages extensively with local partners and communities in order to know the profiles of potential customers, and calculate a suitable payment schedule that allows flexible payment on behalf of the users. Additionally, the Azuri system observes and collects data on consumption patterns, which is used to tailor power provision to ensure that the service delivers the best user experience, depending on the available power.</p> |
| Distribution networks and training |
| <p>Azuri operates through local partners with already established distribution networks, which enables market penetration even in the most remote areas. Local partners provide the necessary upfront capital for purchasing and installing Azuri systems. Subsequently, the outlay is paid off by the on-going and regular top-ups of end users over the course of, typically, 18 months. This model has enabled Azuri to spread its activities across a number of countries since the company is able to focus on engaging with the local partners in each market, who, in turn, are only involved in the particular market they are serving. Furthermore, Azuri has implemented a “Train the Trainer” program where it trains its regional partners who, in turn, are required to train the local agents who finally have to train the end user. The training covers system development, sales training, technical installation, customer management and after sales support. As a result of the program, employment opportunities for people in local communities are created within retail, installation and after sales support.</p> |
| Funding and further expansion |
| <p>The PAYG business model could potentially spread across the African continent. In mid-2013, the replicable nature of the model was recognized through a 1 million USD award to Azuri from USAID’s Development Innovation Ventures for supporting the establishment of solar power in Rwanda. The funding will create a distribution channel, and supply 10,000 Azuri PAYG solar systems. The project is intended to serve as a template for how to replicate the model in other low-income countries. The key to accomplishing this is by working through previously established local distributors to reach communities at a pace that otherwise would not be possible. The spread and dissemination of PAYG solar services is indeed taking place at a high speed. In Kenya, one Azuri partner grew from being a single entrepreneur to comprising a team of six full-time and 50 part-time sub-dealers, installers and top-up card sellers within the span of 18 months. The demand for these services continues to boom, and there are many potential users yet to reach with these new innovation business and delivery models.</p> |
| Socioeconomic benefits |
| <p>Bringing electricity to rural off-grid areas brings with it a number of additional benefits. Aside from the jobs created for local agents and technicians, the availability of solar power enables additional revenue generation by letting local people keep their retail stalls open for longer, or process crops for more hours. Furthermore, due to electric lighting, children can study for longer in the evening, and people generally feel safer having a light bulb outside their house. The SHS also reduces the amount of time and money households need to spend for energy access; a significant drop in the use of kerosene is observed, which, in turn, has positive health and environmental effects.</p> |

Source: GNESD (2016)

continent. The certification scheme comprises a voluntary system with product quality standards for pico-scale solar lighting products. Currently, the system comprises 48 pico-solar systems and 6 SHS. The certification scheme provides unique statistical information on the sale of certified solar lighting products in Africa.

The aim of the certification scheme is to instil consumer confidence by ensuring a minimum level of product quality, and transparent advertising. Table 2 shows the main elements included in the quality standards for pico-solar products.

Table 2. Main elements of the quality standards used by Lighting Africa for pico-solar products

| | |
|-----------------------------|--|
| Truth in advertising | Advertising and marketing materials accurately reflect tested product performance. |
| Durability | Product is appropriately protected from water exposure and physical ingress, has durable switches and connectors and, if portable, survives being dropped. |
| System Quality | Product passes a visual wiring and assembly inspection. |
| Lumen maintenance | Product maintains consistent light output after 2,000 hours of operation. |
| Warranty | A consumer-facing warranty is available; the required warranty duration varies by product type. |

Source: Lighting Global (2015a)

The testing framework developed by Lighting Africa and Lighting Global has been adopted by the International Electrical Committee, and has been further integrated in national programs in countries such as Kenya and Ethiopia (Orlandi et al., 2016). Since 2015, testing of Pico systems below 10 Wp have been supplemented by testing of SHS larger than 10 Wp (Lighting Global, 2015b). In July 2016, 84 different products met Lighting Global's quality standards.

The voluntary quality assurance program under Lighting Africa has provided much-needed standardisation and has been embraced by approximately half of all pico-solar products. However, the program favours big transnational companies, which have the resources to develop products of the required quality and make them go through testing. A number of countries have considered setting up national test stations to ensure product quality of

imported units, but so far these attempts have not been successful due to the high number of different manufacturers and products. Regional communities, such as the West African Economic Community, are another avenue for establishing technical specifications and minimum quality standards to further expand the use of off-grid lighting products (Diecker et al., 2016). The idea is to help best available technologies spread between countries by cooperating on joint test laboratories and disseminating test results widely within the region.

In addition to the certification scheme, Lighting Africa also seeks to accelerate the expansion of the off-grid solar market by providing market intelligence and information, for example, in the form of supply chain mapping studies for various West African countries (see e.g. Chabanne et al., 2013; Dalberg, 2013a; Dalberg, 2013b).

