Decentralized Electrification Pathways in Sub-Saharan Africa—Assessment of Experiences and Business Models

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Abstract

The transition to "SDG7 -modern and sustainable energy for all" may reconfigure the lives of citizens who live "outside the grid" in the rural communities in sub-Saharan Africa. The decentralization approach for developing renewable energy in sub-Saharan Africa has constantly been promoted as a means to rural electrification. This paper reviews the barriers to private sector participation in decentralized electrification projects and the solutions that have been proposed and implemented. It is not only the economic approaches that are analysed but also some of the solutions or drivers that have contributed to rural electrification. There are specific technological pathways which have proven fruitful in sub-Saharan Africa that are unique to its economic and demographic settings and that otherwise would not be adopted or used in developed countries. This paper finally analyses these technological pathways with the objective of matching the drivers and obstacles to potential solutions. Long term energy planning with the integration of regional power pools is instrumental to reduce CAPEX as well as to increase the market size. Blended financing together with already working technologies such as pay-as-you-go, and mobile money will be the pillars to meeting SDG7 goals.

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Keywords

Rural electrification · Decentralized electrification · Solar systems · Mini grid · Sub-Saharan Africa

1 Introduction

Universal access to electricity is key for achieving the global sustainable development goals. According to the International Energy Agency (IEA, 2019), more than 600 million people in sub-Saharan Africa still do not have access to electricity (IEA, 2019). This includes 80% of the population in rural areas (IEA, 2019). The Sustainable development goal number 7 (SDG7) aims exactly at solving this problem by enabling the provision of access to affordable, reliable, clean, and sustainable energy globally for all by 2030.

Electricity supply in emerging and developing countries, specifically sub-Saharan Africa, is unreliable especially in rural areas, where frequently the maximum electric output of generators is completely used for consumption and where, at times, there are no capacity reserves be it primary, secondary, or tertiary reserves for flexibility management of such grids. This is a sharp contrast to the electricity systems in developed countries of the global North where the grids are transitioning from centralized to bi-directional with the onboarding of prosumers as well as Distributed Energy Resources (DER)[1]. Furthermore, the main purpose of distributed electrification in the developed countries of the global North is to improve resource efficiency, increase energy system resilience, and give individuals and communities a stronger role in decarbonization while achieving the renewable targets set by many governments. Currently, DERs only account for a small proportion of the European market but are predicted to outcome centralized capacity globally by more than 5-to-1 (Navigant Research, 2016). To eradicate energy poverty in sub-Saharan Africa, distributed renewable energy solutions can be a particularly good opportunity to increase energy access and help establishing a previously non-existent electricity market. This will also play a vital role in unlocking sustainable economic growth (Corfee-Morlot et al., 2019). Additionally, access to electricity can ensure better health and wellbeing.

[1] Distributed energy resources (DERs) are small or medium-sized resources that can potentially provide services to the power system, directly connected to the distribution network or near the end-user (European Commission, 2015).

Despite the electrification challenges, sub-Saharan Africa has multiple untapped renewable energy resources, having the largest global renewable energy potential. Taking solar as an example, the global irradiation average in this region is about 220 W/m^2 compared with 150 W/m^2 for parts of the USA, and about 100 W/m^2 for Europe and the United Kingdom (Renewable Energy in South Africa, 2021). Solar energy potential is estimated at 470 PWh for CSP and 660 PWh for PV (IRENA, 2014). Africa also has a wind potential of 460 PWh (IRENA, 2014). Hydro has a currently installed capacity of 37 GW which corresponds to only 11% of the total hydro potential. Consequently, sub-Saharan Africa has the highest untapped hydro potential with around 89% being underutilized (iha, 2020).

While it is becoming evident that renewables have a leading role to play in the electrification process of many countries in the region—including at small scale and off-grid—several challenges remain and there is not a straightforward solution due to the socio-economic complexities. These complexities are both on the supply and demand side. On the supply side they are insufficient technical capacity and poor utility performance in most of the rural areas. On the demand side these complexities can be insufficient uptake and low consumption which may discourage investments. The complexities also exist on the government's side when it comes to establishing appropriate regulations, attracting foreign investments, and setting clear targets. There is a need for capacity building in the form of financial literacy and educational campaigns to address some of these complex barriers. The local electricity market has been inaccessible to private-sector companies due to challenges such as market willingness to pay, high transactional costs for managing small loans, lack of clarity regarding leasing regulations for a non-financial institution. In addition, the rural consumers do not have any collateral to enable them to acquire financing from other institutions such as the commercial banks.

