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ORIGINAL ARTICLE

Rural electrification in sub-Saharan Africa with innovative energy policy and new financing models

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Abstract This paper discusses how the 630 million sub-Saharan Africa (SSA) people can be electrified with new government policy, new renewables, and innovative business models. These initiatives are translating the ambitious goals of Sustainable Development Goal 7 (SDG7) on energy and the United Nations Framework Convention on Climate Change Conference of the Parties 2015 Paris Agreement. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise in this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. The objective of this paper is to evaluate the feasibility and cost-effectiveness to electrify the 630 million people within the Paris Agreement. Economic status and willingness to pay for electricity services by the poor are briefly analyzed for four new business models. Cost-effectiveness analyses on technologies are undertaken. The results show that a private investment-based financial model is the most effective and environmentally friendly in rural electrification for the poorest households in SSA. The new policy, new renewable energy technologies, and financing models are shaping contemporary climate strategies that facilitate investment in clean energy, spur community economy, enhance national energy security, and improve global environment.

Keywords Cost-effectiveness assessment · Leasing financial model analysis · Policy for renewable energy investment

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1 Introduction

As of August 1, 2017, the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development—adopted by world leaders in September 2015 at a United Nations (UN) Summit—have officially come into force for 1 year and 7 months. Ensuring all human beings to access to affordable, reliable, sustainable, and modern energy, Sustainable Development Goal 7 (SDG7) is one of the 17 SDGs in the agenda. Universal access to sustainable energy is essential and central to nearly every major challenge and opportunity, including jobs, security, climate change, and food security. Sustainable energy development provides an opportunity for human beings to transform their lives, economies, and the planet. SDG7 underpins progress on a large number of other SDGs, ranging from health and education to gender equality, economic growth, and climate actions. Besides SDG7, there is another initiative on sustainable energy at the UN: Sustainable Energy for All initiative (SE4ALL) led by UN Secretary-General. The objective of SE4ALL is to ensure universal access to modern energy services, improve efficiency, and increase use of renewable resources. The targets of SDG7 are consistent with SE4ALL's objectives on energy access, energy efficiency, and renewable energy. With its huge network of partners across governments, business, international organizations, finance and civil society, SE4ALL stands ready to take a leading role in supporting implementation of SDG7 and to monitor and report on progress towards the goal.

In addition, the United Nations Framework Convention on Climate Change Conference of the Parties 2015 Paris Agreement, dealing with greenhouse gas emission mitigation, climate adaptation, and finance, went into effect on November 4, 2016. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise in this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change and at making finance flows consistent with a low GHG emissions and climate-resilient pathway. The first session of the conference of the parties serving as the meeting of the parties to the Paris Agreement took place in Marrakech, Morocco from November 15 to November 18 2016. The Paris Agreement requires all parties to put forward their best efforts through "nationally determined contributions" (NDCs) and to strengthen these efforts in the years ahead. This includes requirements that all parties report regularly on their emissions and on their implementation efforts. In sub-Saharan Africa (SSA), there are a total of 34 least developed countries (LDCs) and these countries have ratified the Paris Agreement. Many African LDCs committed to mitigating their greenhouse (GHG) emissions by 30 to 50% by 2030 on the emission level of the business as usual scenario. As such, investments in low carbon technologies to meet increasing energy demand must be one of top priorities for LDCs in rural electrification and energy development.

As of August 2017, approximately 630 million people without access to electricity were in SSA. While the average electricity access rates in Latin America, the Middle East, and developing Asia were 85, 78, and 79%, respectively, Africa ranked the lowest, with only 28% of its population on average accessing to electricity (IEA 2016). These 630 million people who did not access to electricity were predominantly in rural areas.

The grim reality of energy poverty in most African countries, however, is in stark contrast to the continent's rich endowment with renewable and fossil energy resources. Africa's reserves of renewable energy (RE) resources are the highest in the world and are estimated to be sufficient for meeting the continent's current as well as incremental future needs. The significant decrease in costs of renewables particularly solar photovoltaic (PV) technologies over the past few years offers huge potential for Africa's power sector; the question remains how best to make use of it. In particular, as of today, some of RE technologies are becoming more and more cost-effective when compared with fossil energy technologies. People in SSA are facing two or three choices to electrify themselves: using fossil energy or renewable energy (RE) or combined technologies.

