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Solar Photovoltaics in sub-Saharan Africa – Addressing Barriers, Unlocking Potential

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Abstract

Africa is endowed with significant amounts of renewable energy (RE) resources, including solar energy. It receives some of the highest levels of annual radiation globally. Yet Africa remains the poorest region of the world, in terms of energy access – in contrast with its endowment. This reality, of abundant sunlight, leads some to have an almost fairy-tale idea about solar photovoltaic (PV) technology and its current role in enhancing access to energy in Africa. In this paper, some of the barriers facing solar PV energy systems development in most countries in Africa are discussed, and recommendation are made on how to address some of these barriers.

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Keywords: Utility.scale PV systems, levelised cost of electricity, reserve margins, solar home systems, feed.in tariff

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1. Introduction

The International Energy Agency (IEA) in 2014 estimated that about 620 million people in Africa, representing two-thirds of the continent's population of approximately 1 billion, do not have access to electricity [1]. In several countries, (Mauritania, Guinea, Burkina Faso, Niger, Chad, Central African Republic, D. R. Congo, etc.) more than three-quarters (75%) of the population has no electricity. With 15% of global population, Africa remains the most energy poor region in the world, contributing just

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about 2.4% of global GDP. As shown in Table 1, countries in the OECD region have average annual per capita electricity consumption of over 8000kWh, however, the average for Africa is just around 590kWh, 20% of the global average and 7% of what pertains in OECD economies. The picture becomes gloomier when the data is analysed to exclude the Maghreb Regions (Algeria, Egypt, Libya, Morocco, and Tunisia) and South Africa. These countries together constitute about 20% of Africa's population, but generate and consume more than 75% of electricity on the continent, and have a per capita consumption of over 2000 kWh/year. This leaves the rest of Africa, predominantly sub-Saharan Africa (SSA), with annual per capita consumption of around 170 kWh [3]. This energy situation stands in contrast with the vast energy resources that Africa is blessed with, both conventional and non-conventional.

Table 1: Key World Energy and Economic Indicators for 2014.

Region/Country/Economy	Population (Million)	% World Pop.	GDP (Bn 2005$)	Share of Global GDP (%)	Electricity Cons. Per Capita (kWh)	Cons per capita against global avg.(%)
World	7036	100	54588	100	2,972.57	100
OECD	1254	18	39490	72.3	8,090.11	272
Middle East	213	3	1430	2.6	3,708.92	125
Non-OECD Europe and Eurasia	341	5	1644	3.0	4,551.32	153
China	1358	19	4756	8.7	3,488.22	117
Asia	2320	33	3568	6.5	892.67	30
Non-OECD Americas	467	7	2369	4.3	2,096.36	71
Africa	1083	15	1331	2.4	591.87	20

Data source - [2]

Because of the triple and inter-connected effects of improved technology, reduction in photovoltaic (PV) module cost and policy initiatives, solar energy is expected to contribute substantially to the future global energy supply. Due to the geographical location of sub-Saharan Africa, its contribution to global supply of energy using solar could be more significant, if adequate infrastructure is available. The global cumulative installed capacity is noted to increase rapidly from 3700 MW in 2004 to over 177 GW in 2014 [4]. In terms of installed cumulative solar power, the top five countries as of the end of 2014 were Germany, China, Japan, Italy, and USA, with installed capacity of 38.2 GW, 28.1 GW, 23.3 GW, 18.5 GW and 18.3 GW, respectively. Despite the fact that most parts of Africa receive in excess of 2000 kWh (see Figure 1) of global solar radiation annually, the continent has not seen substantial development in solar energy power plants. It may be interesting to know that the cumulative installed solar PV power plant in Germany (a country located in a temperate region), in 2014 for example, was more than total installed capacity from all energy resources in individual countries in sub-Saharan Africa (except South Africa).

