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A survey informed PV-based cost-effective electrification options for rural sub-Saharan Africa

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HIGHLIGHTS

- A survey on sources of electricity in Kendu Bay area of Kenya is carried out.
- Survey results are used to determine choices and sources of household electricity.
- Factors affecting electrification are highlighted.
- Survey data are used to build a transition probability matrix (TPM).
- The TPM and data from the survey are used to model temporal PV diffusion.

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ABSTRACT

A comprehensive survey is carried out in Kendu Bay area of Kenya to determine electrification patterns of a typical rural sub-Saharan Africa community and to determine the reasons behind such energy choices. The data from the survey is used to build a transition probability matrix (TPM) for different electrification states for Kendu Bay households. The TPM and the survey data are used to model temporal diffusion of PV systems and PV-based communal (mini/micro) grids in the area. Survey data show that majority of Kendu Bay residents shun the national grid due to high connection fees, unreliability of the system, and corruption; people who can afford-to choose small solar home systems for their basic electricity needs. Without any government policy intervention or help, simulation results show that once 100% electrification status has been achieved in Kendu Bay, only 26% of the residents will be found to be electrified through the national grid alone; the majority (38%) will be electrified through PV-based communal grids while the remaining 36% will be electrified through grid connected PV home systems (26%) or grid connected communal grids (10%).

1. Introduction

Modern energy services are fundamental to all three pillars of sustainable development, i.e. social, economic, and environmental. Most energy developments must be implemented in line with all aspects of the development process, e.g. energy and communication, energy and health, energy and schools, energy and roads, etc. Energy is therefore a complementary factor to socio-economic development. Electricity, the main form of modern energy, is crucial to industrialization and easy access to it is an indicator of a nation's standard of life. It is estimated that there are about 1.3 billion people in the world without access to electricity today and that 95% of these people reside in 20 developing nations of Asia and sub-Saharan Africa (IEA, 2012). On a more local note, Kenya's national electrification rate stands at 23%, while its rural electrification rate stands at 5% (Ministry of Energy and Petroleum, Republic of Kenya, 2013); the country still heavily relies on unsustainable low-grade forms of fuel, especially biomass (firewood and charcoal), for its primary energy needs. In 2014 for example, biomass accounted for 69% of all energy consumed in Kenya (Ministry of Energy and Petroleum, Republic of Kenya, 2013). During the same period, electricity accounted for only 9% of the total energy consumed, with petroleum and petroleum products accounting for the remaining 22%, and for 25% of the national import bill in 2014 (Ministry of Energy and Petroleum, Republic of Kenya, 2013).

In order to achieve 100% electrification rate by 2030, so as to meet its millennium development goals, Kenya has started to expand its national grid network, from the current 3767 km to about 16,000, in anticipation of increased power capacity (Ministry of

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Table 1
Installed PV capacity by market segment.

Market Segment	Estimated installed capacity
SHS and small-scale enterprises	6–8 MWp
Off-grid community systems	1.5 MWp
Off-grid schools	0.5 MWp
Remote communication installations	100–150 kWp
Off-grid tourism establishments	50 kWp
Overall market size	8–10 MWp

Energy and Petroleum, Republic of Kenya, 2013). As with many developing nations, Kenya's national grid is strained and plagued by frequent power blackouts, high system losses, and poor maintenance, and is therefore unreliable; extensions of the national grid has only resulted in further strain on the system and therefore in further reduction in quality of services to those already grid-connected (Foster and Steinbuks, 2009). Kenya can still cost-effectively, and in a timely manner, achieve universal electrification if it formulates better and achievable policies to exploit its vast renewable energy resources; renewable energy has the potential to enhance energy security and reliability in Kenya while generating income and employment, and to enable the country to make substantial foreign exchange savings by reducing dependence on imported petroleum and petroleum products.

