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Thinking outside the Grid: The role of decentralized power systems in electrifying Sub Saharan Africa

By Rim Berahab

Summary

Meeting the energy needs of the developing world remains a critical development priority. Access to energy has been identified as correlating with economic growth as well as having positive impacts on education and health[1]. In sub-Saharan Africa, access to electricity has increased significantly since the 2000s, driven by the considerable efforts of countries such as Côte d'Ivoire, Ethiopia, Ghana, Kenya and Tanzania. But, despite this positive turnaround, nearly 600 million people still do not have access to electricity, as electrification efforts have often been in vain in keeping pace with population growth[2]. Furthermore, electrification progress has been uneven across regions, translating into a two-speed Africa in terms of access to electricity, just as there is a two-speed Africa in terms of economic growth. This further highlights the urgent need to improve electricity distribution and connection in the continent. Therefore, the need for innovative approaches to address this lack of electricity access while at the same time transitioning to a decarbonized energy system is arising. In this context, while many African countries chose to pursue ambitious and sometimes challenging grid connection programs, decentralized electricity generation and distribution are gaining increasing attention. This brief explores the mini-grid approach and its role in bridging the electrification gap in Sub-Saharan Africa, after identifying the limits of the grid expansion approach.

1. Ozturk, 2010; Wolde-Rufael, 2006, Kanagawa & Nakata, 2008
2. Pilling and Fick, 2017

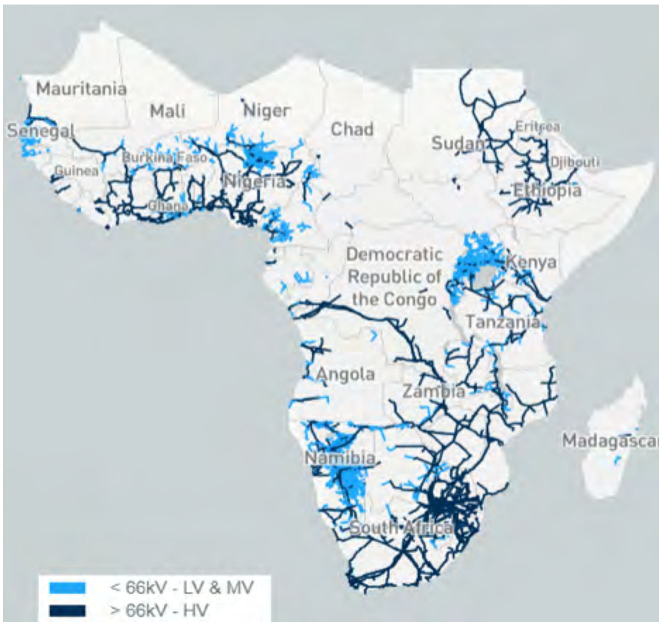
Grid expansion: Instrumental yet faced with several barriers

Historically, centralized grid expansion has been the primary pathway to electrification both at the worldwide level and in Sub-Saharan Africa. It was considered a development prerequisite, with the supply of electricity and infrastructure setting the stage for economic growth[3]. On-grid electricity provided to households is defined as electricity delivered via a connection to a local grid linked to a transmission network. Typically, grids are supplied by large centralized power plants, using either coal, natural gas or hydroelectricity[4]. Updated data regarding existing grid lines in Sub-Saharan Africa is very scarce (Figure 1). However, four main power pools can be identified: The Eastern Africa Power Pool (EAPP), the West African Power Pool (WAPP), the Southern African Power Pool (SAPP) and the Central African Power Pool (CAPP). Their main objectives are to facilitate and secure power supply to the countries constituting them and to foster power system connectivity[5]. These four power pools totalized an installed capacity of 141806 MW in 2015[6] compared to 114962 MW in 2010. Yet, about 57% of the Sub-Saharan population still lacks access to electricity in 2017 or suffers from electricity outages.

It is true that, under certain circumstances, centralized grid expansion is considered the most economical solution for electricity access. However, it is only cost effective when built to serve an area with a high population density. This entails that big centralized grids are mainly located around important urban areas, excluding large sections of the population living in inaccessible rural areas[7]. Moreover, grid electrification in Sub-Saharan Africa is faced with both supply-side and demand-side impediments. On the supply-side challenges, the issue lies especially in the shortage of supply due to a limited infrastructure for the generation, transmission and distribution rather than with the generation systems. Regarding the demand-side challenges, which are believed to make up roughly two-fifths of the electricity access gap in Sub-Saharan Africa[8], the constraints revolve around two factors than can dissuade households from getting a connection to the national grid, thus undermining electrification efforts : power outages, and complex and costly grid connections resulting in high electricity tariffs[9].

Power outages are an important driver of end-user behaviors. When access to electricity is reliable, the electricity uptake rate, meaning the rate of electricity consumption through a connected grid, is high. On the other hand, frequent blackouts tend to be negatively linked to urban electrification rates due to, in large part, extra costs borne by the consumers, which deters them from connecting to the grid. Indeed, unreliable electricity provision pushes households to rely on other inferior and sometimes hazardous sources of energy, like traditional biomass such as wood fuels. This means that the household attached to the national grid will be charged for the consumption of two separate sources of energy – the electricity coming from its connection to the national utility grid and a secondary precarious source of energy. Hence, the potential benefit of investing in a centralized electrical grid becomes uncertain. As an illustration, more than half of the households connected to the main grid, across Sub-Saharan Africa, reported receiving electricity less than half of the time (Figure 2)[10].