In view of this remarkable resource endowment, many have questioned why solar energy is not leading the way in Africa's electrification, particularly, in the face of rapid uptake of the technology at the global level. The objectives of this paper are to highlight and examine some of the factors that holding back the deployment of Solar PV technologies on the continent. The issues discuss in the paper would assist policy makers, project developers and the donor community to view the potential contribution of PV to energy access, energy supply and diversification within the context of the existing financial, social and technical constraints.

This paper is organized into three Sections. Section 1 reviews the energy situation in Africa in comparison with the rest of the world and contrasts its energy situation with its resource endowment. It also presents the motivation and objective of this paper. Using information from relevant literature, documented country experiences, publicly available data and authors' experience with the technology, Section 2 of this paper examines in some detail, key issues impacting the development of Solar PV on the continent and is discussed under three sub-sections, each dedicated to one of the application modes (off-grid, decentralized grid-connected and large-scale utility). The paper concludes in Section 3 by offering some suggestions in respect of the various application modes and the challenges they currently encounter on the continent.

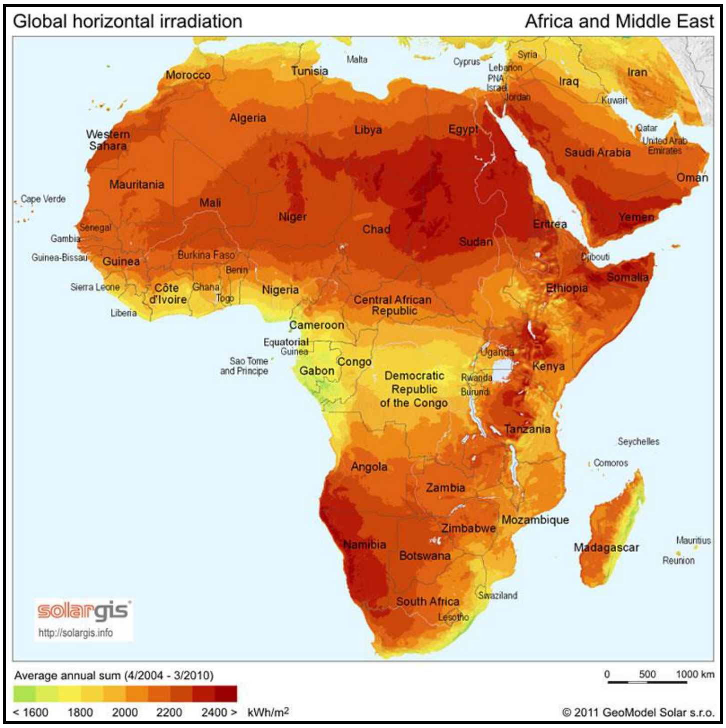

Figure 1: Global Solar Radiation Map for Africa and Middle East [5]

2. Solar PV in Africa –The issues

The section presents barriers to large-scale development of solar PV in Africa, especially in sub-Saharan Africa, under the following common development scale of solar PV systems: off-grid (stand-alone) systems, distributed and decentralised systems and centralised (utility) scale systems. The energy cost profile for solar PV applications shown in Figure 2 depicts how the nature of application influences the cost of electricity. In general, the investment cost and cost of energy decreases as the scale of PV systems increases.

2.1. Off-grid systems

There is an ongoing global effort by the United Nations (UNs) and World Bank, with a number of partners to provide access to sustainable energy for all by the year 2030 under the Sustainable Energy for All (SE4All) initiative [6]. The role of solar PV technologies in providing access to electricity in a least-cost approach (on a life-cycle basis), advancing the SE4All agenda and other national energy access programmes need to be well-studied in various national and community-specific contexts. Some authors [7-10] have discussed the minimum electricity requirements for households and service levels. However, the IEA [11] recently has adopted a definition that considers electricity access to involve a threshold of 250 and 500 kWh/year for rural and urban households, respectively. It is considered that this amount of electricity should be able to serve a 5-member household by powering for five hours a day, a floor fan, a mobile telephone and two compact fluorescent light bulbs for the rural households. Additional appliances such as an efficient refrigerator, a second mobile telephone and another appliance, such as a small television or a computer could be included for urban households. Energy access programmes for off-grid locations should, therefore, endeavour to meet these minimum service levels.