2 Aims & Objectives

This paper aims to:

1. Analyse the technical and socio-economic obstacles and drivers for the decentralized electrification for sub-Saharan Africa.
2. Explore the technological pathways and business approaches that are proven and successful.
3. Derive frameworks and conclusions for various parts of the system (supply to end consumers) based on a comparative analysis approach.

3 Methods

The study is based on a literature review of several case studies and academic papers about rural electrification in sub-Saharan Africa. Several of insights have been retrieved from reports by renown organizations such as International Renewable Energy Agency (IRENA), The World Bank and the International Energy Agency. The assessment evaluates drivers for success and obstacles that countries and regions are likely to face.

This paper also dives deep into the emerging technological pathways that have been implemented as well as regional and country specific responses on the market and policy sides. Furthermore, an investigation of business models that have proven to be successful in certain cases is provided.

4 Electrification Barriers

The obstacles identified can be broadly categorized into four major categories: Market, Technical, Financial and Regulatory Barriers.

One of the biggest market obstacles is low Market Willingness To Pay (MWTP)- where consumers are not sufficiently informed regarding the value of electricity and that by paying for it, they enable provision of continuously running electricity services. Some effects of this are illegal connections to the grid or theft of power. Another market obstacle is low electricity uptake, where in most cases, consumers do not see the urge or the need to be connected to the grid even though distribution lines could be a few meters from their homes (Blimpo & Cosgrove-Davies, 2019). The connection charges and the complete process of getting connected are an entry point barrier because connection charges are high in comparison to income levels (Blimpo & Cosgrove-Davies, 2019). There is a lack of proven business models since most of the adapted economic strategies are relatively new. For private financers, the risk return profile of a project is a determinant as to whether they should fund it or not. Such investors want to get a return proportional to the risk they undertake. Renewable energy projects are affected by foreign exchange risks as well as due to their novelty and short track record. As a result, local financial institutions do not have expertise on how to mitigate currency volatility and heavy reliance on foreign finance (UNEP, 2012). Finally, there is the diminishing utilities factor: connecting more consumers to the existing grid without creating new infrastructure implies higher maintenance costs and low profit margins and at times even losses (Blimpo & Cosgrove-Davies, 2019).

Technical obstacles are mostly driven by the dysfunctional and poor state of existing infrastructure in electricity grids. One reason for this is lack of planning from governments, with no progressive approach combining various delivery modes and harnessing digitalization trends where needed. Electricity together with digital technology is now considered a general-purpose technology (GPT). Digitizing the electrical grid leads to automated technology and analytics that can influence consumption and contribute to new customer services. Digitalization can improve reliability which then improves trust from customers (Blimpo & Cosgrove-Davies, 2019). Another technical obstacle is high rural connection costs due to geographical preconditions. Most countries in sub-Saharan Africa are large in geographical land size with spread but concentrated population settlements, where a majority of households does not meet minimum building connection standards as they have not been built with electrification plans in mind. This can be in part solved by creating regional power pools. National grids in many sub-Saharan countries have not been able to deliver reliable power supply at affordable prices to their citizens. Governments have therefore been interested in regional multi-lateral and bilateral agreements that emphasize coordination and combine their resources to create a more robust regional grid involving cross-border interconnections as well as electricity exchange and trade that can be traced (AfDB, 2011). Cross border transmission has a potential to lower costs and stimulate investments. It may increase trade volumes addressing alack of market challenge. Investments can then be paid up quicker, as more people get connected to the grid (Eberhard et al., 2011). Consequently, it can lead to an increase in market size as well as reducing CAPEX for grid/distribution infrastructure and the system operational costs (AfDB, 2011).

Thirdly, the financing obstacle has been a big barrier to decentralized electrification in sub-Saharan Africa. There is a lack of capital needed to build generation and transmission infrastructure. The region faces an annual infrastructure financing gap of 68–108 billion USD (AfDB, 2019), including electricity distribution grid costs. Unfortunately, there are limited regional financial instruments and institutions that can support such infrastructure. This leads to another problem. Since most of the grid generation and distribution infrastructure are not manufactured or produced within the continent,importing them from other parts of the world results in high CAPEX for investments.