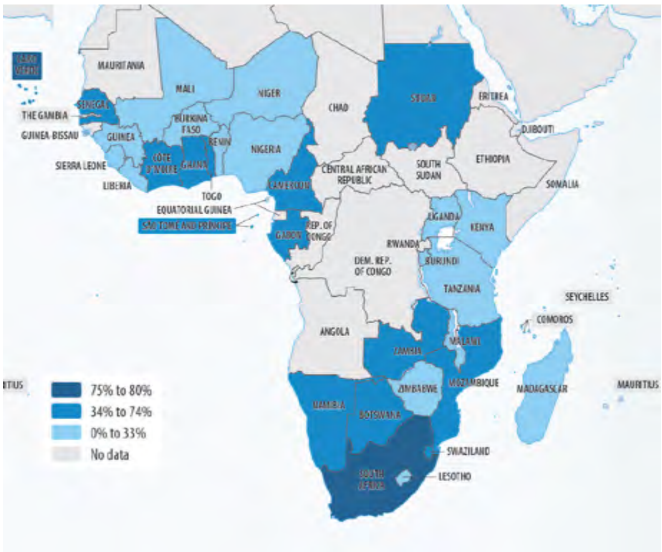
Figure 1: Existing Grid Lines for Sub-Saharan Africa's Countries



Source: Africa Electricity Grids Explorer, Blimpo and Cosgrove-Davies 2018.

3. GVEP, 2011
4. IEA, 2017
5. ICA, 2016
6. Or latest year available
7. Díaz et al, 2010, Tenenbaum et al, 2014
8. Blimpo and Postepska 2017
9. Arlet, Ereshchenko, and Lopez Rocha, 2019
10. Blimpo and Cosgrove-Davies 2019.

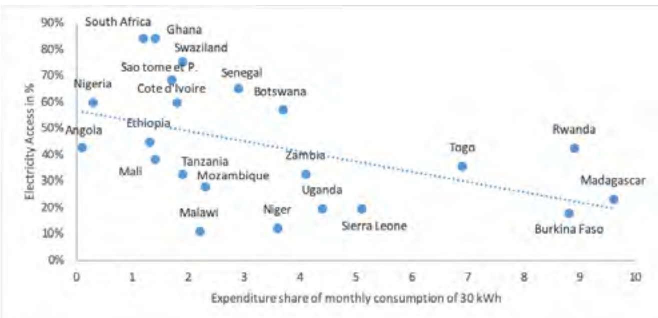
Figure 2: Indicators for of Electricity Reliability Households in Sub-Saharan Africa



Source: Africa Electricity Grids Explorer, Blimpo and Cosgrove-Davies 2018.

Another demand-side factor impeding Sub-Saharan Africa's electricity access is the cost and complexity of the grid connection process. Countries with higher costs, longer time period and complicated procedures to connect to the electricity grid tend to have lower electrification rates[11]. This raises the issue of the unaffordability of grid electricity in some areas. While grid electricity can be cost-competitive and affordable in largely populated urban areas, in secluded areas, grid expansion is usually very expensive due to the costly infrastructureal investments needed, which results in high electricity tariffs. As a consequence, if households cannot afford electricity, they are less likely to connect to the grid (Figure 3).

Figure 3: When Electricity Bills Are High, Electricity Access Is Lower



Source: Kojima et al. 2016. World Bank staff calculations based on utility information and household survey data. Data used is from 2016.

11. Golumbeanu and Barnes, 2013.

As an attempt to expand access to electricity, some African governments tried to subsidize the use of electricity, the cost of connection to the grid electricity supply, or sometimes both. Yet, there is little room for large-scale government support, giving falling fiscal balances[12]. Therefore, while it is undeniable that centralized grid expansion was instrumental in electrifying Sub-Saharan Africa, it has many limitations that have hampered the electrification process so far. Hence, improving access to the grid remains crucial, and requires policies that tackle both supply and demand obstacles. In this context, decentralized power systems are attracting great interest, not as an alternative to grid extension, but rather as a complementary solution, since they can provide electricity to remote or sparsely populated areas, making them more affordable than grid extension in some regions[13].

Decentralized energy systems: A new approach to electrification

Decentralized energy systems are a relatively new approach in the energy industry. They are used as a complementary measure to the existing centralized grid in order to bring power sources closer to the end-user. They also offer promising opportunities for the deployment of renewable energy, the reduction of inefficiencies in electricity transmission and distribution, and the expansion of energy access to remote communities, usually rural areas, where grid extensions are unfeasible. Decentralized electricity access is commonly provided either through mini-grid solutions or off-grid systems such as stand-alone power systems (SAPS) (Figure 4).

A mini-grid system is a localized power network where a totality or a portion of the electricity produced is injected into a small isolated distribution grid[14]. These solutions can supply several households, ranging from a village to several thousand inhabitants. Electricity production from mini-grids can be based on different sources, either from fuel, renewables, or both, with a range starting from 10 kW for 40 customers to several MW for more than 4000 MW.Customers Those customers should verify three conditions: they should be far from