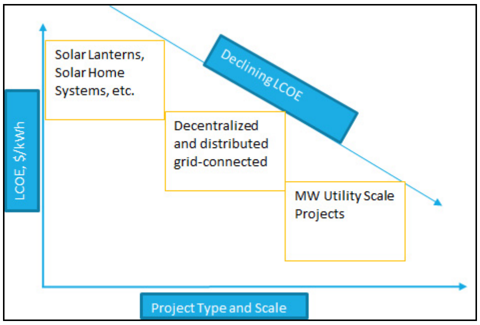

Fig 2: Solar PV application and cost of electricity (Authors' Construct)

It should be highlighted, that, Solar PV technology applications in off-grid mode contributes in a double way to the attainment of the SE4All objective – increasing both energy access and renewable energy mix. The off-grid energy systems can be defined as an energy systems that is not connected to a local, regional or national electricity transmission and distribution system (grid). Due to their mode of connection, off-grid systems are generally referred to as stand-alone systems. With an average electricity access rate of just over 30% in Africa (Baurzhan and Jenkins [12], Adams et al., [13]), a large population are without the electricity grid, and can currently only benefit from solar through off-grid applications.

The potential applications of solar PV in off-grid systems are shown in Figure 3, and samples of practical applications (shown in Figure 4) include solar home systems (SHS), solar lanterns and mobile phone charging systems. While these systems often replace inferior and health-threatening options such as kerosene lamps, dry cells, candles and sometimes-outright darkness, they represent the highest-cost end of solar PV applications.

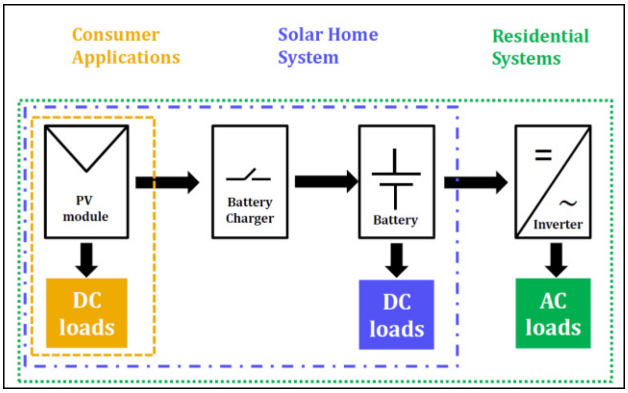

Figure 3: Types of off-grid solar PV systems and their components ((Authors' sketch)

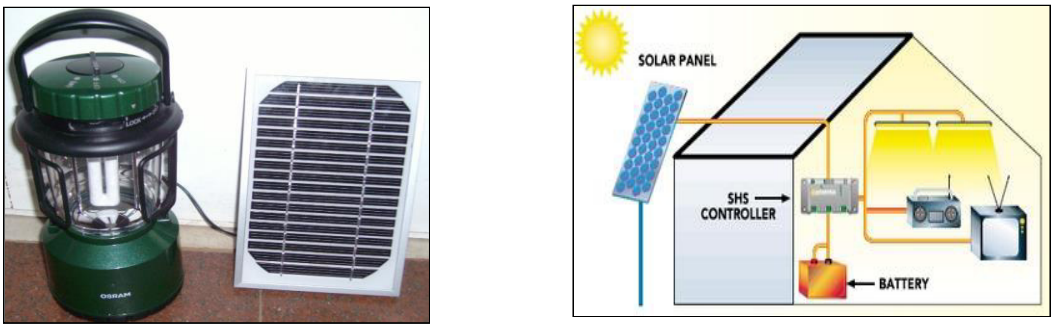

Figure 4: Off-Grid Solar PV Systems (left – Solar lantern[a], Right – Solar Home System [b](Schematic))