4. Conclusion and policy implications

Within the past five years, Sub-Saharan Africa has witnessed incredible growth in the use of pico-scale solar PV products by private consumers. Sales have expanded from less than 100,000 units per year in 2010 to more than 4 million units in 2014, with forecasts expecting further growth in the future. The development has been particularly pronounced in Kenya, Ethiopia and Tanzania, but other countries are also picking up.

This report has drawn attention to four decisive factors that, in combination, seem to have coincided to enable the development of the market for pico-scale solar appliances.

First, the generally rising oil prices and derived (petroleum) products, notably diesel and kerosene, have led to an increase in household spending on lighting and electricity. This appears to have created an incentive for the demand for alternative, low-cost sources of lighting and electricity, including solar Pico and SHS systems.

The second factor points at the simultaneous decrease in the cost and increase in the efficiency of core components of solar products, such as solar panels, batteries, BOS components and LED technology. The price/efficiency improvements have meant that pico-solar products are now able to provide the same service as larger systems did previously, at a much lower cost. This has provided a strong impetus for making pico-scale solar appliances affordable and relevant for a larger part of the population, including those with low income.

Third, the emergence of new and innovative PAYG business models for payment and delivery of solar PV products is made possible by the widespread use of mobile phones and payment systems, such as the M-PESA system in Kenya. In combination with the introduction of new intelligent metering and monitoring technologies, suppliers of Pico and SHS systems are able to manage the provision and payment of electricity services efficiently. This has enabled entrepreneurs to target even the most

remote and low-income groups of society. In turn, the PAYG model offers customers the opportunity to purchase electricity when needed, on a daily basis, thereby avoiding high upfront costs.

The last factor draws attention to the global certification scheme introduced by Lighting Africa, which comprises a system for ensuring the quality of pico-scale solar products. This quality assurance system seems to have provided customers with a greater level of reliability and certainty in the products purchased. Nevertheless, the (large) market for products that are not in compliance with the standard system should not be underestimated, although customers may have less certainty in product quality.

While additional research is required to explore these factors and the observed market trends in further detail, some tentative implications may already be drawn at this stage. As described, the diffusion of small-scale solar in Africa over the last 10 years has gradually moved from being strongly supported by donor organizations to being a fully commercial product sold on market conditions by national and international enterprises to customers outside grid-connected areas. Interestingly, this trend of high-tech green energy solutions diffused by private enterprises can also be identified for the mini-grid sector, addressing people living in villages far from the existing grid. In Kenya, for example, since 2012, four private mini-grid operator start-ups have installed 20-30 mini-grids in the size of 1.4-10 kW, with a few examples of larger systems -- 20 and 50 kW. Two of the companies have received a formal license to operate, and one company has secured financing for establishing a portfolio of another 100 mini-grids (MoEP, 2016). The main difference in individual solutions is that Pico-solutions and SHS provide 12 Volt supply, while mini-grids provide 220 V grid power allowing more universal use of appliances.



Photo credit: DFID – UK Department for International Development

Despite obvious regulatory challenges, it is encouraging to see private sector actors providing solutions to energy supply in rural areas, both in terms of pico-lighting devices, larger SHS and, now, also as operators of mini-grids. The private sector interest indicates that the main technological achievements described in this paper --cost reduction of PV, emergence of energy efficient appliances (LED), and mobile phone-based PAYG technology-- have created the conditions for viable business models, which may ensure a fast roll out of electricity supply to rural areas. The main drawback in this development path is that leaving rural electrification to

the market, and leaving the old principles of equal tariffs in urban and rural areas have social implications benefitting the richest and leaving the poorest groups behind with traditional solutions.

With respect to supporting the poorest individual households outside the reach of grids and mini-grids, experience shows that it is difficult to reach this group with traditional support schemes linked to the product itself (Lee et al., 2016). Support should address the general economic conditions for the poorest groups, enabling them to procure the needed PV devices.