12. Kojima and Trimble 2016.

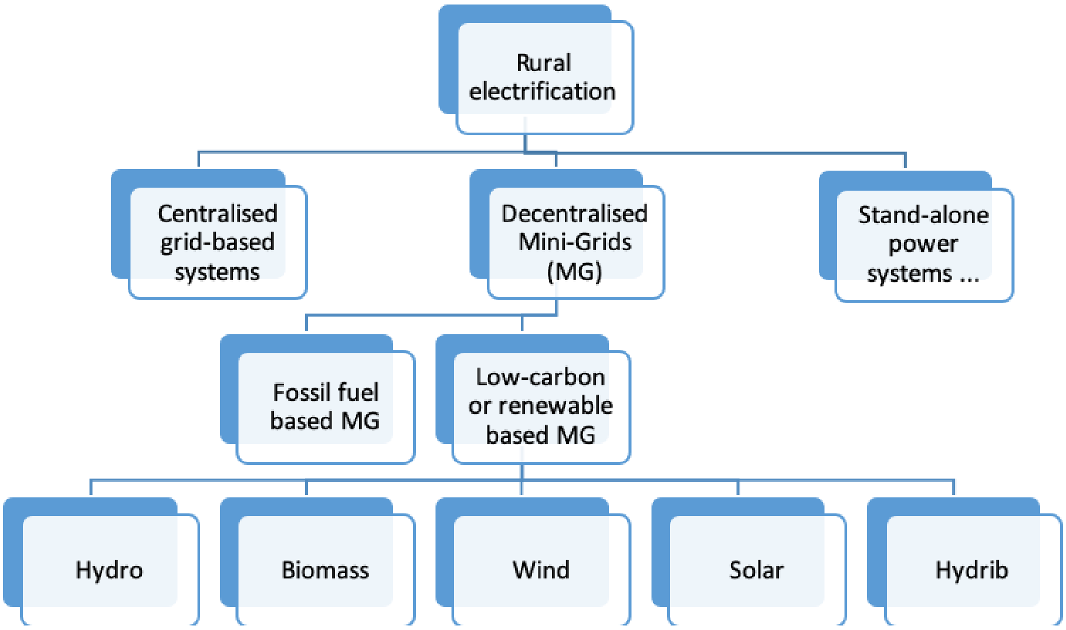
13. Szabó et al., 2011.

14. Capacity4dev.eu, 2016.

the main grid, relatively close to each other, and with sufficient load demand. A mini-grid system can be, later on, connected to the main grid. A stand-alone power system, on the other hand, is an off-grid system that powers single households with one or several generator sources and various electrical appliances[15]. Unless mentioned otherwise, the rest of this Policy Brief will focus on mini-grid systems.

15 Depending on power dimension, they can be classified in four categories: portable lights (rechargeable & solar lanterns), mini kits (pico hydro & pico solar systems), Home Systems (supplied by solar SHS or pico-hydro) and residential Systems (hydro, wind or solar –with diesel backup or not).

Figure 4: Rural electrification approaches



Source: IED, 2012. Sustainable Energy Handbook, 2016.

A mini-grid system is generally composed of a power generator, either with or without storage, a distribution network, a service drop, and a customer installation.

The most commonly used power generator in Africa is a diesel genset, but other types of power generators exist such as hydropower plants, biomass plants, solar pants or wind plants. It is also possible to combine different sources and storage solutions, thus forming a hybrid generator. Each of these power generator types has its advantages and disadvantages (Table 1). For instance, an exclusively diesel-fed system has the advantage of lower capital costs (CAPEX). However, the running cost, or operation expenditures (OPEX), can be very high because of the volatility of fuel prices, the scarcity in supply and the relatively lower generator lifetime. On the opposite spectrum, a fully renewable energy system is characterized by a high capital cost but much lower operational costs[16]. Therefore, an arbitration is required, depending on the demand and load duration curve,[17] as well as on the available renewable resources. Moreover, if conventional fuel, hydro, and biomass generators can usually run continually as they can easily be stored in either a fuel tank, a biomass warehouse or a water dam; with other irregular renewable sources like solar and wind, energy storage might be necessary to improve the penetration and tackle the intermittency issue. In addition, the need for storage is determined by other factors such as the daily load curve and the demand peaks.

16. A renewable energy generator would produce electricity at a levelled cost below the marginal cost of producing that electricity from fuel oil.

17. Load curve is the variation of load with time on a Power Station. A load duration curve (LDC) is used in electric power generation to illustrate the relationship between generating capacity requirements and capacity utilization.

Table 1: Advantages and disadvantages of different types of power generators

Power generator	Advantages	Disadvantages
Conventional fuel genset (Diesel/ gasoline/ Compressed Natural Gas)	Widely spread in Africa Rapid implementation Low investment cost (CAPEX)	High running costs (OPEX)[18] Limited hours/day High environmental impact
Hydro Power (Micro 10-500 kW/ Mini 0,5-10MW)	Water storage (limited) Continuous supply (24h)	Seasonal variation Water use impact (irrigation)
Biomass (Biodigesters/ gasifiers/ biofuels/ cogeneration)	Low cost renewable "fuels" Liquid or solid fuel storage	Seasonal variation High maintenance level By-product disposal
Hybrid systems (solar/wind/diesel/ storage)	Low running costs Continuous supply (24h) Environmentally friendly Increased reliability and load adaptation	Intermittent source Expensive storage required Complex energy management

Source: Sustainable Energy Handbook, 2016

A **distribution network** transmits electricity to end-users or loads at a limited distance from the generators. It comprises transmission lines, transformers and the infrastructure required to permit safe and efficient energy distribution.[18] Different types of distribution networks exist. Based on load requirements and the cost of the project, a distribution network can be an alternative (AC) or direct current (DC), a low or medium voltage, a single of three phases meter[19] etc… For example, although AC has many benefits, as it allows for effective electricity transmission over distances and meets the requirements for consumer appliances; it is also generally more expensive than DC because of the enhanced power electronics. Over the long term, the distribution networks can influence the interconnection conditions of connecting to the main grid.