The African Development Bank (AfDB 2016) recently released a publication with an outlook for lighting up and powering Africa. In that publication, RE technologies combined with fossil energy technologies will be developed and invested under the existing government energy and environment policies. With that scenario, greenhouse gas (GHG) emissions from Africa will keep growing with emissions per capita by 1.2% per annum from 2017 to 2025. Are there any other scenarios using 100% RE resources to electrify the poor? Could the poor afford the electrification with 100% RE resources?

This paper presents an analysis on economic and financial status and willingness to pay electricity service of the poor in SSA. It also shows four business models that are currently used by the private sector in rural electrification for households which cannot access grid power. The solar PV technology under the "pay-as-you-go or PAYG" financial model is acceptable and effective in the rural communities. Even without government subsidies, this new financial model has been and will be playing a very important role in rural electrification in the Eastern Region of SSA over the next 5 to 10 years. When appropriate energy and financing policies are available in other countries in SSA, this model will be quickly duplicated in all countries in SSA.

2 Brief review on economic development in SSA

Economic activity in SSA is projected to have reached its lowest levels in two decades, albeit with highly heterogeneous trajectories. The subcontinent grew at a rate of roughly 3.5% in 2015, and preliminary statistics indicate a slow down to under 2% in 2016 (IMF 2016a). Despite experiencing an average growth rate exceeding 5% in 2010–2014, sustained global low commodity price shocks and slow policy responses continue to affect an overall decelerated pace in SSA.

The economies of many SSA countries have been historically predicated upon the export of raw natural resources, predominantly oil and metal ores. Comparably, higher global commodity prices in the past decade have been an important source of revenue and contributed to an overall growth rate in excess of 5%. However, recent developments in international markets have seen dramatic reductions in commodity prices and demand, and consequently, resource-rich countries have experienced income shortfalls. In particular, oil exporting countries such as Nigeria and Angola have been hit the hardest; in addition to the initial impacts of a global downturn, second round effects have also impacted the non-oil sectors of the economy in SSA, resulting in negative growth. Recent reductions in oil revenue have accounted for as much as 20% of GDP, and the resulting deceleration in overall growth is expected to persist for several years after the initial shock (IMF 2016b). Non-oil exporters such as South Africa have also felt the impact of unfavorable global conditions, albeit to a lesser degree. For example, artisanal mining activity is highly dependent upon the market price. When the price is lower than a certain threshold, mines close and labor moves into other primary sectors such as agriculture. Unfortunately, for many mineral-rich countries in Eastern and Southern Africa, the agricultural sector has been plagued by some of the worst droughts in decades. The impact of the 2015–2016 El Nino has affected over 19.5 million people from the Horn of Africa to Zimbabwe and has caused humanitarian and food security crises in the form of high prices, reduced employment, and food shortages (UNOCHA 2016). Although some economies, particularly oil importers such as Tanzania and Cote d'Ivoire, have continued to enjoy higher growth rates during the same period—up to 7.5%, their robustness has generally been accompanied by widening fiscal deficits and increased debt burdens. In the cases where growth has been significantly bolstered by increased central bank financing—especially when combined with an inflexible exchange rate regime, private activity has been distorted, and borrowing costs can be expected to increase.

The impacts of the global commodity price shocks of 2014–2016 on SSA are expected to persist in the medium term (IMF 2016b), and affected governments may have to implement policy adjustments considering continued slumps in global commodity prices. Furthermore, in recent years, more than half of the countries in SSA have seen slowdowns in private credit growth rates. In light of the economic difficulties facing the subcontinent, it is therefore imperative to explore alternative and affordable renewable energy financing options over the forthcoming one or two decades.

3 Brief review on population growth in SSA

Due to slowdowns in the commodities markets, population growth rates have recently exceeded economic growth in many SSA countries. While this is not by any means an immediate cause for concern, continuing this trend into the long run would be undesirable. Africa is projected to be the home of approximately half of the world's population of 11 billion by the end of the century (UNDESA 2015). Over the next 80 or so years, the share of working age population of Africa will increase from approximately 54% in 2010 to 64% in 2090 (IMF 2015). Mortality and fertility rates are projected to decline, such that by the turn of the century, working age Africans would make up the majority of the world's working age population. In 2010, Africans made up for 12.6% of world's working age population, but by 2100, this share is expected to exceed 40% (IMF 2015).