The IEA reports in its publication - *Pico Solar PV Systems for Remote Homes* [14], - that these Pico systems could cost as much as $20/W ($20,000/kW). In Kenya, for example, the cost of energy from solar home systems was reported as between $1 - $7.6/kWh, depending on the battery type used [15]. Some reasons for the generally high cost of these systems include the fact that they must always come with

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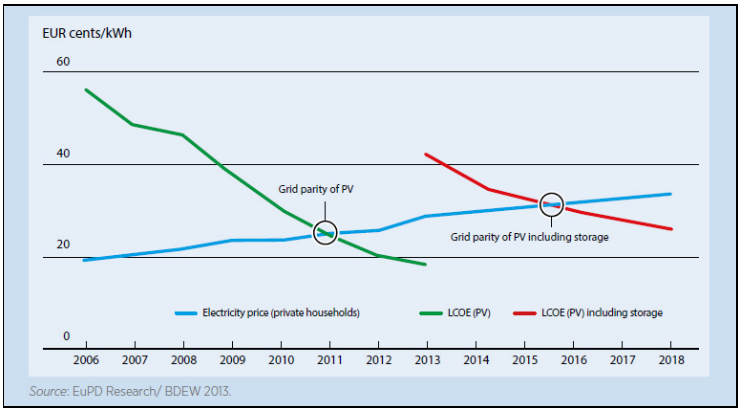
[a] http://www.solagenpower.com/SolarLanterns.html
[b] http://www.zimsolar.co.uk/L1_rural_solar_systems.htm

battery storage (which significantly increases the cost), underdeveloped markets and supply chains [16] [17]. The cost of PV with battery storage remains very high, and even in relatively developed markets such as Germany and US, such systems are hardly cost-competitive with grid-tied PV-inverter option (since cost of battery is avoided) and the cost of electricity from the utility grid. Projections from charts made available by IRENA (International Renewable Energy Agency) in Figure 5 indicate that, while grid-parity was reached for private households in Germany in 2011, parity for systems that include battery storage will have to wait until sometime in 2016 to be competitive. A similar study by the Rocky Mountain Institute (RMI) [18], shows that a significant segment of American electricity consumers will have to wait for up to 30 years for PV with storage to become competitive with grid-based electricity (see Fig 6).



Source: EuPD Research/ BDEW 2013.

Figure 5: Grid parity of PV-storage in Germany [19]

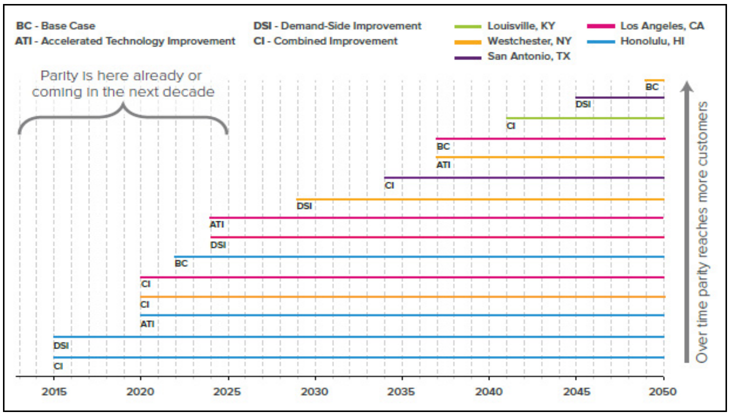


Figure 6: Grid Parity Timeline for Residential Customers [18]

The key issues facing small-scale off-grid solar PV systems in most African countries are lack and access to financial support. Although, recent years have seen the development of several innovative micro-financing schemes in support of the delivery of off-grid PV solutions to many rural communities in Africa, these micro-credit schemes, nonetheless, only make it easier to pay for systems whose energy delivery cost remain the highest. Since some of the off-gird packages come in low wattage units, and are designed to go for as low as US$36 or less [14], the extremely high cost of energy that these end-users are paying tends to be obscured. Solar PV with battery storage currently occupies niche spaces such as remote telecoms repeater stations and off-grid vacation homes for the generally well-to-do [20]. It should be mentioned that, even though the investment cost of these systems are relatively cheap, most rural dwellers living on less than US$2 per day, and hence, they cannot afford these systems without financial assistance [12, 21).

