

The Role of Mini-grids in Rural Electrification Programmes in Africa and beyond: “The State of Art Paper”

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Abstract: During the last two decades, there has been an outcry on how the shortage of power in rural areas can be sorted. Most Developed Countries (MDCs) like the USA, China, German, UK, Taiwan, and Singapore started using renewable energy sources to minimize power shortages in rural areas. Less Developed Countries (LDCs) mostly African countries also followed suit. This was not only to solve the power problem but also to be on the safe side after researches anticipated that in the near future, fossil fuels would be depleted. Over 50 years ago, several countries have attempted to harness power using hydro-power, biomass, solar, tidal, wave thermal, and wind energies. Different researches show that hydro-power has been most developed worldwide due to high levels of investment. Of recent, solar and biomass energies have come on board steadily, gaining trust from people. This still has benefited towns' more than rural areas due to transmission barriers, expected financial returns, and high cost of maintenance. Recently, there has been encouragement and development of solar PV systems and the utilization of mini-grids for rural electrification to minimize the challenge, especially in African countries. International Energy Agency (IEA) has high expectations in mini-grids in playing a significant role in rural electrification. Mini-grid energy solutions are emerging as the next best alternative to rural electricity access coming between the option of large-scale grid extension and solar home systems. This paper, therefore, has discussed the status, Strengths, Weaknesses, Opportunities and Threats (SWOT) strategies, financing options, risk management systems and current trends in renewable energy mini-grid development in Africa and beyond in an attempt to enhance rural electrification. This research used secondary data, internet resources, published data, and World Bank reports to synthesize the evolution and the update status of mini-grids.

Key words: Renewable energy sources, fossil fuels, mini-grids, SWOT strategy, and rural electrification.

1. Introduction

Energy is an essential need for modern world economies. It is a prerequisite for economic growth, enhancing living conditions and reducing poverty. While the UN-SDG 7, emphasizes access to affordable, reliable, sustainable and modern energy for all, renewable energy technologies offer specific different opportunities and solutions to millions of people in need of power. Over world, extending electricity to societies distant from the national grids presents substantial challenges especially in developing nations

[1]. Renewable Energy Technologies (RETs), specifically, can offer the required options for electrification in both rural and urban societies [2].

In Africa, it is approximated that about 590 million people can not access electricity, the majority of these people live in rural areas [3]. Rural electrification is a challenging phenomenon in most developing countries and in particular sub-Saharan Africa (SSA) [4]. It is predicted that 135 million people access electricity every year in order to achieve the universal access by 2030 as targeted by the United Nations member countries and that grid extension will stand at 40% of the population while standalone systems expected to deliver electricity to 60% of the

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non-electrified remote areas [1, 5].

Most African countries view the central grid as the primary choice for rural electrification. However, extending the grid to rural areas has its own technical and technological challenges. This enables technological improvements on decentralized options, such as mini-grids, to emerge as complementary sources of electricity [6]. Fortunately, Africa is rich in renewable energy sources. Its energy mix is dominated by bioenergy, solar energy potential, and hydropower that make up a large share of total power supply in Africa [7].

Tracking SDG7: The Energy Progress Report towards achieving universal access to electricity has been positive according to the World Bank report 2019. In 2017, the global electrification rate was 89%, with the number of people without access dropping to around 840 million compared with around 1 billion people in 2016 and 1.2 billion in 2010 globally [8]. Despite this progress, an estimated 8% of the global population does not access electricity. It is predicted that in 2030; about 90% of those not accessing electricity will be in sub-Saharan Africa [9]. Countries which had the fastest favors in electrification between 2010 and 2018 include Bangladesh, Cambodia, India, Kenya, Myanmar, Nepal, Rwanda, and Tanzania [9]. In relation to the main grid and standalone power supply systems such as solar home systems, mini-grids are a more feasible solution for off-grid areas with high population density and demand. Mini-grids have proven to be the most economically viable option for serving areas that are expensive for the grid extension but with population density to support the commercial viability of centralized electricity distribution.

The high desire for mini-grids is based partly on a crucial need for alternative solutions and partly on highly optimistic outcomes about their advantages [10].

The World Bank's Energy Sector Management Assistance Program (ESMAP 2019) has about 26,000 installed and planned mini-grid projects around the

globe developed as a database [9]. Globally, about 19,000 mini-grids are already installed in 134 countries representing a total investment of \$28 billion, providing electricity to around 47 million people. Between 2014 and 2018, the number of solar-hybrid mini-grids doubled as compared with the period between 2009 and 2013 [1]. Another 7,500+ mini-grids are planned in Africa, connecting more than 27 million people for an investment cost of \$12 billion [11]. These planned systems show serious attention countries have towards shifting from diesel-powered systems to solar-hybrid systems using modern technologies [12].

The ESMAP database 2014 of mini-grid projects around the world indicated that Asia and the Pacific have a combined total of about 16,000 installed mini-grids, representing 85 percent of the global total [13]. The majority of 61% of the installed mini-grids in Asia were in just three countries: Afghanistan (4,980), Myanmar (3,988), and India (2,800). Currently, more than 4,000 mini-grids are being planned for development in Africa. Asia has the most mini-grids installed, but Africa has the largest share of planned mini-grids [9].

More than 10 years ago, the mini-grid sector adopted the digitalization trend leading to the development of innovative approaches and technologies to improve mini-grids and related services. This involves the use of information communication technologies such as the use of smartphones and mobile phones to open up new possibilities for productive use of energy [14].

Also to achieve the ambitious goals on RE development, European Union needed stricter policies and higher-level support to RE advocacy coalitions in order to reduce the unevenness of the political playing field so that providing electricity to all is achieved [15].

2. Status of Mini-grids

The energy sector globally is experiencing a laborious transition, from carbon-intensive fossil fuels to a system based on low carbon, renewable energy

resources, and technologies. The main motivating forces are mitigating climate change and generating economic prosperity. The speed of change and the effectiveness of individual countries to develop and implement policies to provide energy sustainability varies across countries and geographies [16].

The World Energy Council recognizes the value of adopting a whole energy system approach in providing the benefits of sustainable energy to all. To manage the transition involves three core dimensions which include; Energy Security, Energy Equity and the Environmental Sustainability of Energy Systems throughout the transition process [1, 17].

The remote societies with an opportunity to access basic electric services often rely on polluting, unreliable and costly diesel-powered generators operated autonomously, for example, more than 80% of the world's population is exposed to pollutant concentrations exceeding the World Health Organization recommended levels and about 3.6 million deaths are attributed to ambient air pollution [18]. Unfortunately, most remote societies have low economic returns to the government making it financially unsustainable to connect them to the national electricity grid as a priority [19].

The increasing population in remote areas leads to the formation of clustered communities and a substantial increase in energy demand and makes the formation of a localized electric power grid network possible. This, therefore, calls for the use of mini-grids to counteract the challenge among other options. These mini-grids involve the following generations [9].