A demographic transition is on the horizon. While the transition opens a window of opportunity, it also opens windows to social risks. Africa will need to make major transformations in the development and progression of infrastructure, institutions, and governance to adequately accommodate and employ the future generations. Shortages and inadequacies in the electrical infrastructure have severely undermined social and economic development—from youth education to foreign investment. A robust, efficient, and accessible source of electricity is necessary—albeit not sufficient—to propel the social and economic goals of the many African nations that are preparing for the demographic transition.

Africa and Asia are home to largest rural population, accounting for 3 of the 3.4 billion rural dwellers in the world (UNDESA 2015). The United Nations estimates rapid growth in Africa's rural population in the next few decades, reaching over 1 billion by 2050. Electricity is expected to be provided to existing population without access electricity as well as all incremental population. Rural electrification will thus be an increasingly critical issue for SSA. With continued deterioration in global conditions, business as usual in the energy sector would not be able to achieve the goal of SDG7. Alternative technologies, innovative business models, and new financial instruments for rural electrification must be applied to electrify Africa.

4 Underdeveloped power system in SSA

The SSA power system is extremely underdeveloped from the perspectives of energy access rates, installed power generation capacity, and power consumption per capita. The IEA (2016) shows that the world had 1186 million people without electricity, and 65% (630 million) of them were in SSA (Table 1). According to Population Reference Bureau (2016), the world population totaled 7.2 billion in 2014. The 630 million people in SSA region without access electricity supply thus accounted for 8.7% of the world's population in 2014.

Regarding electricity access in individual countries in SSA, only seven SSA countries now have their rates exceeding 50%: South Africa (78%), Ghana (72%), Gabon (60%), Namibia (60%), Côte d'Ivoire (59%), Senegal (57%), and Cameroon (54%). Nigeria's electrification rate is sometimes cited as above or below 50%. The rest of SSA has an average grid access rate of just 20%. Moreover, even when people have access to electricity, there is not enough power supply capacity available and blackout happens frequently. Figure 1 shows more details about the rates of accessing to electricity in Africa (IEA 2016).

As mentioned earlier, Africa is undergoing unprecedented and sustained growth in population. By 2050, the continent will be home to at least 2 billion people—twice as many as today—with 40% living in rural areas. In 2014, more than 630 million SSA people (65% percent of the population) had no access to electricity, and more than 700 million (72% of the population) was living without clean cooking facilities. If these current energy access trends continue, in 2050, there will still be 1300 million people in Africa without access to power, and 1440 million without clean cooking facilities, depriving the majority of the population of the opportunity to pursue a healthy and productive life.

5 A continent of opportunity for investments

Electrifying the 630 million Africans provides a huge business opportunity in the power sector. Although these people earn about $2 a day per capita on average, their total income per day already

Table 1 Electricity access in 2014—regional aggregates

Region	Population without electricity millions	Electrification rate percent
Developing countries	1185	79%
Africa	633	45%
North Africa	1	99%
Sub-Saharan Africa	632	35%
Developing Asia	512	86%
China	0	100%
India	244	81%
Latin America	22	95%
Middle East	18	92%
Transition economies and OECD	1	100%
WORLD	1186	84%

Source: IEA (2016)

