Renewable and Sustainable Energy Reviews 91 (2018) 1148–1161

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: Reducing the gap between current business models and on-site experience

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ARTICLE INFO

Keywords:
Sub-Saharan Africa(SSA)
Photovoltaic (PV)
Hybrid mini-grid
Business model
LCOE
Rural electrification
Energy Development policy
Technology learning
Cost data harmonization

ABSTRACT

The absence of publicly available up-to-date costs breakdown data on photovoltaic (PV)/hybrid mini-grids in Sub-Saharan Africa (SSA) is a barrier that needs to be resolved in order to overcome challenges in rural electrification planning, regulation, life-cycle operation, financing, and funding. The primary aim of this research is to provide better understanding of the cost structures of PV/hybrid mini-grid projects in Sub-Saharan Africa. The review on existing literature reveals significant lack of transparency and inconsistencies in PV/hybrid mini-grid costs. This paper aims to support the fact that there still remains a strong need to reduce the gap between current business model concepts and successfully implemented scale-up electrification models. Based on the experience of PV/hybrid mini-grids projects implemented in various rural communities of SSA, we propose a multi-dimensional cost analysis with a standardised break-down of the real costs of installed projects. Subsequently, we assess the main social and environmental implications and we identify barriers that appear to hinder successful PV mini-grid planning and subsequent implementation in SSA. Africa has the unique opportunity to utilize renewable energy as a primary energy source. Indeed, the continent has the potential to bring electricity especially to its rural population by means of PV/hybrid mini-grids. However, the capability of public and private sector investors to pre-evaluate projects is limited by the lack of locally available information on PV/hybrid mini-grid costs or the reliability of data (when available). Multi-dimensional cost analysis of social and environmental impacts from this study highlight that PV/hybrid mini-grids offer a unique opportunity to create a standardised framework for quantifying costs of PV/hybrid mini-grids in SSA, that can support decision-making processes for designing viable business models. Findings show that there is a strong need to minimise the data quality gap between current business model and that of successfully implemented PV/hybrid mini-grids electrification projects. This gap could be mitigated through studying the issues that influence mini-grid costs (both hardware and software). In addition to understanding other factors that can influence project costs such as the market maturity and remoteness of the site, organisation capability, development approach, and level of community involvement. Regarding policy considerations, stronger political will coupled with proactive rural electrification strategies and targeted renewable energy regulatory framework would be essential in order to establish viable dynamic domestic market for off grid renewables. In the presented benchmarking analysis, the experiences of public and private development organisations are synchronized to contribute to the furthest extent possible to facilitate the assessment. Those include the disaggregation of component costs according to their unit in order to make comparison more accurate and include site-specific parameters in the discussion of costs.

1. Introduction

Sub-Saharan Africa (SSA) though rich in energy resources yet has the least electrification rate globally. The region, with a population of 915 million people, has only 290 million of its citizenry having access to modern energy services [1]. Even though considerable gains have been made in recent years in the provision of energy access services in SSA, population growth appears to be a significant limiting factor. Lack of modern energy services in rural SSA is a pressing challenge in the region, with nearly 80% of rural populace living in the dark. The electrified areas in SSA are typically found in the urban areas, however, as argued by Broto et.al. [2], there nevertheless, remain a growing

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https://doi.org/10.1016/j.rser.2018.04.018
Received 3 July 2017; Received in revised form 22 March 2018; Accepted 10 April 2018
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problem in informal settlements in urban areas on the lack of modern energy services due to increased rural-urban migration.

The International Energy Agency (IEA) reports that the average residential electricity consumption per capita is 317 kWh per year in SSA (less than 1 kWh per day) and notably the least energy consumption rate per person in the world [1]. Primary energy demand in SSA stood at 570 Mtoe (2012) and constituted only 4% of the total, globally [1]. The economy of SSA recorded a 2.5% decrease in energy intensity per year since year 2000 [1]. The falling costs of solar photovoltaics (PV) panels and battery systems as well as the available huge potential of the renewable resource makes it imperative for SSA to explore the technology in its energy portfolio for economic growth.

Despite the large technical potential for solar PV in SSA due to the unlimited resource, only limited use of solar PV electricity generation has been implemented to date. Since the early nineties, the main PV use in Africa was stand-alone systems with however untraceable market records [3,4]. However, during the last decade rapid cost reductions are being achieved for solar PV, due to technological developments, improving learning rate and economies of scale. Since 2012, the number of utility-scale PV projects are rapidly increasing due to the establishment of regulatory frameworks and institutions for renewable energy [5]. Overall, the installed PV capacity has grown more than forty times from 2008 to 2016 [3] with a total capacity of 2.5 GW by the end of 2016. IRENA published in 2015 a renewable technology roadmap study for African countries across the different sectors [6]. According to the roadmap, PV solar power could contribute 4% of total final energy consumption by 2030 produced from 31 GW of installed PV (which is more than a four-fold increase compared to the 2013 level of 5%).