A **service drop** is constituted of cables and accessories needed to connect the nearest distribution network and the **end-user meter**. Regarding the latter, there is a wide range of options, from basic current limiters combined with flat rate tariff and conventional meters to the sophisticated pre-paid meters with data loggers. The recent years have witnessed the emergence of smart technologies that not only enable better mini-grid system control in terms of generation and distribution, but also enable better customers' management. The increased use of Information and Communication Technology (ICT) played a big role in this as smart meters have emerged, as well as new payment schemes using mobile payment platforms.

18. Operating expenses include all costs associated with operating and maintaining mini grid equipment, including fuel, maintenance, repairs, payment collection, and security
19. Single phase induction type energy meter is also popularly known as watt-hour meter. The three phase meter is constructed by connecting the two single phase meter through the shaft.

Organizational models for mini-grids: Different types for different scenarios

There is a wide diversity in the institutional and financial structures of mini-grids, depending on local socio-economic conditions and on the regulatory framework of each country. Mini-grids can be owned and managed by the state, private sector, communities or a combination of different actors who would be involved in different aspects of building and managing the mini-grid. In the literature, four approaches can be distinguished[20]:

- **Utility-based approach**: This strategy is most prevalent for rural electrification in developing countries. The engineering, procurement of equipment and construction of mini-grid solutions is usually ensured by a Rural Electrification Agency. Once built, the mini-grid is turned over to the utility, that can be either a national or regional public

20. World Bank, 2008; USAID/ARE, 2011, GVEP, 2011, Capacity4dev.eu, 2016.

institution, investor-owned or a cooperative, for technical operation, electricity sales, and customer billing at the national rate. Regarding the billing, the government may require the utility to apply prices similar to those charged by the national grid. In this case, tariffs paid by larger consumers connected to the national grid can be utilized to cross-subsidies mini-grid consumers[21]. Initial financing is most likely to be supplied by the utility and subsidized by actors such as the government or donors[22].

- **Private sector operator**: In this approach, a private sector operator oversees all aspects of establishing a mini-grid system, from planning, building, managing to operating. In some cases, ownership of the mini-grid may be passed on to another actor. The funding required for building the mini-grid can either come solely from private sources, which is rare, or from private equity and commercial loans with some sort of government support such as grants, subsidies or public sector loan guarantees. Although the capacity of private sector mini-grids can be lower than those set up by national utilities, they are gaining increased focus due to improvements in technology, innovations in finance, and the development of customer-management platforms and continuous support from donors and national governments[23].

- **Community-based model**: In this business plan, the mini-grid is owned, operated and managed by the local community, who is organized in a cooperative that is governed by government regulations. These types of systems are mainly found in developing countries where the private sector or public services' involvement is still scarce. Financing for mini-grids set up under a community-based model is usually heavily grant-based with some input from the community. Since local communities lack the technical and economic skills to develop and implement mini-girds, the planning, procurement of equipment, installation and commissioning of the project is usually carried out by third parties. To ensure the long-term operation of such models, it is important that community-operated mini-grids charge tariffs that cover at least reinvestment/depreciation, operations and maintenance costs. In addition, it is essential to have the necessary skills for mini-grids operation and maintenance available in the local area to guarantee the durability and sustainability of the mini-grids.

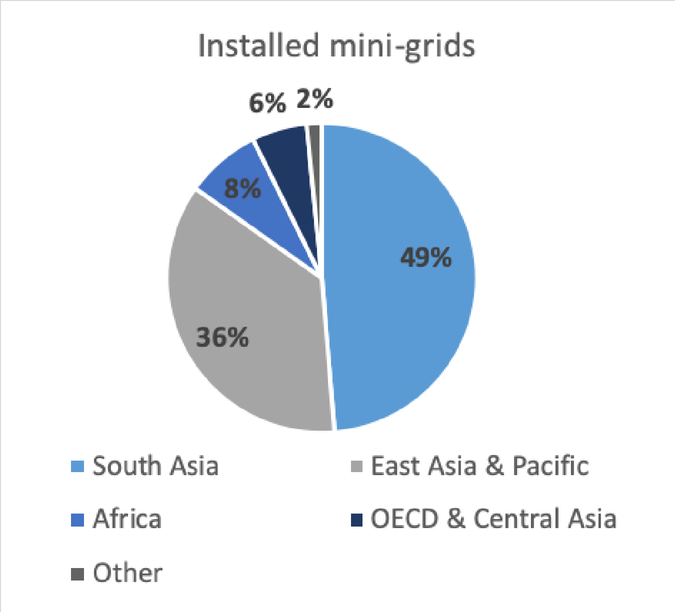
- **Hybrid business model**: This approach integrates various aspects of the different models mentioned above in order to eliminate risks and maximize effectiveness and efficiency. These types of models may involve different entities in investment, ownership, and operation of the mini-grid, which leads to a division of labor between different actors. For example, the ownership, generation and distribution of electricity of a mini-grid can be divided between government companies or private firms, while a community organization operates it on a day-to-day basis and a private company may be involved in the technical support and management consultancy. The success of these models depends however on the regulatory framework and clarity of the property rights.