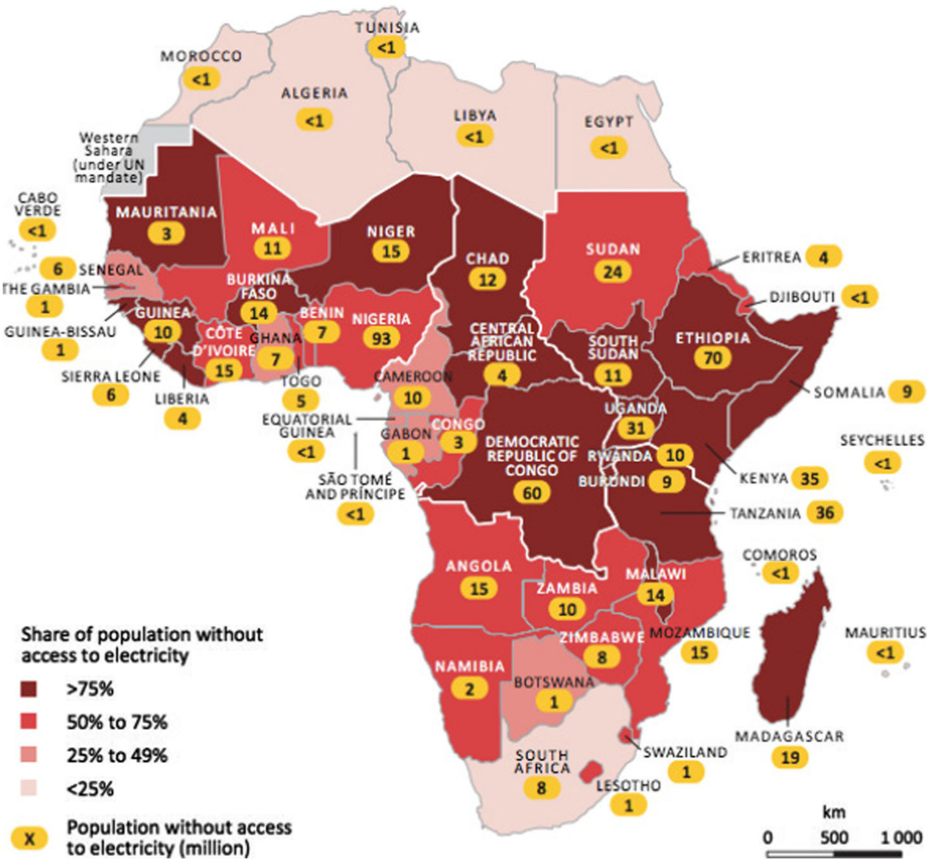

Fig. 1 Rates of accessing electricity in Africa. Source: IEA (2016)

amounts to $1.25 billion or approximately $455 billion per annum. If 10–15% of the income is spent in energy at homes, including lighting, cooking, electric touches, and mobile phone charges, the energy market in SSA amounts to $44–66 billion per year. In 2016, the authors undertook a study for off-grid households in Tanzania, Kenya, and Uganda. The study results show that there are 15.5 million off-grid households, and each of these households spends approximately $200 per annum for energy-related services. These three countries provide a rural electrification market of $3.2 billion per annum. The study also concluded that from 2017 to 2030, there will be a total of 250 million households in SSA that can hardly be electrified by power grid, which provides a market of $50 billion per year for business in off-grid technologies.

6 A continent of opportunities for renewable energy development

With increasing advancement of technologies, renewable-based energy growth is viable and desirable for the SSA region. Africa's renewable energy power potential is substantially larger than the current and projected power consumption of the continent. Local geothermal, solar thermal, and bioenergy resources have an important role to play in covering future energy demand. To date, almost half of African countries have undertaken national resource assessments for one or more renewable energy sources. Solar and wind assessments have been conducted and available for at least 21 countries.

Renewable energy sources are indigenous and therefore enhance countries' energy self-sufficiency by limiting their dependence on fossil fuel imports. Energy self-sufficiency reduces countries' exposure to the price and supply volatility of importing energy and mitigates the negative economic impact of volatility. The soaring cost of importing refined oil already constitutes a significant burden for African countries and can seriously hinder their economic growth. For example, in 2010, when oil prices were high, SSA countries imported $18 billion worth of oil—more than the entire amount they received in foreign aid. In countries relying on imported fossil fuels for large-scale power generation, electricity prices are often high. Rural electricity is even more expensive if it is diesel-based. In addition, oil subsidies in SSA cost an estimated $50 billion every year. Renewable energy technologies are now the most economical solution for off-grid and mini-grid electrification in remote areas, as well as for grid extension in some cases of centralized grid supply with good renewable resources.