2.2. Distributed and decentralized systems

Grid-connected systems typically comprise solar modules and grid-type inverters while the grid serve as the storage facility, thus avoiding the cost of batteries. They are usually installed utilising rooftop spaces and (and car parks), and are designed to feed into the distribution utility grid (with configurations that allow self-consumption). In this arrangement, when the PV produces more electricity than needed, the surplus electricity is fed into the grid while, electricity is taken from the grid when it produces less electricity than needed. Figure 7 shows the schematic of a typical grid-connected solar PV system. Because they avoid the cost of batteries, they significantly reduce system cost (installation cost), and, therefore, the cost of electricity generated is lower than systems with battery storage. Small grid-connected systems mounted on rooftops have been responsible for powering the phenomenal growth of solar PV in Germany and other leading countries around the world (Figure 8). They have been incentivized by schemes such as (micro) Feed in Tariffs (FiTs) and net-metering schemes. By close of 2014, the number of countries with feed-in policies had risen from 34 in 2004 to 108 [4]. The main key barriers to decentralised solar PV are low grid coverage and unreliable grids as well as absence of enabling regulations, institutional frameworks and policies in most SSA countries. These barriers are briefly discussed below.

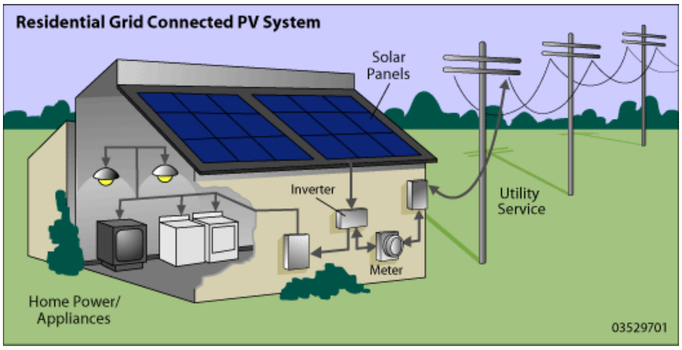


Figure 7: Schematic of a Residential Grid-Connected PV System (http://www.mathworks.com/)

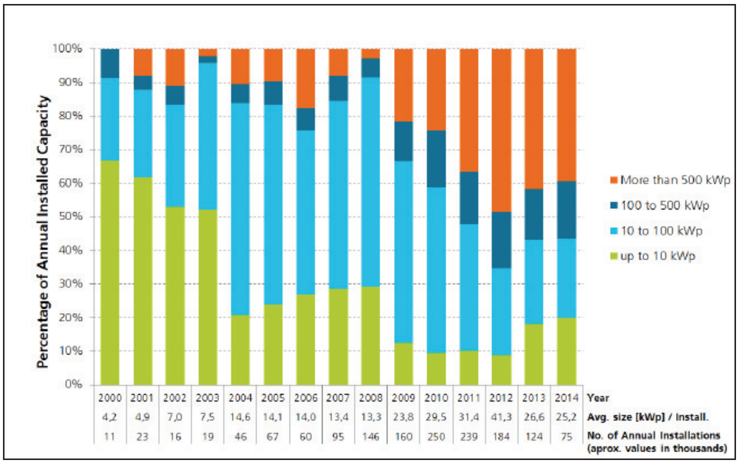


Figure 8: PV Systems Annually Installed in Germany [22]