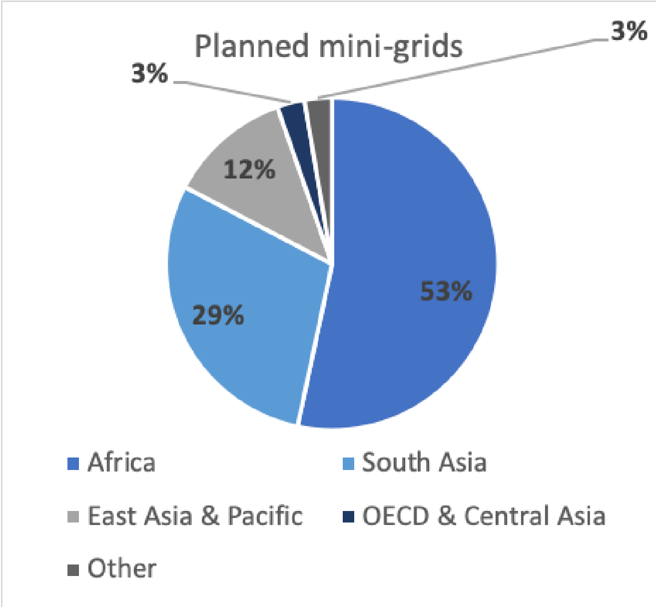
Trends of mini-grids in Sub-Saharan Africa

Mini-grid systems are providing improved electricity access to an estimated 47 million people worldwide in 2018[24]. While diesel-fueled, and to a lesser extent hydro-power, mini-grids were the most common, solar hybrid systems are increasingly being used. Between 2014 and 2018, double the number of mini-hybrid solar-hybrid grids were constructed as compared to the 2009-2013 period. Asia leads the way in terms of installed mini-grids with a share of 49% in South Asia and 36% in East Asia and the Pacific. The majority of the installed mini-grids in Asia are in just three countries: Afghanistan, Myanmar, and India. Sub-Saharan Africa, on the other hand, accounts for only 8%, with 1500 listed mini-grids installed. However, estimates show that the deployment of mini-grids in Sub-Saharan Africa will increase in the upcoming years, with over 4000 planned, representing more than half (54 %) of the total planned mini-grids (Figure 5) - most of which would be located in Senegal, Nigeria and Tanzania.

21. Franz et al., 2014.
22. IED, 2013.
23. Safdar, 2017, IRENA, 2016.
24. ESMAP, 2019.

Figure 5: Share of installed and planned mini-grids by regions





Source: ESMAP, 2019

Even though investments in mini-grids remained rather small in comparison with the total investments in electrification, it totalized 28$ billion's worth of investment worldwide in 2018. However, investment in mini-grids in Sub-Saharan Africa has been limited due to their relatively low penetration in most Sub-Saharan countries. To this day, Tanzania is one of the few countries to stand out through its implementation of a larger mini/micro-grid electrification program since 2009, fed by solar PV or solar-diesel hybrid technologies. In addition, as of recently, mini-grids in Tanzania served not only households but also small businesses. Other Sub-Saharan African countries, like Nigeria, Rwanda, Uganda, and Kenya are catching up by taking actions to improve their regulatory frameworks to support mini-grids[25]. Nonetheless, they are expected to become the least-cost solution for grid quality electricity for over 60% of the population in Sub-Saharan Africa in the case where national utilities do not significantly change their operations[26].

It is worth noting that off-grid solutions, such as stand-alone power systems and pico solar devices, are more widely established in Sub-Saharan Africa, particularly in East Africa. This region has in fact been the recipient of 57% of worldwide disclosed investments in off-grids during the period 2010-2018, thus emerging as a leader in the deployment of off-grid solutions, used mainly for lighting, mobile charging, radio and television[27]. One reason for this is the strong mobile money ecosystems in East Africa that allowed the proliferation of pay as you go solutions for solar home systems, and made them affordable for rural households. Kenya and Ethiopia are amongst the frontrunners in implementing off-grid technologies, with Kenya now being the largest market for off-grid solar domestic systems and solar lanterns in Africa.

According to the International Energy Agency (IEA), the use of decentralized energy systems is projected to increase by 2030. Under the new policies' scenario[28], 68% of the population that would gain access to electricity by 2030 would do so from grid-connection, 20% from off-grid systems and 12% from mini-grids. Another more optimistic scenario[29] of the IEA predicts that only 26% of

25. Africa's Pulse, 2018.

26. ESMAP, 2019.

27. Wood McKenzie, 2019.

28. The new policies scenario, developed by the IEA, projects today's policy ambitions on the future of the energy sector. "It incorporates not only the policies and measures that governments around the world have already put in place, but also the likely effects of announced policies, including the Nationally Determined Contributions made for the Paris Agreement" (IEA).

29. It's the "The Energy for All Case" scenario that develops a pathway that would allow sub-Saharan Africa to meet the goal of universal access to electricity by 2030. It "examines the achievement of modern energy for all against the backdrop of the new policies scenario" (IEA).