2.1 First Generation of Mini-grids

This is the backbone of all the current centralized power grid systems experienced by countries like the United States, the United Kingdom, Sweden, Spain, Ireland, China, and etc. One hundred and thirty (130) years ago, these were the bases for early development and industrialization [15]. These systems were initially few and scattered. Their development was attached

with, and augmented by the co-evolution of supply, demand, disruptive technology, and policy. When technologies improved, demand increased, and the policy and regulatory schemes stabilized, larger generators could be built, and electricity could be transmitted over longer distances. These factors resulted in the emergence of centralized utilities privately or publicly owned [20, 21].

2.2 Second Generation of Mini-grids

These are found mainly in developing countries. They are small and isolated and generally owned by local communities or local entrepreneurs to provide access to electricity in areas with low population densities and low demand, primarily in rural areas that have no access to the main grid typically, such second-generation systems are built to supply electricity to single villages. The public or private developers are motivated by the overriding need to supply rural areas with a sustainable electricity service immediately. When these mini-grids are developed, there is always relaxation as far as connecting to the main grid is concerned but in case it happens, then the majority abandons the mini-grid to join the main grid [20].

2.3 Third Generation of Mini-grid Technologies and Business

These third-generation mini-grids differ from the 1st and 2nd generations in the following ways.

2.3.1 New Technologies

This breakthrough technology promotes innovations seen within and outside the mini-grid subsector and changes the landscape of the industry. The costs of technical components, such as solar PV panels, electronics, and batteries, are falling rapidly.

Other technological advances include the increasing energy efficiency of appliances and devices that can be used in the home and for productive agricultural and other income-generating uses with the electricity supplied by mini-grids [21].

2.3.2 New Players

National and international private companies have replaced local entrepreneurs and community groups, and are proposing to build third-generation projects. They are motivated by the possibility of using the modular technologies that are easy to scale up quickly and serve different sized villages and towns, providing opportunities for cost-reducing economies of scale that were lacking in second-generation developers.

Such companies include Caterpillar, Tesla, Siemens, General Electric, and ABB, which publicly announced a need to enter the mini-grid market and can easily access national and international markets [21].

2.3.3 Public-Private Partnerships

Governments always need to recommend public-private partnerships to promote and operate mini-grids. This is to replace pure publicly owned or pure privately-owned mini-grid systems that are dominant in second-generation mini-grids. The new partnerships are politically easier to channel a subsidy through a government entity in a joint venture than to simply give the same to a private company [9].

2.3.4 Isolation of Mini-grids

No more isolation of mini-grids in the rural villages, For example, in the Indian state of Uttar Pradesh, one private mini-grid operator known as OMC Power has built a good number of mini-grids in villages that are already served by a country-owned distribution utility, due to inability of the distribution utility to provide reliable service, especially during peak evening hours. A similar arrangement has been adopted by the Nigerian mini-grid regulation [9].

2.3.5 Access to New Geospatial Tools

In a half-decade ago, low-cost geospatial planning tools have been readily available to those planning to develop mini-grids. They use satellite imagery data that enable probable developers to obtain important market intelligence on the physical characteristics and probable daily electricity demand profiles of individual villages. The cost of acquiring the data is rapidly coming down [20]. There are also model-based

scenarios that are often used to explore possible environmental trends in relation to the uncertain development of driving forces. These driving forces include population and income development, technology development, lifestyle change and evolving production and consumption patterns. These help in the development of mini-grids [22].

2.3.6 Targeted Regulatory Systems

Just recently, mini-grid developers adhered to government policies and regulations that apply to mini-grid projects. Mini-grid regulatory systems have been developed by some countries like Nigeria, Rwanda, Sierra Leone, Myanmar, India, Kenya, and Tanzania. These systems reduce regulatory uncertainty for mini-grid developers. The innovations in these third-generation mini-grids need to have a business environment that is conducive to new ways of doing business [20].

2.4 Mini-grid Connections as of 2019

Table 1 below shows the number of mini-grids installed globally and those planned to be installed in Africa with their estimated investment costs.

Fig. 1 shows the already installed mini-grids mostly the 1st and 2nd generation mini-grids and Fig. 2 shows planned 3rd generation mini-grids in Africa. The third generation of mini-grids systems uses solar photovoltaics as modular generating technologies. They have storage and backup systems, state-of-the-art control systems; and smart, prepaid meters [1, 12].

2.5 Mini-grid Operation Models

In regard to operation models, an operator has two main functions: to ensure that electricity generation and distribution equipment do their work and to handle revenue from sales of electricity. Mini-grid operator models describe the organizational structure of mini-grid implementation and operation. There are four main mini-grid operator models [23].

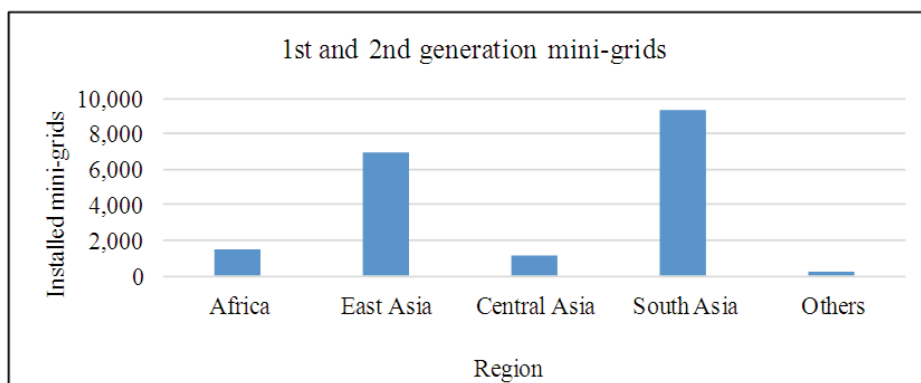
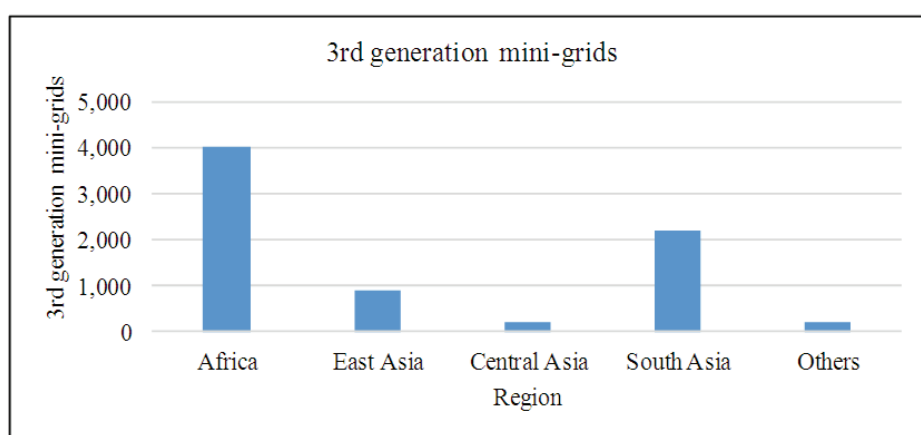
2.5.1 Utility Operator Models

In here, the utility is responsible for all mini-grid operations. The funding usually comes from the

Table 1 Installed and planned mini-grids.