2.2.1 Low grid coverage and unstable grids

With rather low levels of electrification, a very significant proportion of the population in Africa simply do not currently have this lower-cost PV application as an option, as argued in section 1; the estimated two-thirds without electricity in Africa can only currently utilize PV in off-grid mode. This consequently limits the extent to which grid-connected applications could be deployed in most Africa countries. In countries such as Ghana, South Africa, Nigeria and the countries of the Maghreb region, where grid coverage and electrification rates are high, the reliability (power outage) and stability of the grid are major obstacles. The World Bank estimates that African manufacturing enterprises experience power outages on average 56 days per year [23]. Figure 9 from the World Bank Enterprise Surveys shows the frequency and duration of outages of occurrence in selected regions. On average, number of power outages in SSA region is 8.3 times in a month and each lasted for 5 hours per outage compared with 6.3 times and 2.8 hours per outage, respectively.

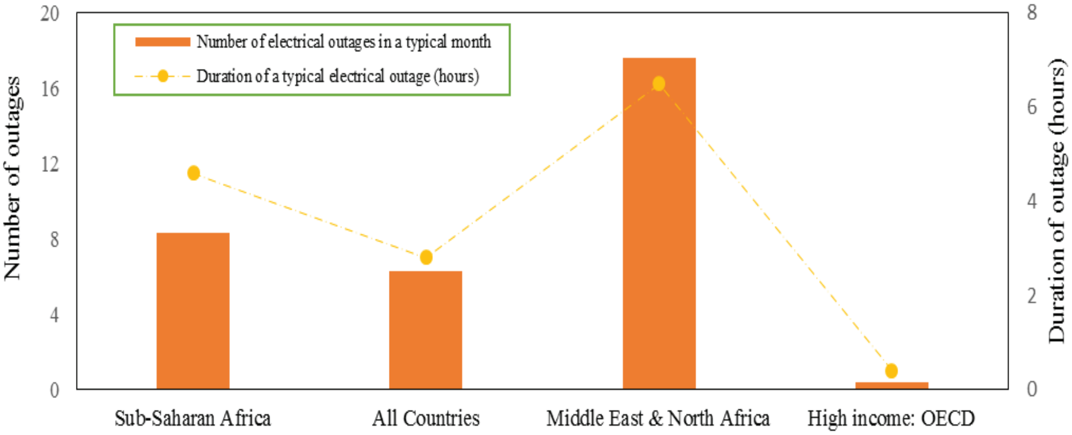


Figure 9: Power Outage Statistic in Africa and Other Regions [24]

System owners in OECD and other developed economies tend to use grid-connected solar PV (supported by Government incentives) to reduce consumption from grid and reduce utility bills. Africa's grids, however, are characterised by high downtimes and cannot serve as *storage batteries*. Since grid-connected systems are designed to disengage from the grid when it is down, the high power outage rates of the distribution networks in Africa means that such PV systems will stop generating when the grid is down. In the absence of loads such as pumps, which are able to operate directly on the output of PV systems, the installation produces no energy even when the sun is shining. Additional investment in battery and Islanding systems add significantly to cost and complexity of the systems' design and operation. A major need in Africa is reliable power for domestic users and businesses, and this need is technology-blind. In the service of this need, viable technology options include gensets (gasoline and diesel based) and solar PV with battery storage. Gensets are commonplace because they are cheaper to purchase and even though levelized cost of electricity (LCOE) is higher than solar PV (with storage) in some instances, it is, from a practical point of view, a more accessible option than the alternative, in which one pays now for electricity to be used in several years to come. Generator ownership rate among enterprises is SSA countries is the highest in the world (see Figure 10).