7 Barriers to renewable energy development

Although RE resources are promising in SSA for the rural poor households, SSA is facing a large number of immediate challenges and barriers in rural electrification. These include the following:

7.1 High cost of electricity production in the Eastern SSA

The average cost of electricity generation in the Eastern region of the subcontinent is, in general, exceptionally high, due to a number of reasons. The first is due to the small size of electricity markets and the resulting lack of economies of scale. Most African rural communities are characterized by low population densities and thus high connection costs. The second is the dependence on often expensive oil/diesel imports as well as drought-exposed hydrogeneration and inefficiencies in transmission. The third is the obsoleteness of the employed technologies and poor state of the overall energy infrastructure. Low levels of resource efficiency lead to high cost per unit of energy production and consumption. The fourth is the manipulation of electricity prices for political reasons (IEA 1999). As a result, the average electricity generation cost in SSA amounts to $0.18/kWh, which is more than double when compared to the tariffs of $0.04–$0.07/kWh in South Asia.

7.2 Low affordability and subsidies of electricity consumption

Since local consumers in SSA have low affordability for commercial energy, governments often keep down energy prices or electricity tariffs by subsidizing commercial energy from already constrained public budgets. For example, household consumer price in Sudan averaged $0.04/kWh in 2013–2014 due to government subsidies (UNDP 2015).

7.3 Poor reliability of energy supply

African manufacturing enterprises experience power outages on average 56 days per year. As a result, industrial firms lose up to 6% of sales revenues. Where backup generation is limited, losses can be as high as 20% (World Bank 2013). The poor reliability of energy supply is due to several reasons including lower levels of economic development, insufficient power generation capacities, and long distance of power transmission and distribution.

7.4 Lack of knowledge in renewable energy/power operations

Energy/power consumers in SSA are widely short of knowledge in renewable energy/power technologies. For example, in Sudan, almost all farmers are unfamiliar with the use of solar PV pumps for irrigating agricultural land. The technology has not been widely demonstrated. Although a few number of solar water pumps have been installed by non-government organizations (NGOs) in Sudan, these pumps have not been accurately sized nor properly maintained, resulting in poor results and limited replication (UNDP 2015). Farmers in Sudan are generally skeptical that solar pumps will deliver sufficient water for irrigation. Agricultural extension service personnel also lack the knowledge and capacity to promote solar pumps.

7.5 Lack of technical specifications and standards

Technical specifications and standards for renewable energy investment and development are essential in a country or a region to ensure quality of goods and services. However, SSA lacks the necessary lab facilities, knowledge, and experience to test, inspect, and approve the quality of components of renewable energy technologies.

7.6 Lack of financial resources

High costs of production and consumption with subsidized prices do not provide profit margin to the power market and prevent the private sector from investing in power generation. As a result, new investment in power generation cannot keep pace with GDP growth rate and population increase. The existing power generation capacities cannot be well maintained. Obtaining financing for renewable energy power plants is currently more difficult than for fossil-fuel plants. In part, this is due to the relative lack of knowledge of renewable energy technologies. Because of this, and a lack of project experience, banks are often either reluctant to finance projects or agree to finance but at premium rates. And while renewable energy projects are often cheaper in levelized terms, they tend to have higher up-front capital costs, requiring more specific financing schemes.

8 Approaches to overcoming barriers

Several measures and approaches can be implemented to overcome barriers to renewable energy investment in SSA. These include the following:

1) Enlarging the scale of production and reducing transaction and overhead costs of renewable energy investment. According to the IRENA (2014), the share of "other costs" in the total of capital investment cost takes the largest share in all kinds of costs including battery cost, inverter cost, module cost, and other hardware cost. Figure 2 shows more information on the costs.