Connection	Region	No. of mini-grids	Investment US billion	Population served (million)
Finished	Globally	19,000	28	47
Planned	Africa	7,500	12	27

Source: ESMAP 2019 [9].

**Fig. 1 Installed 1st and 2nd generation mini-grids.****Fig. 2 Planned 3rd generation mini-grids.**

Source: ESMAP database 2019.

national treasury or government. Power is generated by the utility, fed into the distribution grid and supplied to the consumers at the same rates paid by the utility's customers connected to its main grid [24].

Its disadvantages include; failure to prioritize decentralized systems in rural areas, often inefficient and bankrupt and often driven by political agendas.

2.5.2 Private Operator Models

Private entities plan, build, manage, and operate the mini-grid system. The funding is a result of private equity, commercial loans, and government support, which include grants, subsidies, results-based

financing, or public sector loan guarantees. The private sector is often better suited to manage smaller mini-grids. Its shortcomings include; lack of continuous financial support and difficulty of finding enough experienced companies [25].

2.5.3 Community-Based Operator Models

In here, the local community owns, operates, and manages the system and provides all services for the benefit of its members. The funding is from grant-based and community contributions. Small community models require decision-making structures in the village to avoid conflicts. Communities most of

the time use the cooperative approach for mini-grid ownership and management. The setbacks are; lack of technical and business skills like design and installation; tariff setting, leading to higher costs [23].

2.5.4 Hybrid Operator Models

These combine different features of the three models offered above. Investment, ownership, and operation of a mini-grid are not carried out by the same entity. Joint ventures or specific contractual arrangements between different actors are applied. The generation and distribution of electricity may be split and carried out separately by government utilities, private companies or communities in the form of small power producers and small power distributors. Otherwise, the duties and responsibilities can be split according to who builds, owns, operates and maintains the system. Its main disadvantage is: difference in the management systems brings about an increase in transaction costs [24].

The meaningful deployment of each model depends on its geography, energy resources, weather conditions, socio-economic context, policy, and regulatory environment.

2.6 Mini-grid Energy Sources

There are a number of energy sources to deliver power to a mini-grid system. Recent research developments to renewable energies show that mini-grid technologies are a better option due to

reduced costs and environment friendly. For example, the energy cost of solar PV decreased from \$4/W to \$0.55-\$0.65/W between 2007 and 2016 [26]. Common sources of mini-grid generation include; solar photovoltaic, wind power, hydropower, biomass, traditional fuel generators, and hybrid systems [27]. Fig. 3 below shows mini-grid source technologies in Energy Environment Partnership (EEP) portfolio and corresponding projects.

2.6.1 Solar PV Mini-grids

About half (49%) of Energy Environment Partnership (EEP) funded mini-grids are solar photovoltaic (PV) projects [27]. Solar PV mini-grids play a vital role in the community by providing it with reliable and affordable electricity to cater for electricity demand. One of the largest solar power villages in Africa is in Botswana. The mean investment budget for this solar PV mini-grid project was approximately EUR 1 million with an EEP contribution of about 40% [26].

2.6.2 Hydro and Wind Power Mini-grids

Hydropower mini-grids accounting to 24% funded by EEP are found mainly in East Africa. More than one project is found in Rwanda, Kenya, and Tanzania, and currently one in Zambia. The only hydro project in the portfolio outside of East Africa, the EEP project is in KwaZulu-Natal, South Africa. Hydropower mini-grids are comparatively large compared to the overall mini-grid projects in the EEP. Hydro projects range

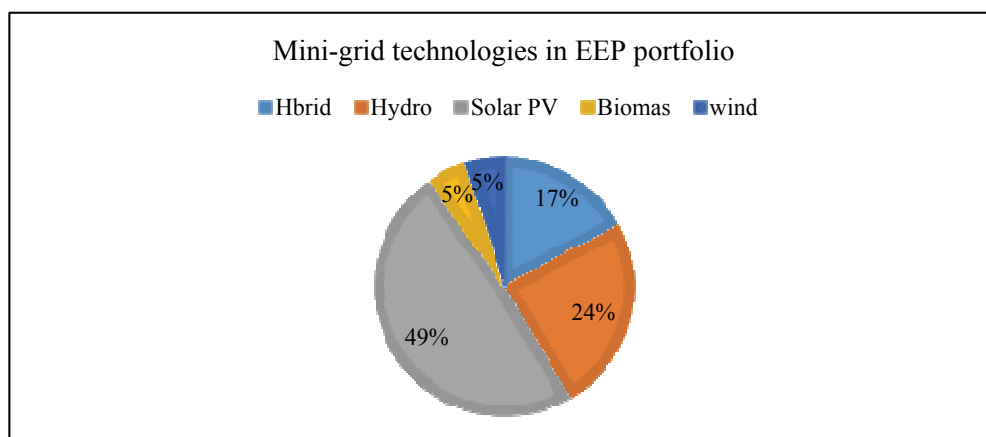


Fig. 3 The mini-grid technologies in EEP portfolio.

from a 23 kW to a 1.7 MW. Hydro mini-grids are always grid-connected and depend on successful negotiations with the national utility. Under the EEP portfolio, there are only two wind power mini-grid projects, one of these in Mozambique and the other in Namibia that provides service to 200 households [27].

2.6.3 Biomass and Waste-to-Energy Mini-grids

The mini-grid projects use various types of biogas, biofuel, biomass, and briquettes resulting from agricultural by-products. In the EEP portfolio, mini-grid projects are considered solid biomass and waste-to-energy. Waste-to-energy projects mainly focus on green waste, using leftovers from agricultural production as raw material and generating either bio-gas.

2.6.4 Hybrid Mini-grids

Hybrid mini-grid systems are the most favorable options that ensure mini-grid reliability, mainly when considering renewable energy sources. A hybrid mini-grid is where the energy generation comes from different sources such as solar PV, micro-hydropower plants, wind turbines, biomass, and small conventional generators. There are two categories of a hybrid system: series hybrid systems which are made of both a renewable energy source and a diesel generator and switched hybrid systems which are made of renewable energy source and storage part to supply power to the baseload and the diesel generator helps in meeting peak energy demand [26, 27].