With an average solar insolation of over 6.5 kWh/m^2/day all year round, and about 8 hours of strong sunlight daily, Kenya's geographical location astride the equator makes it a potentially vibrant solar technology market. The country's estimated solar energy potential is 1,857,790,042 MWh/year, enough to satisfy its energy demands many times over (Acker and Kammen, 1996). However, effectively harnessing this free source of energy still remains a challenge mainly due to lacklustre government support and underappreciation of its potential. Table 1 shows the PV market structure in Kenya today (Ministry of Energy and Petroleum, Republic of Kenya, 2013). Solar Home Systems account for about 75% of the total installed PV capacity, or for 6–8 MWp. Government and donor funded large PV projects which once dominated the early PV market in Kenya now account for between 20% and 25% or about 2 MWp of the installed capacity. PV systems for remote communication installations which pioneered the entry of solar technology into the Kenyan market now account for a negligible segment of the market. However, even with such vibrancy, the installed PV capacity is still way below the nation's potential. PV powered communal grids have hardly taken off in Kenya due to lack of knowledge on the socio-economic benefits of such arrangements, lack of government support and regulation, and most importantly, lack of organizational structures necessary to establish and run such ventures.

Minimum potentials for a communal grid are a minimum of 5 km from existing national grid lines and minimum population density of 250 people/km^2 (Zerriffi, 2011a, 2011b; Yadoo and Cruickshank, 2010, 2012; Reiche et al., 2000). Maximum potential for a communal grid are a maximum of 20 km from existing national grid lines and a minimum population density of 300 people/km^2 (Zerriffi, 2011a, 2011b; Yadoo and Cruickshank, 2010, 2012; Reiche et al., 2000). As per latest estimates, Kenya has a population of 43,629,394 people, only about 33% of whom (14,542,211) can be cost-effectively electrified through national grid extensions (Ministry of Energy and Petroleum, Republic of Kenya, 2013; Central Bureau of Statistics, Republic of Kenya, 2011). 66% of the population (28,825,000) live in areas with densities above 250 people/km^2. Of these, the communal grid population, those living over 5 km from existing national grid lines, is about 10%,181%,127%, or 23% of the national population (Ministry of Energy and Petroleum, Republic of Kenya, 2013; Central Bureau of Statistics, Republic of Kenya, 2011). The remaining 44% of the population (18,906,056) can currently be cost-effectively electrified through stand-alone systems. However, with increasing demands and population growths, this number is also expected to shrink as more and more portions of this group fall into the communal grid category. Table 2 shows communal grid potential for Kenya (Ministry of Energy and Petroleum, Republic of Kenya, 2013). It is clear from the table that rural and off-grid villages in Kenya can leapfrog into sustainable electricity access through solar micro-generation systems, especially PV-based communal grids, as long term solutions rather than as temporary solutions as national grid lines are awaited to arrive; the communal grids could provide 'electricity-beyond-lighting' to stimulate local microeconomic activities and enhance livelihood.

In this work a comprehensive survey was carried out in rural western Kenya to identify the reasons behind different electrification choices and how those choices affected other household energy patterns such as cooking fuels, household appliances etc. Specifically the survey sought to gather as much information as possible on PV installations in the area to identify key drivers of such installations. Rural western Kenya was chosen for this study because Kenya's geographical location astride the equator makes it's a potentially vibrant market for solar energy technologies. It also represents a typical developing sub-Saharan Africa community with low rural electrification rates and development.

A comparative study by Karekezi et al. on energy access among the urban poor in Kenya focused on energy usage patterns in a Nairobi slum, Kibera, with an aim of identifying key energy option for the people in the area and presenting policy measures that could lead to improved energy provision services in the area (Karekezi, et al. 2008). However, the study focuses on general sustainable energy supply and not on PV. Moreover, the study focuses on urban settings, which already enjoy more than 70% electrification rates in Kenya, as opposed to rural areas where electricity access is below 5%. Moreover, 76% of Kenyans reside in rural areas and thus the need to electrify those areas if Kenya is to meet her millennium development goals (Ministry of Energy and

Table 2
Kenya communal grid potential.

Kenya	Wind	Hydro	Biomass		Solar	Total
Population targeted by communal grids (> 250 hab/km^2 & > 5 km of MV)	2,239,848	1,018,113	1,018,113		5,905,054	10,181,127
Share of population for a given technology	22%	10%	10%		63%	
Average energy consumption over 20 Yr. (GWh/Yr.)	568	258	258		1497	2582
Penetration rate (%)	33%	87%	80% (RH)	50% (SC)	40%	
Total Energy need @ Yr5 (GWh)	329	150	150		868	1497
Total Power need @ Yr5 (MW)	62	28	28		163	281
Renewable Device capacity (MW)	153				238	391
Carbon emission Diesel-MG (kTCO2eq/Yr.)	244	292	756		779	2070
Carbon emission National grid (kTCO2eq/Yr.)	153	184	476		490	1 303