Figure 10: Generator ownership among enterprises [24]

2.2.2 Absence of enabling regulations and policies

Although many African governments are beginning to put in place supportive regulations and policies, the framework that guides interconnection with the distribution network and spelling out sell-back rates and periods of accounts balancing between customers and the distribution utility does not exist in several countries. Tunisia is reported to have a net-metering system in place [25]. Ghana has also recently developed its net metering code [26], while Kenya and South Africa are developing such regulations [25], [27][c]. In addition to the absence of required regulations, technical capacity, for example in the installation and management of bi-directional meters and implementation of new or adapted information management systems are lacking. Further, the general absence of investment support and long-term, low interest rate credit (as pertains elsewhere) implies that systems have to be equity financed (and most often paid for prior to installations). The alternative is to finance with short-term, high interest loans, with rates as high as 30% p.a. [28].

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[c] South African National Electricity Regulator

2.3. Centralised/utility scale projects

Centralised (utility) scale PV systems are usually in the order of megawatts, and are developed by power generation utilities (both state and private). In 2010, the West African island of Cape Verde commissioned a 7.5 MW solar PV power plant, which was reputed to be Africa's largest at the time [29]. Since then, several African countries either have commissioned plants of similar scale, or concluded contracts for construction. Selected projects are shown in Table 2. The potential for utility-scale solar PV in Africa is enormous. Studies by IRENA [30] suggest a theoretical annual electricity generation potential of 660,000 TWh for Solar PV in Africa. This is approximately 900 times the current annual generation of 750 TWh on the continent. A study by the United Nations Environment Programme (UNEP), which investigated the potential for solar electricity trade in West Africa, estimated that about 1% of land in Ghana could generate up to 16700 GWh of electricity per year [31].

Table 2: Solar PV Projects across Africa

Country	Capacity, MW	Year	Project Developers/Funding Agencies
Egypt[d]	50	2015	New & Renewable Energy Authority (NREA)
Burkina Faso[e]	30	2014	SONABEL, EIB, EU
Nigeria[f]	30	2013	Nigeria National Energy Council
Zambia[g]	100	2015	Energy Zambia Limited (IEZL)/General Electric/ Rhino Engineering/Belectric
Kenya[h]	320	2015	TARDA (Kenya), Ultra Clean Energy Solutions and Hitachi India.

The cost of solar PV continues to drop, and in 2014/15, tenders in Brazil, Dubai and Panama yielded electricity prices as low as \$0.06/kWh - \$0.087/kWh [4]. These bright prospects, notwithstanding, key barriers need to be surmounted for Africa's power sector to realise the potential contribution of Solar PV at the utility scale. The major barriers to large assimilation of centralised solar PV system relate to technical capacity of grid infrastructure and reserve capacity in most SSA countries. The solar resource varies significantly throughout the day and is not available in the night. This variation in resource availability directly affects the output of power plants, and presents significant challenges for grid managers who must keep electricity transmission and distribution systems balanced and stable. An IEA report on the integration of variable renewable resources into electricity grids [32] emphasizes the need for grid systems to have flexibility resources to manage the intermittency of electricity productions from

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[d] http://www.pv-magazine.com/news/details/beitrag/egypt-unveils-50-mw-pv-project-and-50-mw-module-fab_100019986/#axzz3k1TUJVhY

[e] http://www.eib.org/infocentre/press/releases/all/2014/2014-201-west-african-solar-project-gets-eur-23m-eib-backing.htm

[f] http://www.pv-magazine.com/news/details/beitrag/nigeria-partners-with-germany-on-420-mw-solar-projects_100013206/#ixzz3k1fUmtIr

[g] http://www.agenceecofin.com/solaire/1606-29816-zambie-general-electric-entamera-bientot-la-construction-de-la-centrale-solaire-de-kumi-kumi-zuba

[h] http://www.greentechlead.com/solar/tarda-plans-320-mw-solar-park-in-kenya-28222

variable renewable resources. The report identifies dispatchable power plants with the ability to ramp output up and down on demand as the largest source of flexibility in current power systems.