2.7 Characteristics of Mini-grid Sub-systems

According to Ref. [28], there are three characteristic features of mini-grid subsystems:

- the nature of how power is supplied by AC/DC;
- the market that is targeted;
- the size of the system.

These characteristics are further divided into four sub-systems.

2.7.1 DC Village Mini-grids

These are modular PV systems in the size range of 0.2-5 kW. The “DC village mini-grid” delivers DC

power at a voltage between 12 and 48 V and for a number of hours, usually 5-7. It consists of a DC power-generating unit, wires for distribution, a control unit, and an electrical storage unit. It supplies power to a cluster of villages. The DC village mini-grid can also supply power appliances like LED lighting, cell phone charging, radios, and DC TVs or fridges [10, 29].

2.7.2 Anchor-Business-Customers (ABC) Mini-grids

They range from 0.2-15 kW and supply power to three different sets of targeted customers, viz, an anchor client, who ensures steady revenue for the developer; small village businesses with a high load demand than regular households; and rural household customers. ABC mini-grids supply AC power through an AC low-voltage network e.g. 230 V/50 Hz, 120 V/60 Hz. The system has a generating unit, distribution wires, storage unit, load controller, and inverter. The heart of the AC-coupled system is the bi-directional battery inverter, that provides the voltage and frequency control of the grid.

Presently, the ABC mini-grid is linked particularly with the telecoms sector and greening of the current diesel-powered generators used to supply remote mobile masts [10, 29].

2.7.3 AC Village Mini-grid

The technical makeup areas are almost similar to those of ABC mini-grids. The AC village mini-grid supplies power to rural villages. AC village mini-grids have the potential to deliver three-phased grid-quality power with high reliability. They supply power to high-power devices such as fans, agricultural machines, pumps, etc. and can thus support productive uses. They range from 1-300 kW [29].

2.7.4 Large Mini-grid

These have a reasonable installed capacity but are similar to AC village mini-grids in operation. These range above 300 kW to several megawatts. Large mini-grids are targeted at urban centers located far from the main grid and large agribusiness. In Africa, large agribusinesses that generate electricity for their

own consumption and supply power to nearby societies are also examples of large mini-grids [10, 29].

3. Mini-grid SWOT Strategy

SWOT strategy refers to Strengths, Weaknesses, Opportunities, and Threats associated with mini-grids globally. It is used as a tool to assess the operation and existence of mini-grids [30, 31]. Since the inception of developing an idea of coming up with mini-grid as an energy source, it is important therefore to trace the strength, opportunities and obstacles mini-grids have gone through up to present status.

A SWOT analysis (Fig. 4) takes into consideration both internal and external factors and covers the hidden factors and is able to minimize the external effects of weaknesses and threats [32].

SWOT has its application in the energy sector in the following sub-sections:

- generation, transmission, and distribution;
- energy technologies;

- products;
- energy networks.

The main indicators of SWOT are determined by several factors which include internal situations described by its strengths and weakness while the external factors described by opportunities and threats. SWOT analysis in the energy sector has the following uses:

- to identify changes to improve;
- a detailed cost-benefit analysis can be performed mainly from an economic view using SWOT analysis;
- internal and external factors can be well managed and earn rich rewards through SWOT analysis.

SWOT analysis (Fig. 4) helps in stating clearly the internal and external factors. Strengths are internal but positive aspects managed by the organization whereas opportunities are likely due to external factors that could decrease weakness and advance strengths, while threats are external aspects that could pose difficulties to the organization in the short term and long terms [33].

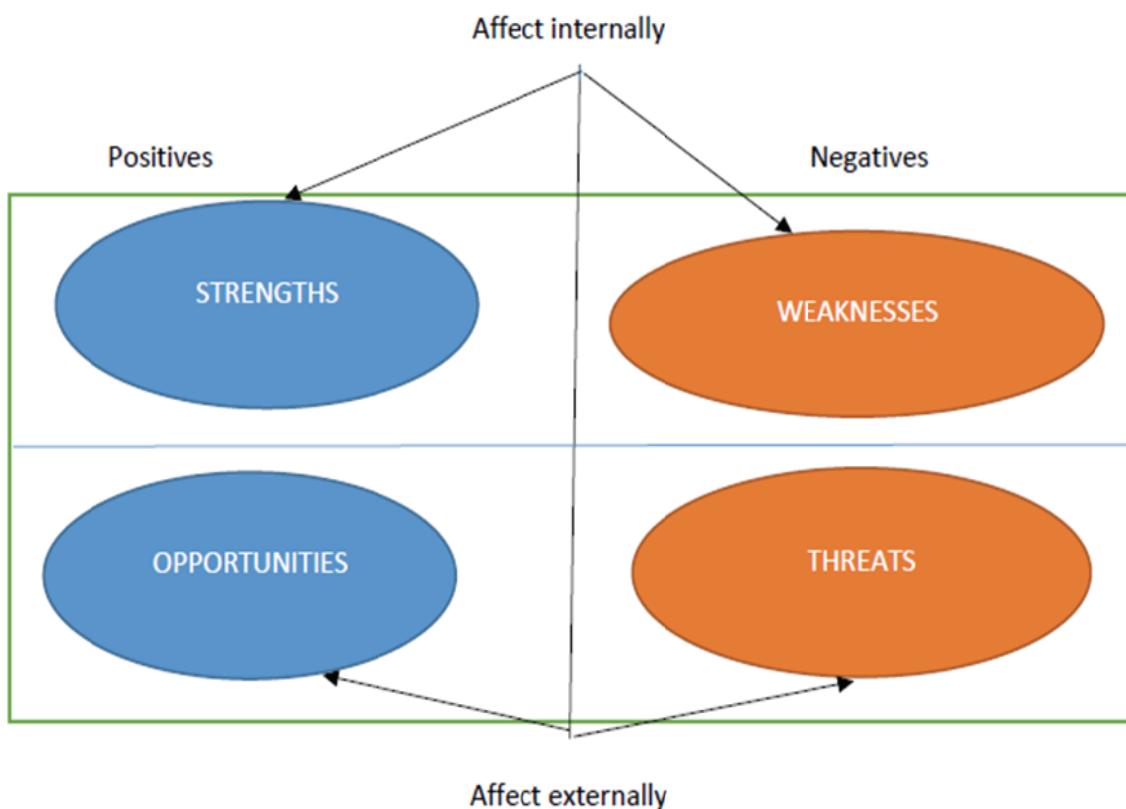


Fig. 4 SWOT analysis structure.

3.1 Strengths Associated with Mini-grid Development [31]

- The future of the world is targeting to use more renewable resources like solar PV that is readily available.
- World over, countries approve mini-grid projects annually.
- The positive attitude of both leaders and citizens towards mini-grid development.
- A lot of research is being done to improve the technology that favors low operation and maintenance costs of mini-grid development.
- The willingness of financial institutions to offer soft loans for growth and expansion.

