Solar-powered mini-grids and smart metering systems, the solution to Rwanda energy crisis

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Abstract. As the population and economy of Rwanda continue to grow, the energy consumption in Rwanda has shown a continuous rise correspondingly to the population and modern socio-economic life desired in the past few decades. According to the Ministry of Infrastructure, Rwanda household access to electricity increased to 52% by September 2018. Not only does 48% of Rwanda’s population have no electricity, but also the grid is not stable where persistent power failures occur. However, the government has invested in the power sector in order to achieve 100% access to electricity for all population by 2024. To ensure that the country gets affordable and reliable power supply, it needs very strong energy sector’s projects, policy and private partners to achieve these objectives. In this paper, policy and semi-private operator model were proposed where solar-powered mini-grids and smart metering systems will provide a sustainable solution to the energy crisis by increasing electricity reliability and providing power to different energy consumers. The challenges discussed include community engagement, financial and technical. The focus is on the partnership between the government through local people and private partners by maximizing investor attraction, mutual profitability, intense model and reliable or inexpensive energy for the population. The continuation of policy supports would be necessary for this century to maintain and enhance the growth of solar energy in this country which is the essential strategy for rural electrification, for climate change and low carbon footprint development.

1. Introduction

The government of Rwanda envisions transitioning from a developing country to a middle-income country. To achieve this goal, the government is targeting 100% of electricity access by 2024. Rwanda is endowed with natural energy resources including hydro, solar, and methane gas. It currently has only 218 MW of installed generation capacity. According to the Ministry of Infrastructure, Rwanda’s national electrification rate is estimated at 52% [1]. In Rwanda, people live in rural communities like small-scale farmers or small business owners are waiting in vain for government-supplied electricity
to arrive. But, today, few private companies coupled with cheaper solar panels, better batteries, and mobile charging systems that facilitate the economic growth of different sectors especially in health and education are available. Energy may be needed as heat, as light, as motive power etc. The present-day advancement in science and technology can make it possible to convert electrical energy into any desired form. This can give electrical energy a place of prioritizing it in Rwanda. Although solar-powered mini-grids are easily practicable in rural electrification, it generates impacts by improving customers’ quality of life through the provision of affordable and clean energy solutions. Forty eight percent (48%) of the population is without electricity and are better serviced with mini-grids or stand-alone systems. However, the uptake of decentralized generation is slow, mini-grid deployment requires supportive policies to increase uptake and encourage private sector participation [2]. The overseas private investment and clean energy finance initiative supported the early stage development of several generation projects. Furthermore, many companies have received U.S embassy support to move transactions forward. Through The United States Agency for International Development (USAID, power Africa is working to strengthen the Rwanda Energy Group (REG) (the country’s utility) and the Rwanda Utility Regulatory Agency (RURA) to ensure the sustainable development of sector [1].

The Private sector has particularly been low; lack of capital from public and donor sources has severely impeded achieving access goals, leading to calls for greater private sector participation in electrification activities [3]. The government of Rwanda should work with the private sector in implementing the strategy of attracting them especially in increasing competition within the private sector which can lead to reduced costs and improved choice of technologies on the market. The government wants to support private companies to have access to different mechanisms and protecting consumers through establishing standards and carrying out awareness campaigns [4]. While Rwanda’s power generating capacity has improved over the years, the energy sector still has difficult issues such as load shedding, no fixed electrical energy tariff, and many people who lack access to electricity. Since electrical energy is produced from energy available in various forms in nature; it is desirable to look into the various sources of energy. Solar power is pollution free, it causes no greenhouse gases to be emitted after installation and its initial cost is low compared to hydropower plant that Rwanda is mostly using now. So, it can be successful to invest in solar-powered mini-grids and smart metering systems where all solar radiations experiments show that solar systems in Rwanda can be implemented [5].

This paper develops a standard operator strategy model focusing on low initial cost, free running cost, reliability, cleanliness, simplicity risks, and payments cost by deploying sustainable energy solutions in Rwanda. This paper is organized in six sections where section 1 is the introduction, section 2 examines the benefits of solar-powered mini-grids in rural electrification and in climate change, section 3 discusses challenges to private sector investment, section 4 discusses operator model, its benefits, Section 5 is the paper discussion and section 6 is the paper conclusion.