Lack of regulation is the fourth major electrification barrier. Legitimate businesses may find it difficult to operate and compete with informal markets. These sell products such as solar PV home modules—typically with low-quality standards and in some cases smuggled into the country. They also do not pay any taxes or incur an administrative cost. As a result, they tend to be cheaper and, hence, more appealing to local customers. This in turn locks out potential legitimate competitors. In certain circumstances, there may also be political manipulation of prices, especially in countries where electricity prices are subsidized by the government. As a result of locally vested interests defending the status quo, private investments may face adversities regarding cost coverage. Bolivia may serve as an illustrative example, where electricity prices increased due to reforms in the subsidy percentages, and this resulted into a public backlash against the reform (E. Besant-Jones, 2006). As much as some of the political risk may seem vague, trends like political sabotage, expropriation and monopoly by national utilities are still a common phenomenon (UNEP, 2012). There are, in theory, possibilities for new coming prosumers or commercial consumers to obtain bank loans from commercial banks to finance installation of distributed solar PV modules. However, commercial banks are usually not interested in issuing such loans because transaction costs for managing them are too high compared to expected returns. Costs involved in the administration and management of such small loans are usually in the range of 50 to 200$ (ECA, 2018). Also, given the absence of lending history for such decentralized electrification products, their risk profile is perceived to be high (ECA, 2018).

From the regulatory perspective, standardization is needed for fair competition. It is exceedingly difficult for companies to enter, operate and compete in an economy where the electricity tariffs are fully regulated by the government. The wholesale electricity prices are normally high while the regulated retail tariffs are low (Blimpo and Cosgrove-Davies 2019).

Finally, there is lack of laboratory and R&D facilities or skilled knowledge for testing and inspection to approve the quality of such products. Also, there is no government entity or a regulatory body to control the quality of products supplied in such markets.

5 Drivers

Electrification in sub-Saharan Africa has partly been driven by stakeholder initiatives such as NGOs and Development Corporations. A strong example of such initiatives is Power Africa, an initiative led by United States Agency for International Development (USAID) with the aim to bridge the financial gap and double electricity access for millions of people in sub-Saharan Africa. Since the launch of Power Africa, the African Development Bank in cooperation with the World Bank Group and the Swedish government through the Swedish development corporation (SIDA), have committed cumulatively over nine billion dollars in support of electrification in Africa (AfDB, 2019). Another example is the International Finance Corporation (IFC) which established a leading position promoting private sector investment in Africa. Over six decades, IFC has invested more than $25 billion in African businesses and financial institutions, with the current portfolio exceeding $5 billion (IFC, 2021).

On a similar front, NGOs such as Lighting Africa, whose aim is to catalyse markets to deliver affordable, high-quality off-grid lighting and energy products such as solar home systems, have made a contribution. Lighting Africa has already enabled 32.3 million people across Africa to meet their basic electricity needs such as lighting and phone charging through quality verified solar off-grid products (Lighting Africa, 2021).

As explained previously, the region's ability to attract global commercial financing to tackle challenges is hampered by the high perceived risks of investing as well as a lack of scalable investment opportunities. To reduce the perceived risks, there is a need of de-risking private debt funds by combining them with impact financing. Such an innovative financing has been termed as blended financing. Blended financing is proving to be instrumental to incentivize commercial investors to invest in small and medium companies working towards sustainable infrastructure projects. Blended finance is the use of catalytic capital from public or philanthropic sources to de-risk transactions and improve their risk-return profile allowing for increased private sector investment (Wamicwe, 2020). Illustrative blended transactions include the Universal Green Energy Program by Deutsche Bank which has raised $302 m to increase access to clean energy in sub-Saharan Africa, especially for rural populations (Wamicwe, 2020). It is estimated, this instrument could bridge the 2.5 trillion dollar per year of the investment gap in need for electrification in sub-Saharan Africa. In 2018, DFI blended concessional finance projects saw a more than 70% increase in the total volume of projects financed with an increase in private mobilization and doubling in growth in the low-income countries (DFI, 2020).