There is a need to accelerate the pace of rural electrification in order to achieve full access to electricity by 2030, especially rural areas in Sub-Saharan Africa (see Fig. 1). Mini-grids offer a modular and competitive solution to accelerate the electrification in rural areas, characterised by remoteness and sparse population density [7]. Under this rationale, this paper focus its attention to the status of PV/hybrid mini-grids in rural areas in SSA.

Further penetration of solar energy to the energy mix of Sub-Saharan Africa has been achieved through the establishment of PV/hybrid mini-grids for rural electrification as an alternative to grid extension [7]. Different autonomous mini-grid sizes and architectures can offer a lower or higher tier of service [8] depending on the quality and duration of electricity provision. Thus, enabling energy access to remote population at a lower cost. Nonetheless, rapid deployment and replication of successful projects would be achieved via deep understanding and reduction in costs structures of related hardware and software costs. This paper presents and thoroughly explains the costs of installed PV/hybrid mini-grid projects, through a joint collaboration between the private and public sectors.

Table 1
Summary of literature coverage for PV/hybrid mini-grids in Africa.

Region covered	Technology	Framework covered	Selected references (cited in main text)
Global	PV	Costs (breakdown)	[13–20]
Global	Mini-grid	General status and barriers	[24–26,29,41,42]
Global	Mini-grid	Costs (general)	[7,22,27–31]
Africa	PV	Costs (general)	[4,7,21]
Africa	Mini-grid	General status and barriers	[26,37,43]
Africa	PV mini-grid	Costs (model)	[32–36]
Africa	PV mini-grid	Costs (breakdown)s	[21,31,38–40]

1.1. Overview of PV/hybrid mini-grids in Sub-Saharan Africa

The renewable energy (RE) based mini-grid sector is growing and attracting interest from public and private sector investors [9,10]. The latest report from the Africa Progress Panel calls for a diverse energy mix with immediate deployment of off grid solar systems that can be deployed in tandem with the improvement of grid infrastructure [7]. Nevertheless, comparative studies of PV/hybrid mini-grid installation costs in Sub-Saharan Africa are scarce. The capability of private and public investors to assess rural electrification options is restricted by the lack of consistent data, for example of disgreggated PV/hybrid mini-grid cost factors.

Table 1 summarises the regional, technological and specific coverage of the exisiting literature not only specific for PV/hybrid mini-grids but as general overview of relevant literature. At the international level a number of leading institutions and networks have provided relevant literature on PV costs, as examples the work done by REN 21 [11], the Joint Research Centre (JRC) [3], and Latin American Energy Organisation (OLADE) [12]. The International Renewable Energy Agency (IRENA) [13], JRC [14] and IEA [15] have examined PV system pricing by disaggregating costs and technologies including survey reports and PV breakdown costs. Bazilian et al. [16] analysed the

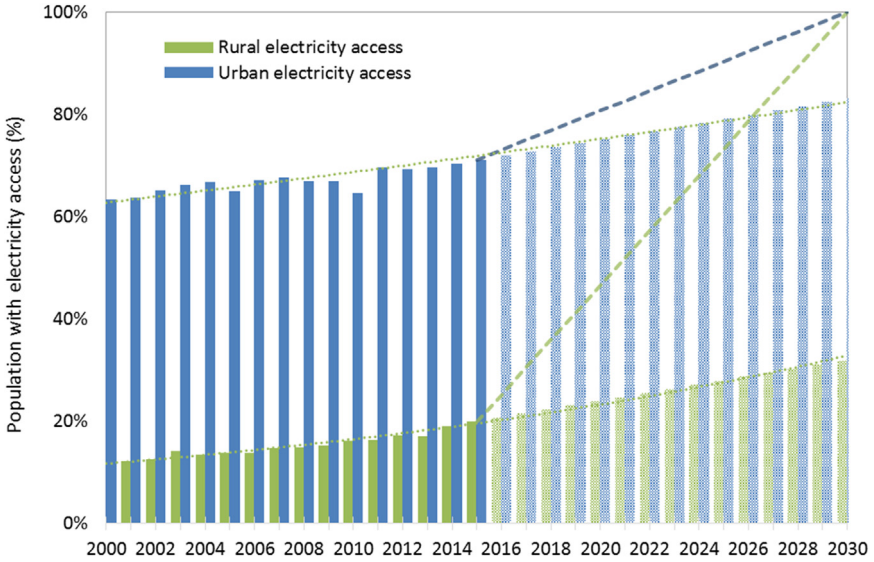

Fig. 1. Evolution of fraction of population with electricity access in SSA (linear increase needed to reach 100% electricity access in 2030).
Source: Based on [1] and JRC calculation

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