3.2 Opportunities [31]

- Establishment of the Association of Renewable Energy Agencies of States to constantly monitor mini-grid programs.
- Renewable energy costs are dropping worldwide e.g. solar PV module prices reduced to more than 75 percent since 2009 according to IRENA's 2014 [24].
- Opportunity for job creation: many more jobs are being created for example Solar PV employs 2.5 million jobs worldwide, up from 2.3 million at last followed by wind up to 1 million jobs mark, from 834,000 by 2018 [34].
- Solutions to rural electrification: mini-grids which are localized, then generation, transmission, and distribution of power are adopted as better sources of energy in rural Africa, India, and Asia due to falling in prices in recent years. There is a saving of up to 60% for mini-grid connected places if they are switched from diesel to a hybrid of diesel and hydroelectricity and about 16% if they switched to a hybrid of diesel and solar [24].
- High chances of political support of governments and institutional financiers to the renewable energy sector most especially in Some African countries, for example, Kenya (81%) and Senegal (40%). Also,

countries like South Africa, Egypt, Morocco, Kenya, Madagascar, Rwanda, Cape Verde, and Mali have adopted national targets for renewable energy, and feed-in tariffs for renewable energy electricity [34].

- Attention to development of a legal and regulatory framework for renewable energy investments: some countries in Africa, such as Kenya and Uganda, are already in high gear in developing legislative and regulatory mechanisms to regulate and encourage investment in the renewable energy sector [35].
- Engineering and technical skills development: most African universities are presently offering a master's degree in renewable energy such as the University of Zimbabwe, in Zimbabwe, Makerere University in Uganda, the University of Dar es Salaam in Tanzania, University of Rwanda in Rwanda and Mekelle University in Ethiopia [23, 26].
- Reliability of electricity supply: mini-grids improve environmental performance in terms of energy efficiency and carbon emissions. Hybrid mini-grid systems often integrate a 75-99% renewable supply [27, 36].
- Increase in fuel prices and reduction in the cost of renewable technologies: this makes mini-grid systems more economically attractive. These systems require subsidies, but these are often a smaller percentage of investments than on-grid subsidies [37, 38].

3.3 Weaknesses

The following is internal weaknesses mini-grids face:

- Inadequate Government incentives required to start on more facilities and subsidies for solar ventures.
- High investment and space costs for the creation of a grid utility plant.
- Only very large businesses are favored due to capital intensive nature.
- Spread system designs cause baseload difficulties.
- Research, innovations, and development projects with simulation designs for shaded conditions are not easily taken up.

3.4 Threats

These refer to external factors that pose threats to mini-grid systems:

- Reduction in cash flow that limits the sustainability of the mini-grid operation.
- A limited supply of skilled persons for mini-grid industries.
- Delays in policymaking and implementation of current projects.
- Security and reputation concerns also pose a threat.
- Most government national plans leave out min-grid allocations.
- Expected potential land dispute and court expenses.
- High levels of perceived corruption.

4. Comparison of Mini-grid Development

Despite the many opportunities, the development of mini-grid systems remains low in most developing countries. The development of mini-grid has been the highest in Afghanistan (4,980), Myanmar (3,998), India (2,800), Nepal (1,519), and China (1,184) as in Fig. 5 [9].

China has approximately 60,000 schemes and Nepal, India, Vietnam, and Sri Lanka, each has between 100-1,000 mini-grids. The majority of these schemes

are government-run and mostly use diesel or hydropower generation [26, 36, 39].

During the implementation of mini-grid schemes, the countries may incur the following technological failures:

- maintenance failure or the use of old or untested technologies;
- inadequate primary energy resources;
- improper assessment of local physical parameters affecting power output and economics and these include; population density within the location of the mini-grid, type of terrain, seasonal resource fluctuations and future policies like a study in South Africa found that mini-grids were not viable because of lack of suitable sites and ambitious national rapid rural electrification programs [40, 41].

Mini-grid development can also be hindered by policy and regulatory barriers. These are associated with high-level political priorities, such as those favoring extended grid connections in urban and semi-urban. Investment obstacles have also been created by complicated or out of date energy regulations, such as those relating to the process of tariff setting [11, 33, 42]. In Africa, it is informative to consider why off-grid intervention often fails. In regard to this, a four-stage path to failure of mini-grid deployment is noted according to Refs. [43, 44].

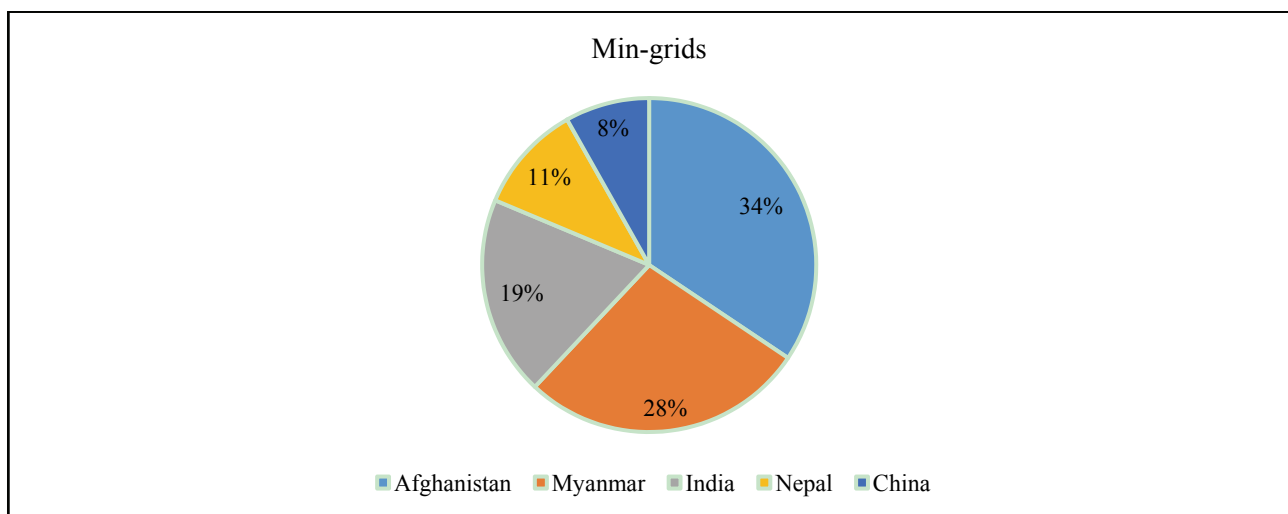


Fig. 5 Mini-grid development in few selected countries in June 2019.

Source: Ref. [9].

- RE projects carry high up-front capital cost and therefore call for additional support.
- RE intervention is employed in a specific grant-based program, especially with limited local engagement and skills training.
- No support is given to on-going projects if intervention programs come to an end.
- Lack of both local and in-country technical support.