On the technologies perspective, the falling photovoltaic (PV) costs have been an enabler to electrification in sub-Saharan Africa. Solar PV costs decreased by roughly 77% between 2010 and 2018 according to the International Renewable Energy Agency (Schwerhof & Mouhamadou, 2020). The development of Unstructured Supplementary Service Data (USSD) has been leveraged with the accessible photovoltaic technology to revolutionize electrification in sub-Saharan Africa. In an ecosystem where mobile connectivity is higher than access to affordable electricity (44% of the population has mobile subscription (GSMA Intelligence, 2019) against 80% with no access to electricity (IEA, 2022)), there has been a huge development, since 2013, on the so called USSD. USSD has enabled the development of mobile money that is revolutionizing access to financial services and therefore to electrification in the region. USSD is an advanced mobile technology that allows its users to perform transactions or banking without using the internet. This is made possible since USSD is an interface that links the merchant account and the user through a telecom operator. The users are therefore able to use banking features through short messages (SMS). Mobile payments, using USSD, allows users to receive, withdraw, and send money without being connected to the formal banking system, just between cell phone devices. It has been adapted to serve numerous operator functions and value-added services. This has high relevance in rural areas with limited network access or with no internet connection, as it enables the rapid proliferation of mobile payments. It has been the key driver for pay-as you-go ("PAYG") business models, allowing low-income customers to pay off their purchases over an extended period. The PAYG business model emerged to provide electricity generated from Distributed Energy Resources (DER) at affordable prices and between 2015 and 2020, around eight million people gained energy access globally through it. The package usually includes a solar home system that customers pay for by using mobile payment technologies and mobile phone credit. An energy service provider rents or sells solar PV systems in exchange for regular payments through mobile payment systems. This also has benefits for energy companies that are able to reduce operational costs that would be incurred in physical collection of fees.

Financially, the incorporation of PAYG financing through mobile money has driven electrification in sub-Saharan Africa enabling consumers to pay in periodic instalments. It has also made it possible to incorporate smart metering and data analytics. Small businesses owners have often been forced to adopt solar photovoltaic technologies for electrification due to unreliable grid power supply which experiences frequent load shedding. Solar off-grid electricity suppliers are also more affordable than the electricity tariffs of the utilities, especially Energy Service Companies (ESCOs) offering aPAYG model. The switch to mini grids will be more beneficial and make more sense to entrepreneurs who in average experience 31% losses in sales due to power outages and lack of reliable supply to their businesses (World Bank, 2019).

Finally, electrification in sub-Saharan Africa is sometimes fuelled by the development of specific purpose infrastructure for critical needs such as hospitals, military bases that have in turn led to the development of microgrids and nanogrids. A case example was in Tanzania where the Bulongwa minigrid which was initially constructed exclusively to provide power to the Lutheran hospital enabled villagers to access electricity through standardized power producer's agreement (SPPA) since the generation from the minigrid was beyond the hospital's consumption (Ngowi et al., 2019).

6 Technological Pathways

Micro-grids and mini-grids, stand-alone solar off-grid systems and other technological solutions have become commercially viable and climate resilient to provide access to clean energy in sub-Saharan Africa. 40 million out of 315 million people in rural Africa that will gain access to electricity will be served by mini grids by 2040 according to the International Energy Agency Energy outlook for subSaharan Africa (PWC, 2016). In accordance with the SDG7, connecting 500 million people in sub-Sahara Africa by 2030 would require more than 210,000 mini grids and a total investment of around 220$ billion. The current cost of solar hybrid mini grid is 0.55 $/KWh, and to become economically more attractive across geographies, needs to be reduced to 0.22 $/KWh by 2030 (World Bank, 2019). This will make the LCOE of Hybrid mini grids (at load factor of 40%) less than the LCOE of 24 of the 39 Utilities in Africa. Mini grids have already been implemented in countries like Kenya, Nigeria and Ethiopia and have proven to be successful. According to the World Bank more than 700,000 standalone solar systems have been installed in sub-Saharan Africa so far, ranging from lanterns to solar home systems (SHS). These systems are now driving a new market segment called PULSE (Productive Uses Leveraging Solar Energy) Systems applications. The most common PULSE appliances are water irrigation pumps, grain milling machines, cooling, and refrigeration and agro-processing, all powered by solar. A good example of PULSE application is a solar maize mill which can be used in rural areas and is an attractive option for remote farmers, bringing higher return on investment than a diesel generator after two years of use (Clean Energy Solutions, 2020). Currently, the estimated serviceable market for PULSE applications is around 734 million dollars with the potential to soar to 11.3 billion dollars in the future (Lighting Global 2021). Standalone Solar PV systems have proven to be cheaper than the costs of running diesel generators. For example, in Nigeria customers of Lumos (the largest provider of off-grid solar in Nigeria), are now paying only 15 $ a month instead of relying on diesel generators whose fuel costs are around 70 $ per month (Silverstein, 2019).