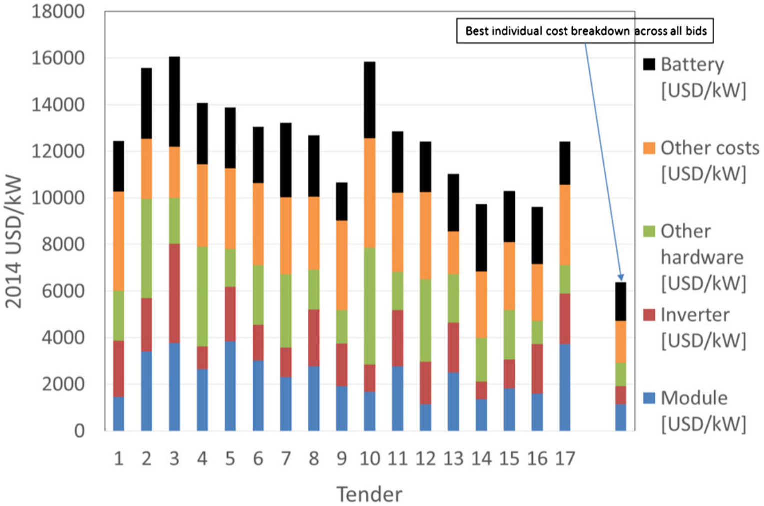

Fig. 2 Costs and shares for solar PV investment. Source: IRENA (2014)

2) Reducing or terminating government subsidies to fossil fuel consumption. Government energy policy should change energy subsidy budget from encouraging fossil energy consumption to promoting renewable energy consumption.
3) Developing regional and national standards and procedures for production and trade of renewable energy technologies
4) Building labs and technology centers and upgrading the skills of professionals who work at the labs and centers
5) De-risking the investment and hence reducing cost of capital in renewable energy investments in the financial market
6) Engaging local/commercial banks and the private sector in RE financing
7) Building capacity and providing trainings for community-based-technology supporting centers

Of the above-listed barriers, the most significant ones are the lack of appropriate energy policies and financing business models to catalyze the private sector in renewable energy investments in SSA. In the following, this paper focuses on these two issues and proposes best energy policies and financial models to overcome these barriers.

9 Government policies on renewable energy development in SSA

Considerable effort has been made across SSA to harness the vast renewable energy potentials in the region, with about 40 countries formally adopting renewable energy targets in National Energy Plans. Such energy plans broadly aim to promote national energy security, improve rural electrification, develop human capacity, and develop effective institutional frameworks for investment and private participation (IRENA 2015). The differences in rates, technology mixes, and size of targets differ, reflecting the diversity across regions, and successful implementation of national plans is likewise confronted by diverse economic and political challenges. There are no simple solutions for the challenges that lay ahead, but with improvements in technology and financial development, it is not unreasonable to remain optimistic.

Governments can use a portfolio of policy tools to support renewable technologies as they mature. Feed-in tariffs and feed-in premiums are standard power purchase agreements with a set price or premium—meaning that the developer has a price guarantee for a fixed period of time. They are well established, especially in Europe, where costs of such schemes are typically passed onto electricity consumers. They have also been implemented in several African countries. However, local conditions must be favorable to the implementation of each specific instrument. In the case of feed-in tariffs or premiums in developing countries, the spending power of consumers is limited and requirements for new capacity are often much higher than in developed markets due to high economic and population growth.

Innovative government policy and regulations in mobile banking and credit systems are widely needed to boost private investments in mini-solar PV kits for the remote and poor communities. Over the past few years, a number of private companies have developed the PAYG financing model which is eventually a lease and own model. With that model, a household pays upfront fee at approximately $20, namely 10% of the total capital cost of the solar PV kit, brings the kit home, and installs it for power generation and use. Then, the household pays affordable installments at $0.5/day or $3.5/week. The financing model has worked well in the three targeted countries—Kenya, Uganda, and Tanzania—because these countries have developed their mobile banking and credit systems. A sound national government policy and regulation system will support establishing sound mobile banking and credit systems.

Streamlining and standardizing procedures can also be an important element of successful public policies. Recently, reverse-bid auctions and tendering mechanisms have resulted in competitive prices, while ensuring full government control over technology choice and project size. For large projects, where significant economies of scale can be achieved and which utilize technologies with site-specific risks, such as concentrating solar power and off-shore wind, the price-revealing function of auctions can result in notably lower prices. To maximize additional benefits, governments can also impose other criteria on auctioned projects, including environmental considerations and local manufacturing.

Confidence in a robust and stable policy framework, as well as in long-term national objectives and targets backed up by sound market forecasts, also play a crucial role in their decisions. Policy makers have an essential role to play in addressing these non-economic barriers (i.e. institutional, regulatory, knowledge, information, infrastructure, technology and market) in order to develop an enabling environment for investors and entrepreneurs.