2. Benefits of solar-powered mini-grids in rural electrification and in climate change
The decentralized nature of solar-powered mini-grid has proved several essential advantages such as technical performance, environmental sustainability, and social impacts. In general, Mini-grids have continued to make easy the growth of socioeconomic development in rural areas [6]. The sun is the primary source of energy. Rwanda is a location where strong radiation is received very regularly [5]; this paper offers more interest to the solar-powered mini-grids. Solar energy technologies can help address energy access to rural and remote communities, energy security and climate change mitigation are a key tool to lower worldwide carbon emissions [7].

Solar energy can be helpful in education where children can undertake more study at home in the evening. Additionally, electricity can provide the opportunity to the local people in the countryside to start new small businesses and to expand and flourish in existing businesses. These small businesses like mills, food processing, sewing machines, electrical tools, carpentry and construction are the key to boost the countryside economies and reducing their economic issues [8].
The Sun is the biggest source of renewable energy for the Earth where it receives only a part of the energy generated by the Sun (i.e. solar energy). This leads solar energy technology markets to compete in different modern energy markets. The traditional approach to comparing the cost of generating electricity from different technologies relies on the "levelized cost" method [9]. The levelized cost (LCOE) of the different power plants is given by:

\[ LCOE = \frac{OC}{CF \times 8760} \times CRF + OMC + FC \]  

where OC is the overnight construction cost (or investment without accounting for interest payments during construction); OMC is the series of annualized operation and maintenance (O&M) costs; FC is the series of annualized fuel costs; CRF is the capital recovery factor; CF is the capacity factor; r is the discount rate and T is the economic life of the plant (plant lifetime in years). The economic analysis comparison of solar energy with other energy made by authors showed that solar energy is cheaper. For example, the overnight night construction cost of grid-connected solar PV system varies from US$2,878/kW to US$7,381/kW ([10], [11]). However, the overnight construction costs of concentrated solar power vary from US$4,347/kW to US$5,800/kW ([10], [11]) which show a big economic difference compared to others like hydro, coal and nuclear plants.

3. Challenges to private sector investment in electrification via mini-grids

Despite solar mini-grids relatively very small scale at present, the solar industry has attracted a great deal of attention from all levels of government in Rwanda especially in the eastern province of Rwanda. Expanding electricity access to rural areas in under developing countries is encouraged by the government, but as with any investment opportunity, the private sector will measure the attractiveness of a project by its expected financial returns and its associated risks. This section examines and makes clear intense challenges that private sectors meet, and so do not participate in mini-grid electrification. We divide them into seven categories as represented in Table 1.

| Challenges         | Description                                                                 |
|--------------------|-----------------------------------------------------------------------------|
| Financial          | Unfavourable conditions attached to the loans and grants from suppliers of funding. |
| Technical          | Lack of technical skills of local people, lack of adequate local expertise to manage the energy sector. |
| Policy             | Lack of legal and regulatory framework                                        |
| Institutional      | Lack of institutions/mechanisms to disseminate information.                   |
| Data               | Lack of reliable data.                                                       |
| Community engagement | Lack of community engagement.                                                  |
| Electricity tariffs | High electricity tariffs for non-industrial customers.                        |

In order to achieve the overall economy, the balance between risks and expected interest should be considered while selecting a site for solar-powered mini-grids. Off-grid schemes fare less well because they have higher costs but lower benefits [12]. Rural mini-grids often serve poor populations with limited means to pay for electricity services. However, people from the countryside do not have the ability to invest in mini-grid construction, this issue causes the financial markets to be resistant to financing capital-intensive facilities unless there is some assurance of a revenue flow that returns principal and interest [13]. There are several technical issues that affect the feasibility of mini-grids for rural electrification that should be noted. The solar-powered mini-grid construction needs technical
engineers and experts in mini-grids design. However, many African countries lack people trained to install, to maintain and to repair modern mini-grid technology. Once the project has been constructed, a lack of local agents with technical skills brings challenges in maintaining and operating the system [14]. On the other hand, Micro-grids (Mini-grids) are also clearer to local energy consumption patterns than interconnected national grid systems. Because loads are aggregated over smaller geographical areas, the variability of demand is more pronounced than in large national and regional grids [3].