5. Financing Mini-grids

Mini-grids are sponsored through grants, subsidies, equity, and loans. The choice of financial instrument and type of investment depends on the type of mini-grid and the stage of project development either early or late stage [36, 45]. The early-stage and risky projects are financed through grants, subsidies, and equity, while the more advanced, less risky projects are financed by debt.

5.1 Grants and Subsidies

Most mini-grid development depends on grants and subsidies to the tune of 30% of the investment costs. The grants are particularly used for pilot projects, early-stage development costs, capital investments, and technical assistance. They are from a wide range of grants: international development agencies, local government agencies, trusts and foundations and private individuals [42, 46].

5.2 Equity

The majority of the developers require capital from equity investors. The following are types of equity investors:

- private equity and family;
- impact investors and;
- development financing institutions (DFIs) [42, 46].

5.3 Loans

It is possible for mini-grids of recent to secure short term and long term loans. Those that provide short-term

loans are the DFIs. These concessional loans have better terms than market-based loans although the high transaction costs of the DFIs are not well suited to small mini-grids. Commercial banks offer long term loans and often lend to mini-grids when business models are proven and the main project risks mitigated [45].

5.4 Guarantees

Any successful financing of a mini-grid requires guarantees to improve the debit or creditworthiness of the project. The guarantees give assurance to investors that mini-grids can ably meet their revenue expectations and contractual obligations. There are two main types of financial guarantees:

- loan guarantees: these cover full and timely repayment of a loan up to a pre-determined amount.
- risk guarantees: these cover all or part of a loan and are paid out only if specific risks cause the default [42, 46].

5.5 Foreign Exchange Risk

In sub-Saharan Africa, mini-grid developers suffer foreign exchange risk. The capital cost of mini-grids is mostly in hard currency, while their revenues are in local currency. Therefore, mini-grids are abandoned if the local currency loses value against the dollar. This currency mismatch results in substantial problems for projects funded in dollars or Euros [10, 47].

5.6 The Standing of Mini-grid Global Funding

In Fig. 6, growing global investment in mini-grids as per 2019 was \$28 billion and cumulative global investment in Africa and South Asia in mini-grids by 2019 was \$5 billion. Determined development partners include AFD, AfDB, DfID, Islamic Development Bank, GIZ and World Bank and these committed \$1.3 billion.

World Bank set aside \$660 million to develop mini-grids in 33 countries until 2025.

Private sector investment in mini-grid developers in low-income countries since 2013 amounted to \$259 million [6].

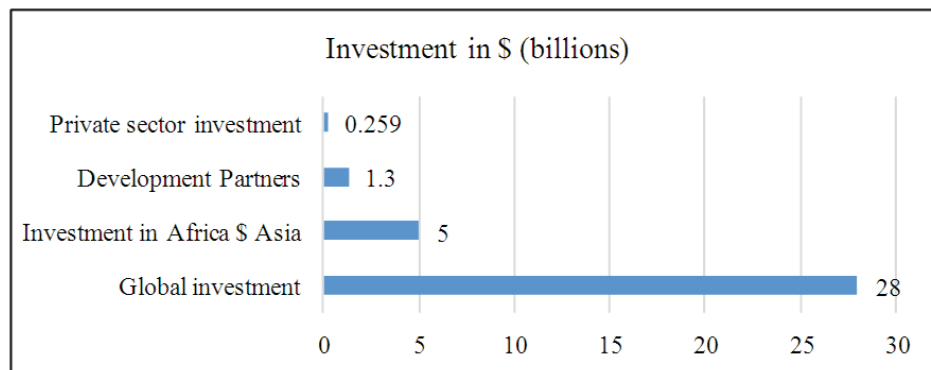


Fig. 6 Mini-grid investment as per 2019.

Source: Ref. [7].

Over the last decade, mini-grid investment costs have been declining and by 2030, costs are expected to be even lower. The prices of solar panels, inverters, batteries, and smart meters, have decreased by 62-85% as a result of innovations and economies of scale due to the 3rd mini-grid generation. Declining costs, modern technologies, and favorable environments have made mini-grids an option to connect 490 million people [6, 9].

5.7 Economic Barriers That Hinder African Countries to Finance Mini-grid Development

- Unpredictable economic returns in areas of scarce population density make the operation of cost-reflective pricing more difficult and hence reducing morale for private investment [5].
- The reluctance of risk-averse lends institutions to get involved in financing mini-grid schemes. Only 5-8 of the 20-30 micro-finance institutions worldwide give specialized energy loans that are meaningful in sub-Saharan Africa [5].
- The poor performance of utilities, power theft, and poorly managed community schemes result in low efficiency. In sub-Saharan Africa, technical and non-technical losses are very high 30 to 35%.
 - Lack of liquidity in utility companies [17].
 - Specific regulations in some countries. These affect the costs of technology in African countries where the costs of importing technologies are prohibitively high [18].

- Level of expertise in Africa to develop and operate mini-grids is still wanting and hence slows mini-grid development [18].

5.8 Notable Mini-grid Key Success Factors in Financial Mechanisms [24]

- The use of cost-reflective pricing that is based on real economic assessments very well linked to the business model [48].
- Splitting responsibilities for the operation of schemes between different actors. These increase ownership and enhance independence.
- Well-designed payment and collection mechanisms. These must be clearly defined, well-publicized and with clear record-keeping.
- Supporting local financial institutions to provide training in order to increase project awareness [48].
- Government initiative to support private sector participation at the same time preventing market distortions [49, 50].
- Cutting transaction costs through the standardizing administrative procedures which are needed for establishing tariffs [36].

6. Mini-grid Regulation Framework

Many series of decision trees have been developed by ESMAP to regulate mini-grids and give conditions under which each decision tree is suitable [9, 20, 24]. The decision tree provides guidance to regulators on how to select the regulatory approach that suits their

objectives and context, and given legal and policy constraints. The decision tree is not exhaustive or prescriptive but does aim to designate what might make sense in certain common scenarios. Decision trees provide guidance to regulators and policymakers to help them make informed decisions basing on five regulatory areas namely: market entry, tariffs, technical specifications, service standards, and what happens when the main grid arrives in the service area of a mini-grid [51].

Across Asia and Africa, countries like Bangladesh, Cambodia, India, Kenya, Nigeria, Rwanda, Tanzania, and Zambia have developed regulatory frameworks for mini-grids that address pertinent issues regarding mini-grid development. Regulatory decisions are put in a legal contract between the developer and a government authority charged with the responsibility of overseeing the mini-grid.

Mini-grids of different sizes have different market entry requirements, for example, smaller mini-grids need only to register, whereas larger mini-grids must obtain a permit or license. Analysis of different countries’ regulatory frameworks for mini-grids requires five approaches to regulate mini-grid retail tariffs which include the following:

- bid tariff;
- efficient new-entrant price cap;
- individualized cost-based tariff limits;
- national uniform tariff;
- willing buyer/willing seller.