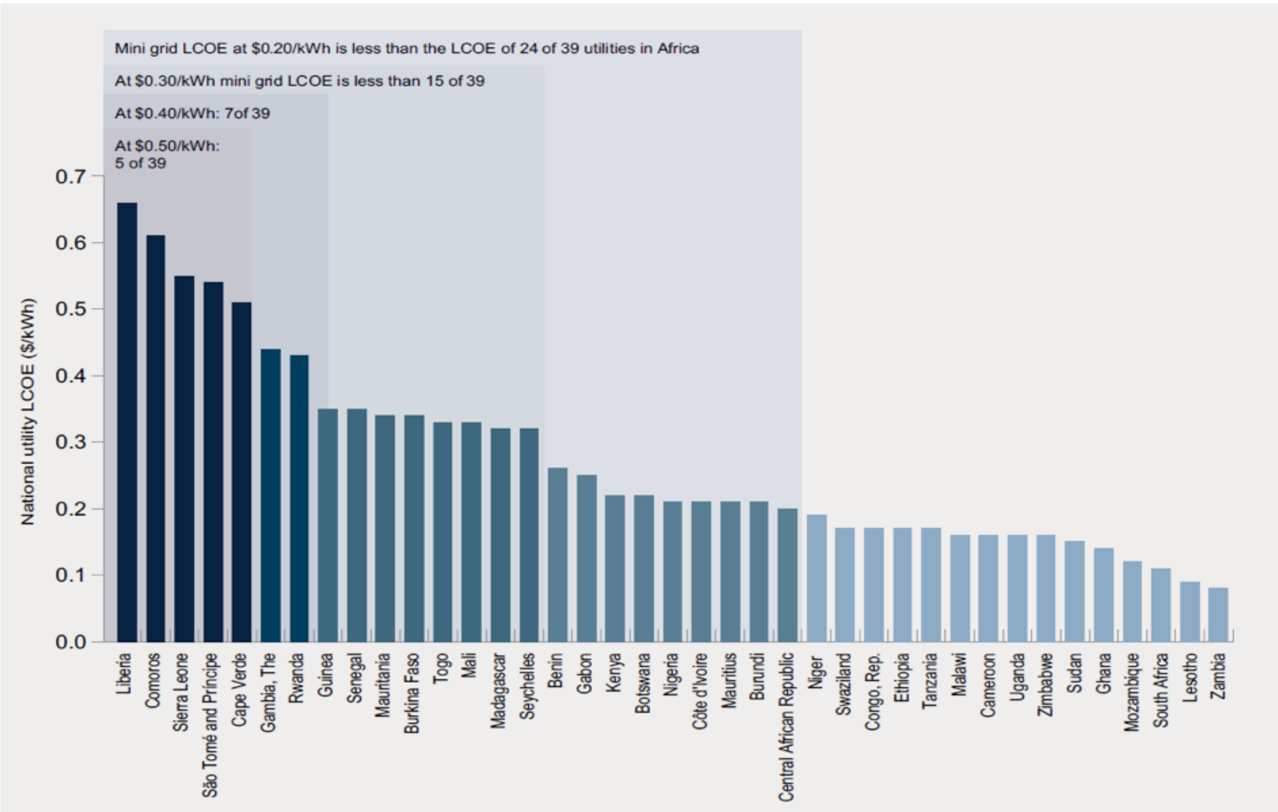
the population would gain access to electricity through grid connection by 2030, whereas 30% would do so via off-grid and 44% from mini-grids.

Various opportunities for mini-grids in Sub Saharan Africa…

Mini-grids, traditionally considered a niche solution, are now an upgradeable option to supplement grid expansion and stand-alone power grids. Compared to the main grid and stand-alone power systems, mini-grids are more appropriate solutions for areas with high population density and medium electricity demand. Indeed, as stated in the previous sections, expanding the main grid to remote communities that consume limited electricity cannot only be very expensive, but also not economically profitable, whereas stand-alone power systems are more suited for areas with low population density and low demand. Therefore, mini-grids, constitute a good opportunity in countries lacking in grid development but having a more involved private sector. A good example of that is the case of Somaliland and Puntland, where the private sector provides more than 90% of electricity in urban and peri-urban areas using local private mini-grids[30].

In addition, mini-grids are becoming economically attractive in many regions of the world as the cost of renewable technologies falls and fuel prices rise. Capital costs of mini-grid have, indeed, been declining over the past decades and are expected to further decrease by 2030, while increasing the quality of service. Thanks to innovation and economies of scale in utility projects, the costs of some of the essential mini-grid components, like solar panels and batteries, have fallen by 62% - and in some cases by 85%. As a result, capital costs have declined from $8000dollars per kilowatt of firm power output[31] (kWfirm) in 2010 to $3,900/(kWfirm) in 2018 in Asia and Africa[32]. The falling capital costs are expected

Figure 6: Comparison of levelized cost of electricity of mini grids and utilities in Africa



Source: ESMAP, 2019, Based on Kojima & Trimble 2016.

30. GVEP International, 2011.
31. Dollars per kilowatt of firm power output. It is defined as the sum of the mini grid's battery inverter and the system's diesel generator capacity.
32. ESMAP, 2019.

to decrease per-kWh cost of mini-grid in the future. In Africa, the levelized cost of electricity[33] (LCOE) ranges from 0.1 $/kWh to over 0.7 $/kWh (Figure 6). In some countries, like Tanzania and Ethiopia, the LCOE from mini-grids is less than that of 24 out of 39 utilities in the continent.

Moreover, mini-grids can promote inclusive growth and local development in isolated rural areas through different channels. In one hand, mini-grids are able to increase the reliability of electricity supply[34], therefore promoting productive and income generating uses of energy[35], such as establishing new small businesses, thus supporting economic activities. On the other hand, machines and equipments connected to mini-grids require staff to oversee operations and maintenance activities, which implies job creation opportunities. A recent study[36] suggests that mini-grid development has the potential to yield 50,000 direct formal jobs related to mini-grids in Nigeria and around 5,000 direct formal jobs in Kenya. The mini-grid sector also relies heavily on informal work, and could employ twice as many people in the informal sector.

Mini-grids can also create gainful relationships with national utilities in the long-run. Indeed, as highlighted in the paragraph above, income-generating uses of electricity provided by mini-grids contribute to the economic growth of rural economies, which can attract national utilities, since the extension of the national grid in this case is deemed economically viable thanks to two factors: a significant demand would already exist and customers would, theoretically, be able to pay electricity tariffs due to the economic benefits that they would have acquired by gaining electricity through mini-grids (ie. Productive use of electricity). Nigeria is one of the few countries in Sub-Saharan Africa who anticipated new sets of mini-grid regulations that facilitate the transition from an isolated mini-grid to the interconnection with the main grid and include aspects like licensing and retail tariffs setting.