In 2011, the UN Secretary-General launched the Sustainable Energy for All (SE4ALL) which is a Multi-stakeholder partnership between Governments, the private sector, and civil society [1]. Therefore, mini-grid solutions, including solar-powered mini-grid will play a key role. Once the government does not create policy and environment to attract private projects with low income and strong people’s welfare motivations, the needs of the private sector and the goals of public policy in providing social services would not be mutually balanced. The next section discusses how the policymakers in Rwanda can attract the private sectors and private organizations to participate in rural electrification. The Government of Rwanda has taken strides toward developing an enabling off-grid sector policy, regulatory and planning environment over the past few years. Nevertheless, many problems continue to foster unease and to postpone development in the sector [15]. Rural electrification stimulates long-term development impact. In addition to providing energy access to rural households and institutions, they bring business opportunities and job creation to the local people. Therefore, effective administration of policy and regulation relies on clear institutional structures with the well-defined allocation of roles and responsibilities. All too often, institutional structures and regulatory processes are complex and difficult to navigate, acting as a barrier to potential project developers and investors [14].

The lack of reliable data is one in the major challenges for private investors in mini-grids. On both the national and regional levels, there is often limited information on grid expansion plans, policy and regulatory framework. Developers are getting around some of these problems by using GIS-based tools to fill data gaps. Others, particularly solar developers, are starting projects with diesel generators and small grids (which have lower upfront capital requirements) in order to assess demand before they invest in solar panels and larger grids [16]. Due to the initial capital costs, the electricity from mini-grids remains very expensive compared to the electricity from the national grid. As a result, many countries seek grants to cover initial capital costs. As mini-grid technology has become more standardized and conventional, innovation in the sector can be found more in terms of business models and community engagement that seek to increase demand and expand productive use of energy [17]. Since rural populations value the structure of the community, the creation of local organizations creates a sense of ownership and accountability ensuring that project equipment is not vandalized or stolen [2]. This can help Rwanda and Africa generally to participate in sustainable energy which is one of the global goals that make up the future agenda for sustainable development. To promote the use of solar energy, it will be very important to operate solar micro-grid (mini-grid) systems across broader geographical areas and to build the inter-regional infrastructure needed for future electric supply systems. Whereas, Rwanda’s electricity tariff was estimated to be about 22.2% more expensive compared to the highest electricity tariff of other East African Community (EAC) countries [18]. This means that the achievement of Rwanda electricity tariff structure is needed.

4. Solar mini-grid operator model and policy support for mini-grids

4.1. Source of financing and semi-private model

Reliable and affordable energy has a great impact on future efforts at poverty reduction and development. Since traditional biomass is still used in countryside areas in Rwanda and Africa generally, many African countries still face the task of satisfying the demand for energy services of a vast majority of its population to meet basic needs and provide employment for local people. This
section discusses the proposed strong model and Policy interventions to support the private sector in solar mini-grid electrification.

Rwanda, one of the East African countries, has a power sector that faces challenges that are common to other African countries. The challenges include inadequate physical infrastructures that need to be retrofitted and developed, poor institutions, technical capacity and lack of enough financial means stemming from the immaturity of the country’s private sector which ought to drive development [19]. Over the last 10 years, Rwanda puts in place implementation mechanisms to rapidly achieve its long-term goals, for instance, Poverty Reduction Strategies—EDPRS (2008-2012) and EDPRS-2 (2013-2018). These two goals are designed to help the country realize its Vision 2020 development plan. As a result, the government of Rwanda has been supported by the World Bank to strengthen the energy sector [20].

In this paper, a semi-private operator model was proposed (Figure 1) and solar-powered Mini-grid connected to the main and off-grid as the technology to be used. In 2014 the report of European Union Energy Initiative (EUEI) showed that over 30% of the world’s rural population, currently without access to electricity, is best served by extensions of the main power grids. The remaining 70% are often better served through the creation of mini-grids, which have emerged for providing rapid, cost-effective and high-quality electrification in rural Africa [21]. Solar mini-grids are easily installed, flexible and can be connected to national power grids if and when such networks expand. However, the government of Rwanda needs to increase the national grid capacity, because much additional power capacity by the deployment of new mini-grids is a much more sustainable solution because the alternative would be overloading the national grid. Once the national grid is expanded, a Public Energy Developers (PED) framework should be extended which are the future affordable off-grid stations with reliable energy.