African grids are characterized by very low or no reserve margins, and countries like Ghana and South Africa have been shedding load because of inadequate levels of generation. This situation puts constraints on the potential of solar PV at the utility scale. In spite of the rapid growth of solar PV, globally, it still constitutes a rather small amount of generation in national grid networks, partly due to grid-integration challenges (See Table 3). The EU, which is world leading in solar installations, accounts for just about 7% of its installed capacity and 2.1% of generation with solar PV, and this is dominated by small distributed systems as shown in Figure 8. The challenge of integration and potential impact on national grid led authorities in Ghana (for example), in 2014, to impose a cap of 150 MW for utility scale solar PV in the national grid, in capacities not exceeding 20 MW per single installation [33].

Table 3: Levels of Solar PV Integration in Regional Networks

Region	Installed Capacity (Total), GW	% Solar (Capacity)	% Solar (Generation)
Global	5683	1.70%	0.4
EU	960	7.20%	2.1
OECD Americas	1356	0.10%	0.2
OECD Asia Oceania	454	2.20%	0.5

Source: [34][i]

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[i] The Energy Technology Systems Analysis Programme (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976.

Another barrier to the large-scale development of centralised solar PV installation is the issue of Power Purchase Agreements (PPAs). The PPAs signed by utilities have had issues with bankability without government guarantees. Early MW-Scale projects in Africa, registered in countries such as Cape Verde and Ghana had significant government-level involvement [29, 35]. In Ghana, for example, the Electricity Company of Ghana (ECG), is mandated by the Renewable Energy Law of 2011 to sign Power Purchase Agreements (PPAs) with investors under the Feed-in-tariff programme, which is currently at $Cent 18.25 - 20.14/kWh depending on whether the installation has grid-stability systems [36, 37]. Yet, the ECG has continuously made operating losses over the past years [38] and has had difficulties in honouring payments to its power suppliers in the conventional power sector [39]. In the absence of government guarantees, the poor financial integrity of the power utilities makes their ability to honour long-term PPAs questionable. This constitutes a major barrier to the development of this segment of Solar PV Projects. A transition from government-led and largely donor-supported PV investments to a regime that takes advantage of private capital and the continuous decline in PV prices is unlikely to take place in Africa despite the passage of renewable energy laws and the publication of Feed-in-tariffs. Financially viable utilities and off-takers are critical to this transition.

3. Concluding Remarks

In the case of off-grid systems, which typically come in low wattage and have restrictive usage, they must clearly be seen as interim and transitional solutions. Additionally, they must be delivered with significant levels of grant financing as a means of ensuring equity between those in off-grid locations and grid-connected communities. It should be noted that in most African countries grid infrastructure is usually publicly financed (including funds from taxes of off-grid dwellers). Therefore, effort should be made either to extend grid or to develop community-based micro/mini (hybrid) grids depending on economics and other strategic considerations within the national context. High quality electricity, beyond basic lighting and mobile-phone charging services, is a pre-requisite for the growth of enterprises and an escape from the vicious cycle of poverty for millions in Africa. A transition from small solar home system (SHS), pico-watt lighting and phone-charging solutions to national grid or mini-grid (RE-based/RE-supported) systems should be accomplished as quickly as practicable. It is proposed that the target year of the SE4All initiative (2030) be adopted in this transition.

For the distributed and decentralized systems, regulations need to be developed for this segment of PV applications, as many of the current arrangements focus on large MW-scale PV systems. This segment holds enormous prospect in unlocking the potential of solar power in Africa, and opening up participation by thousands of homes and organizations.

To enable power grids in Africa to integrate significant shares of large-scale centralized power plant, there is the need to invest in strengthening transmission infrastructure. The new transmission infrastructure should have a portfolio of dispatchable power technologies (both conventional and non-conventional) that have the ability to ramp up and down at the required rates in response to fluctuations that Solar PV plants introduce to the interconnected systems. This implies improving reserve margin of the power systems.

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