In addition to national efforts, regional cooperation and integration are also paramount to successful development in the SSA's renewable energy sector by taking advantage of economies of scale (IRENA 2015). Maximizing supply potential and managing shared resources can be facilitated by removing barriers in trade, regulatory frameworks, and conflicting policies. Cross-border financing would benefit small landlocked countries, while providing opportunities for investment for their neighbors. International cooperation in the energy sector would go hand-in-hand with regional integration in trade, financing, transportation, and industrialization.

10 Innovative financing business models

10.1 Public fund-led investment model

Governments play a crucial role in coordinating the development of infrastructure at the local, national, and international level in SSA. Electrification and infrastructure programs can help connect isolated grids to main grids—realizing economies of scale and improving grid balancing and stability. Governments can bring about price convergence by cooperating to build regional long-distance grids, linking abundant and economical resources with centers of high demand. Estimates indicate that power trade at full potential can save African countries approximately $2 billion in annual costs of power system operation and development. Adding renewable energy into existing energy systems brings diversification and resilience.

In 2012, African Heads of State endorsed the Program for Infrastructure Development for Africa (PIDA), including a pipeline of 15 priority energy projects amounting to a total budget of $40.5 billion, to be implemented between 2012 and 2020. The project portfolio, selected partly on the basis of the projects' ability to enhance cross-border energy market development, includes nine hydroelectricity generation projects, four transmission corridors, and two pipelines, one for oil and the other for gas. The four corridors include the following: (a) the North-South transmission link, from Egypt to South Africa, with branches mostly into eastern Africa; (b) the Central corridor, from Angola to South Africa, with branch lines into central and western Africa; (c) a North African transmission link from Egypt to Morocco, with links via Libya, Tunisia and Algeria; and (d) the West African Power Transmission Corridor, linking Ghana to Senegal. The four planned power corridors will reinforce interconnections across the four established power pools in SSA:

1) The Southern African Power Pool, created in 1995 by 12 Southern Africa Development Community (SADC) countries
2) The West African Power Pool, launched in 2000 by 14 Economic Community of West African States (ECOWAS) countries
3) The Central African Power Pool, established in 2003 by 11 Economic Community of Central African States (ECCAS) countries
4) The East African Power Pool, launched in 2005 by East African member countries of the Common Market for Eastern and Southern Africa (COMESA) and the Nile Basin Initiative, including Egypt and Tanzania

Cross-border transmission can bring important benefits to countries dependent on fossil imports or to countries with less abundant economical renewable resources. Power trade can be particularly helpful for countries with very small loads, where economies of scale are hard to obtain.

In May 2016, the AfDB published a brochure entitled: "The New Deal on Energy for Africa: A transformative partnership to light up and power Africa by 2025." The New Deal aims at achieving the goal of universal access to energy in Africa by 2025 with the following measures:

- Increasing on-grid generations to add 160 GW of new capacity by 2025
- Increasing on-grid transmission and grid connections that will connect 130 million new homes by 2025, 160% more than today

- Increasing off-grid generations to connect 75 million non-electrified homes by 2025, 20-fold of what we have today
- Increasing access to clean cooking energy for approximately 130 million households

Universal access to energy by 2025 in Africa means connecting over 200 million additional households, more than doubling grid generation capacity today, and more than tripling the use of clean cooking solutions in the African continent. Table 2 shows AfDB's dynamic baseline scenario of power and energy development for Africa with current energy polices.

To achieve the goal of universal access by 2025 that has been targeted in the New Deal on Energy for Africa, innovative mechanisms are required to mobilize an additional $40–70 billion annually from 2016 to 2025 in domestic and international capital. This is a significant increase on the $22.5 billion invested in the sector in 2014 (AfDB 2015). Thus, the total targeted capital investment is between $400 and 700 billion over the 10 years from 2015 to 2025; in other words, to electrify one person in SSA, the need of capital investment is between $642 and $1120, with an average of $882. It is well known that rural electrification is much more expensive than urban electrification. In SSA, it has been widely accepted that the cost of connecting a rural household to the grid in remote areas is more than $1000. This kind of capital cost may not be affordable by many poor households in SSA. A study by the authors showed that a poor household in rural areas of SSA can hardly pay the $1000 connection capital up front for the grid electricity. It is evident that some other kinds of financing models are needed in rural electrification for the poor and remote communities in SSA.