Different business approaches have been exploited to tackle electrification in sub-Saharan Africa and within the electrification value chain, entities can play distinct roles: manufacturers of electrification components, financiers, installers and DESCOs:

- Financiers could be impact investors that accelerate, scale, and improve deployment of capital in the decentralized electrification sector. Some players identified in that sector are CrossBoundary (CrossBoundary, 2021) and Responsibility (responsibility, 2021).

- Manufacturers mostly develop the hardware and then partner with local organizations for distribution. An example for this case would be Solaris, a start-up that offers modular solar home systems with integrated PAYG technology in Tanzania to more than 10 K customers. Some manufacturers also take the role of installers. Some installers do not operate the grid but instead train local communities to do it. An example is a start-up called Bennoo which through their Enterprise resource management software helps local entrepreneurs manage micro-grids by acting as an energy agency. Bennoo working in Djekloue, Togo has installed their system in 75% of the households reaching it to almost 220 families.
- Finally, Distributed Energy Service Companies (DESCO's) build a customer relationship by installing assets such as solar home systems or connections to mini grids at or near dwellings and small businesses. DESCOs then collect an on-going payment for energy (or recurring fees) from the customer (PAYG model), eliminating upfront costs thereby addressing the issue of affordability for households. DESCO has been proven to be a business model that provides return on investment.

Not only solar technologies are contributing to the transition of Africa in access to clean energy, but three modelling tools have been identified to play a role to electrification in sub-Saharan Africa. The focus areas for the tools can broadly be classified as monitoring of policy frameworks, creation of investment scenarios and finally country and regional long-term energy planning scenarios. The three tools are as summarized below:

1. RISE (Regulatory Indicators for Sustainable Energy): This is a tool designed specifically to monitor the status of policy frameworks to advance modern and renewable energy in the developing world. (Strasser et al., 2018).

2. OnSSET (Open-source Spatial Electrification Tool): It has been used to generate 216 electrification investment scenarios per country for sixty countries in Sub Saharan Africa, Central America, Asia, and the Pacific. This tool has been the basis of the UNDESA modelling tool for universal access to electricity. The same tool has also been used as the basis for the World Bank's Global Electrification Platform (GEP) (GEPE, 2021). The major electrification pathways are increasing investments into the existing grid, stand-alone PV and new grid connections. Figure. 1 shows that achieving 100% universal electricity access targets in Kenya will be achieved by doubling investments in the existing grid, increasing the investments in stand-alone PV by a magnitude of 5. An investment of around 3.6 billion USD would be required in new grid connections and stand-alone PVs, which are the major pathways in achieving global elec-