Requiring main grid-level standards is normally possible only if subsidies are available. It has been found out that Nigeria and Peru are the two examples that have set service different standards for different types of mini-grids.

The private mini-grid developers are always at risk especially when the main grid arrives. Mini-grid regulations should clearly state the choices when the main grid arrives, and provide as much clarity as possible about how each option would be implemented. The following is options taken by the mini-grid owner

when the main grid arrives:

- Allow the mini-grid to operate as a small power distributor (SPD).
- Allow the mini-grid to operate as a small power producer (SPP).
- Allow the mini-grid to operate as an SPD and SPP.
- Allow the mini-grid developer to sell its eligible assets to the utility.
- Allow the mini-grid to coexist with the main grid.
- Require the mini-grid to decommission and remove its assets [51].

The SPP, SPD, and SPP + SPD options require the mini-grid to have been built at least to main grid compatible standards. Some countries are implementing regulations that specify options to cater for the arrival of the main grid in the service area; examples are Bangladesh, Cambodia, India, Nigeria, Rwanda, Tanzania, and Zambia [9, 20, 24].

7. Power Tariff

A mini-hydro plant may be power-limited. It produces energy around the clock at no extra cost. However, there is a limit to the peak power that can be derived from it. A power tariff allows consumers to use as much energy as they can as long as they do not exceed their maximum allowed wattage [52].

The common notable type of tariff in mini-grid development is a feed-in tariff (FiT). A FiT is a policy mechanism designed to accelerate investment in renewable energy technologies. It is noted that instead of paying equal amounts for energy, generated technologies like wind power and solar PV are awarded a lower per-kWh price, while technologies such as tidal power are offered a higher price, reflecting costs that are higher and allowing government to encourage the development of one technology over another [53].

Feed-in tariffs usually include “tariff digression” (this is a mechanism upon which the price ratchets reduce overtime). The purpose of feed-in tariffs is to give cost-based compensation to renewable energy

producers, providing price certainty and long-term contracts that help finance renewable energy investments. FiTs essentially include three key provisions namely; cost-based purchase prices, guaranteed grid access and long term contracts [53, 54].

Suitable renewable electricity generators, involving homeowners, business owners, farmers, and private investors, are paid a cost-based price for the renewable electricity they supply to the grid under a feed-in tariff. This allows diverse technologies wind, solar, biogas, etc. to develop and provide investors a sensible return [55]. The tariffs are classically designed to decline over time to track and inspire technological change. FiTs characteristically offer a guaranteed purchase agreement for long about 15 to 25 years. Performance-based rates give incentives to producers to exploit the output and efficiency of their projects [56].

7.1 Tariff Compensation

There are three methods of tariff compensation namely [52, 54]:

- Feed-in tariff: when the percentage of adopters increases, the FiT is reduced to the retail rate.
- Net metering: this allows producers to consume electricity from the grid, e.g. when the wind stops. Payments depend on net consumption.
- Power Purchase Agreement: this pays for the generation of electricity and is usually below the retail rate.

8. Risks Involved in Mini-grid Development (UNDP June 2018)

A risk is defined as the standard deviation of the return on total investment [57].

Mini-grids and stand-alone systems play a vital role when providing energy access in developing countries.

8.1 Technical Risks [50]

8.1.1 Load Uncertainty

Wrong data on the estimation of load size, growth, and schedule, result in under- or oversized systems

which ultimately lead to increased investment/running costs, lower efficiency, and unreliable supply. Its control mechanisms include the following:

- putting into use modular designs;
- the possibility of future expansion should be included;
- control the initial generation capacity and rise it progressively as demand grows;
- match consumption to the available capacity;
- recommended to perform in-field power ratings;
- estimate load using design tools.

8.1.2 Power Quality

Bringing together PV and batteries, on existing systems, affects the stability of the grid due to incompatibilities and an ineffective control system. Its control mechanisms include the following:

- matching control strategy;
- relevant design simulation prior to implementation;
- encourage distributed generation since it is less variable than centralized systems.

8.1.3 Equipment Failure

Premature failure of hardware causes service interruption and damage to the entire system. These are hard to fulfill due to the remoteness of the said area. It is mitigated as follows:

- relevant constant routine maintenance;
- equipment used should be of high-quality standards and environmentally friendly.

8.1.4 Battery Life Span

Batteries have a short life-span and this impacts the energy balance and supply hence affecting the operation of generators. Its probable controls include the following:

- consider product selection;
- adhere to operators and user's expectations;
- proper planning and budgeting for spare parts to replace the non-functional.

8.1.5 Installation Issues

If the hardware is incorrectly installed, the operation of the said machinery has to meet challenges. Its

control mechanisms include:

- proper training for local installers and operators;
- use reliable and well-trained contractors for installation and operation;
- hire consultants to oversee project implementation.

8.2 Geo-Political Risks [51]

8.2.1 Arrival of the National Grid

When the national grid arrives in the area payback and further cash flows become threatened. Its control measures include continuous involvement and consultation of local authorities during the development and implementation.

8.2.2 Delays in Approvals

Bureaucracy in mini-grid management delays the approvals hence affects the development of any energy access project. It is overcome by continuous involvement and consultation of local authorities during the development and implementation.

8.2.3 Policy Changes

Increase in taxes levied on technology or import and export duties may change depending on the existing situation. This is mitigated by political risks with a high probability of occurrence. It is not always easy to mitigate.

8.2.4 Political Instability

These include unrest, social conflicts, and war and this is overcome by democratic tendencies, peace talks, and negotiations.

8.3 Aspects of Risk Management

The valid risk management approach for mini-grids is still minimal. Different industries explain their own strategies and approaches according to their necessities and specific understanding of risks. BASEL III is a concept to mitigate financial risks related to banks, COSO ERM for industry, and ISO 9001 for issues related to quality management. But when rural electrification markets exhibit a high degree of complexity, it has to employ its own tailor-made risk-management approach [57].

The risk management process has a minimum of four unique steps namely:

- Risk identification: this is the core step in the risk management process and ensures the gathering of insights and thoughts on the full range of potential risks [50].
- Risk assessment: this is the second step that pursues the objective to determine the impact of each of the identified risks qualitatively and quantitatively [51].
- Risk prioritization: this is the compilation of all risk-relevant information in a layout so that appropriate decisions about corresponding risk management strategies are made during the final step of the process [57].
- Risk treatment: this is the final step that represents the eventual purpose of the risk management process, and if all steps are followed, then the risks are thereby appropriately mitigated.

Serious risk management has the mandate to balance the cost of risk management and the benefits of reduced negative impacts. Risk is well accounted for when the costs of risk management do not exceed the potential cost of risk impact.