33. It is the average revenue per unit of electricity produced that would be required to recover the costs of building and operating a plant over a hypothetical financial life cycle and use.

34. In that respect, hybrid mini-grid systems, especially, generally offer greater reliability of supply compared to single technology approaches since they can tackle the issue of intermittency, particularly when relying on a renewable source of energy.

35. Productive use of electricity is described as an agricultural, commercial and industrial activity involving electricity as a direct input into the production of goods or the provision of services.

36. Powerforall, 2019.

Furthermore, well thought renewable mini-grids can have positive environmental impacts and promote resilience against climate change effects. Modern mini-grid systems are believed to introduce mostly lithium-ion batteries for energy storage, which while not yet fully environmentally friendly, can nonetheless help promote many sustainable actions such as storing renewable energy during intermittence periods, thus playing an important role in the energy transition. In addition, modern mini-grids are also designed to introduce energy-efficient appliances, which allow energy savings hence improving performance in terms of energy efficiency. These efforts are expected to result in nearly 1.5 billion ton of carbon dioxide emissions avoided globally[37]. Mini-grids have also the potential to support clean cooking in Sub-Saharan Africa, which is an often overlooked issue. Sub-Saharan Africa is, in fact, very dependent on the use of traditional biomass, mainly wood fuel and agricultural and industrial waste, for cooking and heating, which constitute a health hazard for households as well as increased risks of in-house pollution.

... But several challenges to overcome

Despite becoming attractive from an economic stand point at the global level, mini-grids in Sub-Saharan Africa still face several technical, financial and regulatory challenges to achieve a wider penetration. A first set of challenges are of the technical type. The first identifiable challenge is the inadequate or lack of maintenance of the mini-grids due to either insufficient funding to perform maintenance or a lack of local skills to do so. Indeed, the deployment of mini-networks requires a high level of technical expertise, which is often carried out by highly skilled external actors, rendering the community dependent on them. As a result, frequent technical failures have become a recurrent fate for Sub-Saharan countries. This raises the issue of education and capacity-building that local people need to acquire for the continuity of the project. Another challenge is the poor assessment of the diverse local parameters prior to building the project, such as population density that directly affect load factors and thus the proper functioning of the mini-grid. Other parameters to be considered are the type of terrain, which can determine the overall costs of the project, and the natural resources fluctuation. Regarding

37. ESMAP, 2019.

the latter, this is particularly the case for renewable-based mini-grids, where there is the issue of matching the daily demand with fluctuating renewable energy production, especially during night time where most of the demand manifests. The recourse to a storage system must hence be considered.

A second set of challenges are of a financial nature. Although mini-grids are becoming more cost-effective than extending grids to provide electricity for productive purposes in remote areas, they are still to this day highly grant-based or heavily subsidized. In addition, their initial costs to cover investment and operating costs and generate adequate profit can still be high. This may result in high tariffs[38]. In addition, mini-grid project developers often lack experience in financial analysis, risk mitigation and business plan development. This calls for the improvement of access to affordable capital through development financefinancing institutions and other actors for projects financing, but also to alternative sources of capital like venture capital. Diversifying risks for local banks can also act as an incentive to promote the involvement of the private sector in financing mini-grid systems.

A third set of challenges are regulatory challenges. These challenges are inherently linked to financial barriers, as investments for mini-grid projects can be hampered by outdated regulations, laws and procedures. These policy and regulatory barriers can be classified in three categories: tariff settings, licensing and permits, and the procedures to undertake when the centralized grid arrives to a village supplied by mini-grids. Setting appropriate tariffs is crucial for both mini-grid developers and consumers in rural areas. There are different tariff options from applying the same retail tariff as the main grid to setting bulk sales tariff[39] or feed-in tariffs[40]. Hence, the success and sustainability of the project depends on the choice of the best tariff configuration. Experts agree that developers should propose flexible retail tariffs and tariff structures that would be subjected to regulatory approval in order to promote innovative business models that would leverage efficiency gains and provide affordable energy services to their final customers. In addition, charging city dwellers and rural residents who are dependent on mini-grids the same tariff is likely to hurt rural consumers as they often live in poorer areas. One option to address this problem is to either cross-subsidies from network customers to mini-grid users, or to subsidize the initial costs of a mini-grid in order to lower the end-user rate, or, where subsidization is not feasible, to use variable rates.

A license or permit is a government-granted legal right to conduct a business, in this case related to the generation, distribution and sale of electricity, in a particular location on the basis of a finding that the authorized entity is technically and financially capable of carrying out the activity in question. In the utility sector, a license or permit are essentially a type of consumer protection, particularly in situations where the company is a monopoly supplier. At the same time, a license or permit can shield a facility from competition for a specific period of time and prove the legitimacy of the mini-grid project to lenders or other key stakeholders. However, mini-grids are a gray area in this case. Indeed, the regulatory process for getting a license for a mini-grid project can impose high costs both for the licensee and for the granter of the license and is a very lengthy procedure. Therefore, licensing is generally required for larger mini-grids, for example those exceeding 1 MW for the case of Tanzania. Smaller projects are exempt from licensing, but can require registering their businesses, which means that the regulators and other government agencies are aware of the existence of the enterprise and that it provides services, but are not require to approve it.