![Figure 1. Semi-Private Operator Model (a partnership between local people and the private sector in mini-grid electrification).](image_url)

The Climate Investment Funds (CIF) is the largest fast climate financing in the world. These Loans and grants are provided by Scaling up renewable energy program (SREP) of African development
As CIF is helping African countries, Rwanda should move forward to get these loans and grants in order to expand clean technology and scaling up renewable energy program. Energy efficiency and renewable projects are the trust fund managed by the World Bank to increase private sector participation in the renewable energy sector and to improve the framework and energy efficiency of renewable energy [23].

As a result, the Development Bank of Rwanda (BRD) can be supported in granting loans to saving and credits cooperative institutions (SACCOs), Commercial banks and Microfinance institutions as shown in Figure 1. Unavailable and expensive financing is the major challenge for scaling rural mini-grids with rates of commercial debt typically 15% or more in sub-Saharan Africa [24]. Once SACCOs, Commercial banks and Microfinance institutions get these grants and loans from World Bank and SREP through BRD, local people and private energy developers (PED) will be provided affordable loans to acquire certified smart grids projects which will be the partnership of private sector and local people (semi-private operator model: Figure 1). The access to reliable and affordable clean energy improves the lives of local people. In addition, it can provide local people savings and creating new businesses. After a short period of time, local people can start to pay small amounts of money on a regular basis because most customers do not have enough money for the total amount of the loan. Through a mini-grid income, Private energy developers will get the money back to offer a way to upgrade the distribution grid, operation cost of mini-grids, and their loan payment.

4.2. Smart metering systems

4.2.1. Smart meters introduction. In the context of a Smart Grid, smart meters are a home's connection between the electricity needs and the rest of the smart grid. Smart meters can communicate with in-home displays to let us know how much energy we are using to provide consumer benefits. They are more accurate, they are also not a health threat because they use wireless signals. Additionally, smart meters are not a security risk where it only collects energy consumed by using data. As a result, smart grids and smart meters help to save money on electrical bills and support the green environment [25].

**Figure 2.** Metering Architectures of Conventional Energy Meter and Smart Meter [26].

Figure 2 shows the Architectural model of a conventional energy meter and smart meter, which consists of a conventional energy meter and smart meter. Smart metering in mini-grid measures the electrical energy consumed and also provides additional information compared to the conventional energy meter [27]. Smart meters are connected to the database of the utility company by means of a gateway of communication interface protocol. One of the major drawbacks of Smart meters is their shorter life expectancy (5 to 7 years), compared to traditional meters (20 to 30 or 40 years). However, there are no disadvantages for the environment [28]. As a result, the health risk can be reduced by decreasing greenhouse gas emissions from existing power plants, by preventing new power plants which create pollution by gases production, etc.
4.2.2. Benefit of Smart Metering Systems in Rural Electrification [29].

- Information is easily accessible, immediately useful for the consumer and updated daily.
- Direct load control where the shifted load is now measurable and verifiable.
- System-wide availability of a peak time rebate (customers stay on current rate but receive an incentive to shift load during certain hours on very high priced days)
- Ability to opt into a critical peak pricing program.
- Ability to charge an electric vehicle with a time-varying rate.
- Incremental to programs that can be implemented without AMI (advanced metering infrastructure).
- Developed from a societal perspective, not simply an individual customer’s bill savings.

4.2.3. A review of the smart metering scheme in smart grid. With the trend towards larger and larger interconnected systems, it has become necessary to employ appropriate methods of the smart metering scheme in a smart grid. Following is the review of works of different researchers on the smart metering framework in the smart grid.

S. Raj Rajagopalan proposed the utility-privacy framework of a smart meter. The theoretical framework that they developed can help precisely to quantify the utility-privacy trade-off problem in smart meter data. Smart meters deploy advanced information and communication technology to control the electrical grid [30].

For the security requirements of the Smart Grid and the user privacy of different techniques, Hajer Souri showed the domains and essential protections of the smart grid. In addition, they provided the study of previous techniques so that they can prevent the privacy disclosure caused by the new technology in smart grid [31].