References

- A.T. Kearney and GOGILA, 2014. Investment and Finance Study for Off-Grid Lighting. A.T. Kearney Incorporated.
- Adomdza, G.K., McBagonluri, F., Kemausour, F., Nygaard, I., Hansen, U.E., Lauritzen, H., 2016. Exploring product development possibilities and alternative uses of PV solar cells in Ghana. Department of Energy Conversion and Storage, The Technical University of Denmark.
- Alstone, P., Gershenson, D., Turman-Bryant, N., Kammen, D.M., Jacobson, A., 2015. Off - Grid Power and Connectivity - Pay -As -You-Go financing and digital supply chains for pico-solar. University of California, Berkeley and Lighting Global.
- Bazilian, M., Onyeji, I., Liebreich, M., MacGill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D., Zhengrong, S., 2013. Re-considering the economics of photovoltaic power. *Renew. Energy* 53, 329–338. doi:10.1016/j.rene-2012.11.029
- Chabanne, A., Dansette, S., Lindner, K., Neebe, M., Siles, B.R., Taylor, H., 2013. Mapping the Supply Chain for Solar Lighting Products in Burkina Faso Final Report. MicroEnergy International.
- Dalberg, 2013a. Mapping the supply chain catering the base of the pyramid in Senegal. Lighting Africa.
- Dalberg, 2013b. Mapping the supply chain catering to the base of the pyramid in Mali. Dalberg.
- Diecker, J., Wheeldon, S., Scott, A., 2016. Accelerating access to electricity in Africa with off-grid solar: Policies to expand the market for solar household solutions. Overseas Development Institute.
- Faris, S., 2015. The Solar Company Making a Profit on Poor Africans. *Bloom. Businessweek* 1–11.
- Fox, B., 2015. Can “pay as you go” solar light up rural Africa? *African Bus. Mag.*
- Frauenhofer ISE, 2015. Current and Future Cost of Photovoltaics. Long-term scenarios for market development, system prices and LCOE of utility scale PV systems, Study on behalf of Agora Energiewende. Study on behalf of Agora Energiewende.
- GNESD, 2016. PayGo solar home systems to rural off-grid communities in Sub-Saharan Africa, GNESD Energy Access Database. <http://energy-access.gnesd.org/cases/50-paygo-solar-home-systems-to-rural-off-grid-communities-in-sub-saharan-africa.html>.
- Gongloff, M., 2015. Oil Prices Actually Aren't That Low , Historically Speaking. *Huffington post*. www.huffingtonpost.com/2015/01/13/crude-oil-price-chart_n_6463054.html (Accessed 21.10.16)
- Hagan, E. Ben, Mifsud, O.V., Diecker, J., 2015. Developing Effective Off-Grid Lighting Policy. UNEP.
- Hansen, U.E., Pedersen, M.B., Nygaard, I., 2015. Review of Solar PV market development in East Africa. *Renew. Sustain. Energy Rev.* 46, 236–248. doi:10.1016/j.rser.2015.02.046
- Jäger-Waldau, A., 2013. JRC Scientific and Policy Report: PV Status Report 2013. European Commission, DG Joint Research Centre, Luxembourg. doi:10.2790/93822
- Jäger-Waldau, A., 2014. JRC science and policy reports: PV Status Report 2014. European Commission, DG Joint Research Centre, Luxembourg. doi:10.2790/941403
- Kaplinsky, R., 2011. Schumacher meets schumpeter: Appropriate technology below the radar. *Res. Policy* 40, 193–203. doi:10.1016/j.respol.2010.10.003
- Lee, K., Brewer, E., Christiano, C., Meyo, F., Miguel, E., Podolsky, M., Rosa, J., Wolfram, C., 2016. Electrification for “under Grid” households in Rural Kenya. *Dev. Eng.* 1, 26–35. doi:10.1016/j.deveng.2015.12.001
- Lighting Global, 2015a. Lighting Global Quality Standards. Lighting Global.



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- Lighting Global, 2015b. Solar Home System Kit Quality Standards. Lighting Global.
- MoEP, 2016. Current activities and challenges to scaling up mini-grids in Kenya. Ministry of Energy and Petroleum, Kenya and ESMAP, World Bank.
- Moner-Girona, M., Ghanadan, R., Jacobson, A., Kammen, D.M., 2006. Decreasing PV Costs in Africa: Opportunities for Rural Electrification using Solar PV in Sub-Saharan Africa. *Refocus* 7, 40–45.
- Nygaard, I., 2009. Compatibility of rural electrification and promotion of low-carbon technologies in development countries: The case of Solar PV for Sub-Saharan Africa. *Eur. Rev. Energy Mark.* 3, 125–158.
- Orlandi, I., Tyabji, N., Chase, J., 2016. Off-grid solar market trends report 2016. Bloomberg New Energy Finance, World Bank, IFC and Global Off-grid Lighting Association. doi:10.1017/CBO9781107415324.004
- REN21, 2013. Renewables 2013: Global Status Report. Renewable Energy Policy Network for the 21st Century (REN21), Paris.
- Rolfs, P., Ockwell, D., Byrne, R., 2015. Beyond technology and finance: pay-as-you-go sustainable energy access and theories of social change. *Environ. Plan. A* 47, 2609–2627. doi:10.1177/0308518X15615368
- Scott, A., Miller, C., 2016. Accelerating access to electricity in Africa with off-grid solar: The market for solar household solutions. Overseas Development Institute.
- Tracy, J., Jacobson, A., 2012. The True Cost of Kerosene in Rural Africa. *Light. Africa Rep.* April 25, 1–10.
- UNEP, 2014. Lifting the Darkness on the Price of Light: Assessing the Effect of Fuel Subsidies in the Off-Grid Lighting Market. United Nations Environment Programme.