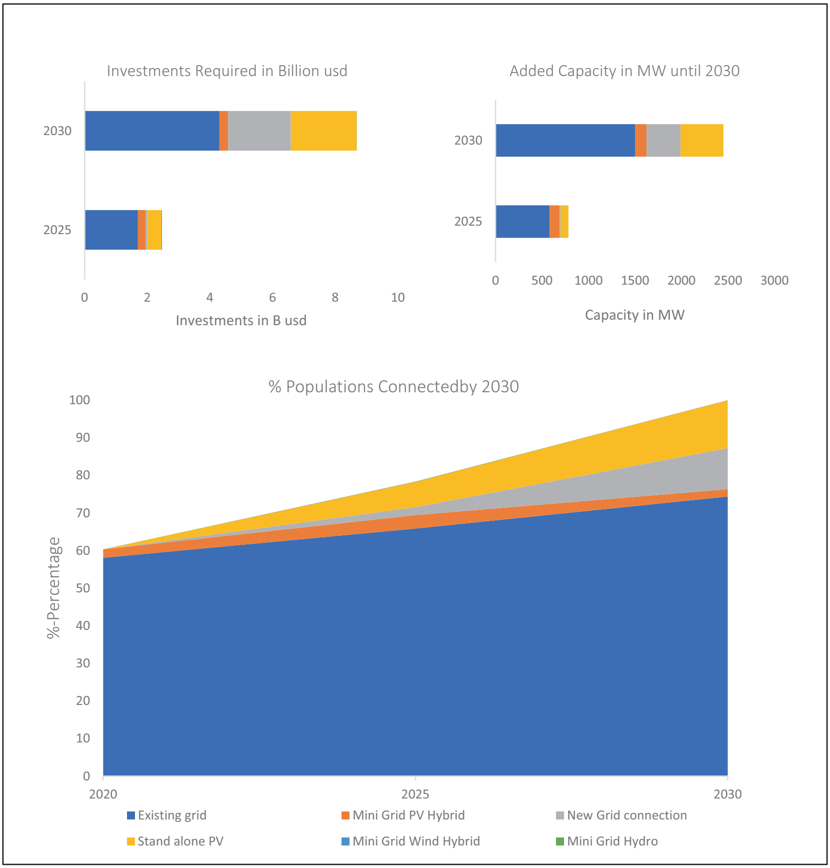

Fig. 1 Open-source spatial tool depicting electrification scenario in Kenya. (Source: www.electrifynow.energy.data; ONSSET.ORG (2022))

trification by 2030, followed by an investment of around 2 billion USD into the existing grid. An increase in capacity of roughly 1.6 GW of power is needed to achieve the electrification targets, mainly contributed to by stand-alone PV with new grid connections.

3. OSeMOSYS (Open-Source Energy Modelling System): It is a full system optimization model for long-term energy planning.It was featured as one of the United Nation's Modelling Tools for Sustainable Development. This tool calculates the least-cost of electricity, energy, and resources supply options for

countries all over the world. From this it is possible to evaluate and decide the necessary investments and their timeframe and location (OSeMOSYS, 2021).

All the tools mentioned are open-source, and simple energy modelling tools, readily accessible for researchers and decision makers from developing countries. This offers an alternative for energy policy makers and analysts from governments with limited resources and funding, to develop investment scenarios or even to be able to create longterm energy plans and roadmaps on how they want to develop the electrification infrastructure in a majority of the sub-Saharan countries.

7 Conclusions

Obstacles can be categorized on what part of the electrification value chain they are encountered. On the supply side there are both technical as well as financial obstacles. Poor and dysfunctional infrastructure can be in part answered by applying modelling tools for long term energy planning. Poor utility performance which is a market obstacle as it results into low revenues can be solved by the creation and integration of regional power pools which will reduce the CAPEX for grid and generation infrastructure and increases the market size.

From a governance perspective, lack of appropriate regulations and no clear electrification targets from the government are regulatory obstacles which can be solved by using free and open-source modelling software such as OseMOSYS for long term planning. RISE can be used for regulation tracking and monitoring. Also, the government should lead in attempts to attract and de-risk foreign investments which can be achieved by promoting blended financing instruments.

Finally, on the demand side, market obstacles such as insufficient uptake and low consumption can be addressed by raising awareness campaigns and education on the benefits of electrification. Demonstrating the benefits of adopting stand-alone solar off-grid systems and PULSE applications (such as irrigation systems and pico-devices) to local communities, farmers and small business owners will increase adoption as well. Also, if more energy companies adopt the DESCO model and offer a PAYG model option to local energy communities and small business owners, the main pain point of high upfront electrification costs will be decreased. For the 600 million people who live without electricity—80% of who live in rural areas—governments need to do more, and they need to do it better. There is not a one-size-fits-all solution, but there are positive changes (in technology, policy, and financing) happening that are transforming lives and increasing access to clean energy. To bridge the gaps in sub-Saharan Africa, it is necessary to focus on the actual people who lack connections, those who are unable to pay for electricity services despite being connected, those with illegal connections, and those with unreliable or insufficient supply. Without this in mind, SDG7 and other development goals that rely on the availability of electricity will remain a distant reality.

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