Adam Hahn and Manimaran Govindarasu evaluated a model which utilizes a pragmatic development process which integrates within a modern risk management process and is based on information that is well known to security engineers and operators. Due to the risk management such as security models that have the capability to scale to such a complex environment, it is the reason why these authors dealt with the quantitative security metrics for large scale networked environments such as a smart grid [32].

5. Discussion

The partnership between the local people and the private sector in mini-grid electrification is the essential model of how to expand access to electricity in Rwanda in this decade and next decade. The development of sustainable solar energy is one of the solutions when addressing the energy crisis where the balance between electricity demand and supply can be maintained. The rapid dissemination of solar mini-grid technology can be done using the model which was explained in section 4 (see Figure 1). Therefore, it must increase the access to modern clean energy resources in order to reduce the charcoals usage, candles and petrol in some countryside which must reduce carbon emissions. Despite the economy grew in recent years, some small cities still lag far behind on energy; with a portion of countryside people who are totally lacking access to electricity. Solar energy can be the bases to build the future foundation of clean energy development. To extend the national electricity grids is very expensive and slow. Fortunately, the other approach that can solve the problem of the energy crisis is solar-powered mini-grids where they can provide electricity more quickly and at a much lower cost.

Experience in the Republic of China, shows China as one of the world’s energy leader countries. It is the world’s leader in solar power and the world’s largest energy consuming country ([33-35]). China government has invested more in wind, hydro and solar power than any other country, and they have built the largest floating solar farm in the world. Their reliable and affordable energy was caused by China’s energy policy to invest strongly in sustainable energy development. As a result, China concentrated on the extraordinary pace of its development, the country’s success in powering more than a billion of its citizens out of energy poverty.
If local people and PED get loans and grants, the government should design a solar mini-grid strategy plan and model that work locally. In this paper, a semi-private operator model was proposed which is a partnership between local people and the private sector in mini-grid electrification. That means a coherent framework of technical, financial loans and grants, and procedural regulations should be established before the implementation of the project. As a result of this framework and policy, it will be possible to use sustainable energy resources in Rwanda. A large number of mini-grids will be synchronized with the national grid which will solve the power shortage problem in big industries and factories. However, others will connect a huge number of people who are living in the dark in different countrysides.

In modern technology, electrical energy from the generating station is delivered to the consumers through a network of transmission and distribution networks. It is necessary to use modern technology to produce, transmit, distribute and even consume power. In European countries the economic case for the smart metering systems installations showed a positive profit ([36-38]). This experience can encourage Rwanda energy utilities to integrate smart metering systems. If both technologies are used, it can help our energy sector to achieve energy efficiency, to reduce power outages, to reduce energy wastage and it can help the environment by reducing the need of new fossil power plants construction.

6. Conclusion

Last decades, the government of Rwanda has shown very significant progress to install more generation capacity and to invest in economic growth in order to achieve the electricity access target by 2024 of supplying affordable, reliable and abundant energy services to all people, economic sectors and industries. Reliable and affordable energy can help to create new innovations and productivity, thereby contributing to economic structural transformation. Ultimately the use of electrical energy can accelerate the national income while improving different services costs and environmental impact.

Solar energy is developing rapidly in Rwanda due to business partners, competitor’s energy policies and targets proposed by the government of Rwanda. Solar-powered mini-grid can help address energy access to rural communities; businesses, energy sustainability and climate change mitigation which is a key tool to decrease the carbon emissions. In this paper, a semi-private operator model has shown and described which is more favourable to make easy the partnership between the private sector and the government through the local people in solar-powered mini-grid projects. Although the challenges that private sectors meet, and so do not participate in mini-grid electrification are described in this paper. However, by using a semi-private model in different grants and loans, it can be a good way of tackling this problem.

Although the country continues to invest in different energy technologies, the smart metering or advanced metering infrastructure (AMI) can run as well as maintain mini-grid technology on the national grid and off-grid systems. This paper has concentrated on different smart metering schemes in smart grids of other researchers which show that the smart metering systems can be implemented everywhere. Smart metering systems help to collect data and the communication between the meter and central system. With the implementation of the smart metering system in Rwanda; it can change the paradigm of electrical supply. Therefore, the current growth of solar mini-grids should be helped by smart metering systems which can surely help us to tackle the government target of supplying affordable electricity by 2024.

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