9. Mini-grid Projection Activities 2019 and through 2030

According to World Bank Group 2019, they planned 3rd generation mini-grids in five selected countries which include; India, Senegal, Nigeria, Indonesia and Tanzania as shown in Fig. 7.

It is observed that India will have the biggest share of the number of 3rd generation mini-grid installed (1905) followed by Senegal then Nigeria, Indonesia, and then lastly Tanzania with 301 mini-grids. These installations are expected to be complete by 2030 [51].

AS per 2019, there were three top private sector developers in Africa and India as shown in Fig. 8 and top three Utilities in Philippines, Russia, and Madagascar as shown in Fig. 9.

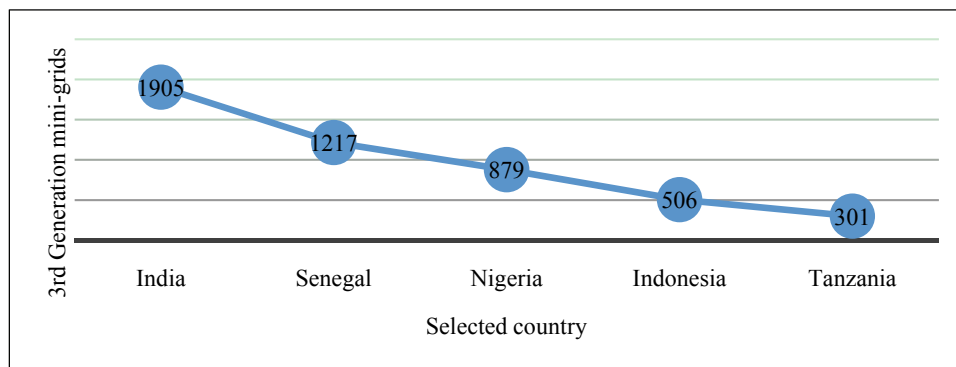


Fig. 7 Mini-grid projection activities in selected five countries 2019 up to 2030.

Source: World Bank Group 2019.

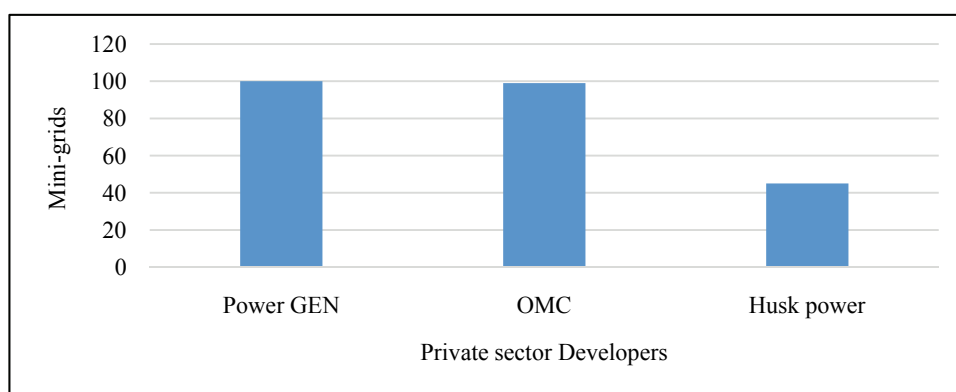


Fig. 8 Mini-grid private sector developers.

Source: Refs. [6, 44].

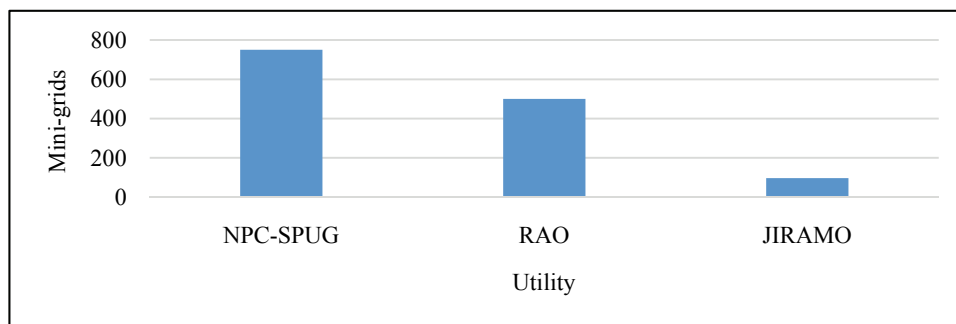


Fig. 9 Mini-grids installed by utility companies.

Source: Refs. [51, 58].

Power-Gen is operating in seven countries in Africa working on 100 mini-grids; OMC is in India working on 99 mini-grids, and then Husk power in India also working on 45 mini-grids as shown in Fig. 8.

Utilities are companies that perform a public service subject to government regulation. These include NPC-SPUG in the Philippines working on 750 mini-grids, Rao in Russia working on 500 mini-grids

and JIRAMA in Madagascar working on 96 mini-grids as shown in Fig. 9.

It is expected that over \$3.3 billion annually is available for developers for mini-grids to be invested in between 2019-2030 and approximately \$4.7 billion net profit potential across all mini-grid component and service suppliers to be realized in 2030 alone [16, 31, 51].

Environmentally, it is expected that by 2030, the mini-grid impact will be as follows: 10-15 GW solar PV installed, 50-110 GWh batteries mostly lithium-ion to be installed, 60% energy savings from energy-efficient appliances and finally 1.5 billion tons of carbon dioxide emissions to be avoided [16, 31, 51].

10. Conclusion

Despite the difficulties, challenges, and risks encountered in mini-grid development and operation worldwide, it has been observed that there have been:

- increased awareness through increased sensitization of the existence and use of mini-grids;
- a tremendous increase in the number of mini-grids in both the developed and the developing countries;
- an increase in the population accessing power from mini-grids to more than 20% over the past 10 years;
- increased funding for mini-grid development by governments and other non-government organizations;
- increased research that has led to the shift to 3rd mini-grid generation and hence increased mini-grid development;
- more feasibility studies, pilot and demonstration projects are done to increase rural access to electricity using mini-grids;
- more private investors are getting interested in mini-grid investment hence increasing the number of mini-grid development for rural electricity connectivity;
- a motivation for most countries especially in Africa, to embark on policy formulation and electricity regulation acts and tariff measures to better mini-grid use, operation, and practices.

Note that mini-grid development can be recognized as one of the key indicators to realize SDG 7 by 2030.

A lot of research has been done on mini-grids and more is being done and yet to be done. The difference is coming out with outstanding ideas to add to the existing knowledge.

This State-of-Art-Paper has looked at mini-grids as

one of the means of rural electrification processes and has brought out the status of mini-grids globally, installations, operations, financing, regulations, tariff, risks involved and how they are managed and concludes with the trend of mini-grids in the years to come.

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