One key question for investors looking to invest in decentralized power generation is what happens once the main grid reaches the mini-grids. Will it render their investment useless? A report of the World bank and ESMAP[41] suggest five different scenarios that should be taken into consideration by regulators and project developers. The first scenario is the continuation of the production and distribution of electricity from the mini-grid to the customers and, at the same time, purchase of electricity from the national grid to meet peak consumption needs while selling the excess electricity it produces. The second scenario is the shutdown of electricity production from the mini-grid and the transition to a distribution activity only through the purchase of electricity in bulk in order to resell it through its distribution network. The third scenario is, on the

38. D'Agostino, Lund, and Urpelainen 2016.

39. The bulk sale tariffs are calculated by computing the generation costs, the transmission costs and the supply costs according to the set methodology.

40. Feed-in tariffs are fixed electricity prices that are paid to renewable energy (RE) producers for each unit of energy produced and injected into the electricity grid.

41. Greacen, Nsom, and Rysankova. (2015).

contrary, the cessation of distribution but the continuation of production and sale of electricity to the national grid. The fourth scenario is the purchase of the mini-grid's assets by the national network. The fifth scenario is that the mini-grid abandons the site and moves its assets to another location. Each of these scenarios require specific actions to be undertaken and will depend on particular country circumstances, type of mini-grids built and the business strategy of the developers. The mini-grids must be built to standards that facilitate the connection to the main grid, if that's the scenario chosen (scenario 1 or 2), while regulations must specify, beforehand, the type of retail tariffs that would be applied during the transition phase and once the interconnection is made. Moreover, regulators should enact a series of commercial and technical regulations that aims to accommodate for a safe and reliable interconnection between mini-grids and the main grid (scenario 2 or 3). If the mini-grid is sold to the national utility (scenario 4), it should be subjected to regulatory intervention in order to protect the value of the assets, meaning accurately evaluating its value after depreciation while recognizing that these assets can be useful to a utility if built to utility standards. Finally, abandoning the mini-grid and moving to another location (scenario 5) can be possible only if the assets are moveable, which is not always the case.

Key elements for successful mini-grid projects

To be successful, mini-grid projects must be carefully designed. First and foremost, mini-grid developers must take into account the local social, economic and environmental conditions of the area where the project is to be carried out. In addition, they need to cautiously select the adequate geographic location. Indeed, mini-grids should neither be located too far nor too close to a main grid system. In the first scenario, their operation and maintenance can be very difficult to carry on while in the second scenario, they can be quickly replaced by the main grid, rendering the initial investment useless. Site selection also entails conducting detailed spatial analysis to allow policy makers, communities, NGOs and governmental agencies to identify the most appropriate technologies to be used (whether it is diesel, solar, wind, hybrid or with/without a storage unit) that meet the specific energy's demands. This involves, on one side, a good understanding of current and future fuel availability and prices as well as of solar insolation, wind speed and hydrology, and an in-depth insight of the economic opportunities of each of these technologies on the other side. Another pre-requisite for planning successful mini-grid projects is the conduct of a demand analysis through field studies, while at the same time accounting for future demand growth. With regards to operation and maintenance, specialized training programs, which pay special attention not only to the technical aspects of mini-grid schemes, but also to the regulations surrounding aspects such as tariffs and fee payments have to be provided for the staff involved in order to reduce conflicts within the communities, like electricity theft.

Moreover, mini-grid projects need a well-functioning policy and regulatory framework that takes into account the requirements of mini-grid construction as well as a strong private sector and committed industry associations. In Mauritius, for instance, the private-sector's sugar industry played a key role in the success of mini-grid programs using cogeneration of bagasse[42][43]. Clear governance structure has to be established, particularly in the case of a community based mini-grid model, and clear provisions for dealing with risks need to be anticipated. Another crucial element for the success of mini-grid schemes is the existence of sustainable financial models. It is easier said than done as this is a very complex process that is determined by the decisions of both operators and the external environment. On one hand, operators need to adopt prices that reflect costs and that are based on feasible economic assessments based on the chosen business model. They also should split responsibilities for the operation of mini-grids between different actors and build clearly designed payment collection mechanisms with defined record-keeping. On the other hand, policymakers and legislators should support local financial institutions by reducing perceived risks for lenders. Governments should, on their part, incentivize private sector participation and limit market distortions[44]. Finally, for their commercial viability, mini-grid developers need to take into account the following factors: the share of electricity used for income-generating purposes, the share of electricity consumed compared the electricity generated, and the electricity price negotiated or fixed by regulation[45].

42. Which is a residue of the sugar cane stems from which the juice was extracted.
43. USAID/ARE, 2011.
44. GVEP International, 2011.
45. EEP, 2018.

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About the author, Rim Berahab

Rim Berahab is an economist at the Policy Center for the New South, a think tank based in Rabat that she joined in 2014. She is currently working on themes related to energy issues and their impacts on economic growth and long-term development. Her research areas also cover trade and regional integration challenges in Africa. Previously, she has also worked on questions related to gender inequalities in the labor market of North African countries. Rim spent three months at the International Monetary Fund (IMF), in 2016, in the Commodities Unit of the Research Department. She holds a State Engineering degree from the National Institute of Statistics and Applied Economics (INSEA).

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Policy Center for the New South

Suncity Complex, Building C, Av. Addolb, Albortokal Street,
Hay Riad, Rabat, Maroc.
Email : contact@policycenter.ma
Phone : +212 (0) 537 54 04 04 / Fax : +212 (0) 537 71 31 54
Website : www.policycenter.ma