10.2 Business as usual—kerosene lighting and battery torches

In most remote rural areas of SSA, households use imported fossil energy—kerosene—for lighting. Many of the lamps used in these households would be recognizable to the ancient Romans, with small flames flickering in the wind, emitting an acrid smoke that burns the eyes, irritates the throat, and slowly turns walls and ceilings black. It is also expensive. According to Faris (2015), in 2014, an average off-grid household in Kenya spent about $0.75 a day on energy, or $272 a year, including $164 on kerosene, $36 on charging their mobile phones, and $72 on electric torches and radio batteries. Carbon emissions that are related to kerosene consumption are 513 kg per household per annum.

Table 2 New deal on energy for Africa

		Current energy situation	Growth (times)	To universal access in 2025
Power	Population (M)	1174	1.3	1499
	GDP ($ billion)	2173	1.7	3742
	Elec rate (%)	43%	2.3	97%
	HH connection (million)	87	3.6	292
	Grid	83	2.6	213
	Off-grid	4	20	79
	Grid capacity (GW)	170	1.9	332
	Consumption (kWh/capita)	613	1.5	941
Clean cooking	Penetration rate (%)	31%	3.3	100%
	HH using clean cooking (million)	70	3.1	220

Source: AfDB (2016)

10.3 Private investment model 1: diesel generators

Diesel generating sets are used in some places in SSA where households or small business do not access to electricity. A diesel generator is the combination of a diesel compression-ignition engine with an electric generator to produce electricity. In Tanzania, for example, some residents use diesel generators to produce electricity for their own use and sell surplus electricity to rich neighbors via simple micro-grids. Figure 3 shows a micro-grid which transmits electricity from a single diesel generator to local village residents via a few thin iron wires. This kind of power generation and micro-grid is very expensive due to high cost of fuel and spare parts of the machine and high loss of power distribution. A household in a rural area in Tanzania pays approximately $3 per kWh of electricity consumption from such a private owned micro-grid. The power generator is installed at the backyard of a household which causes high volume of noise and pollution to the neighborhood. More importantly, the power generator and the micro-grid are not regulated by the local or national government. The system with falling posts and wires can easily cause damage and death to properties and human lives.

10.4 Private investment model 2: Devergy—solar PV-based micro-grid

Devergy is an energy service company (ESCO) that provides affordable and reliable energy to low-income households in remote rural villages without access to the power grid. The company aims at empowering people in the least developed countries by improving freedom of choice—customers can use as little or as much electricity at any time as they want. Devergy builds local off-grid power distribution networks with solar PV towers that are installed at many different places of the networks (Figs. 4 and 5). The solar PV towers are generally installed at the backyards of rural households which generate 24-V direct current (DC) electricity which is primarily for power consumption of the individual households. Any surplus electricity from a household can be transmitted to and shared with a neighboring household. The average distance between two households in the rural area in Tanzania is about 1 km. The major cost of capital investment in

Fig. 3 Diesel engine powered rural mini-grid in Tanzania. Source: Authors' collected information in 2016

such a business model is at the power transmission cable that links the individual households. Customers do not own any power generation and distribution assets. They pay the tariffs whenever they want to use electricity. The company uses Internet communication technologies to switch on and off power supply for individual households depending on their time and amount of money paid for the electricity supply services. The outstanding features of the technologies and financial models are as follows: (1) the power generation and distribution system is safe, because the power system has only 24 V; (2) the power supply with this technology is more reliable than individual isolated solar PV kits, because the system interlink many solar PV power generation towers in the area. If any of the power generation tower fails to work, others can back it up; and (3) customers do not have any worries about investment risks in power generation. They pay for the use of electricity. Per the company's report, rural customers can save money when compared to what they were spending previously in using kerosene and candles for lighting. This micro-grid rural electrification with solar PV technologies also mitigates carbon emissions, reduce in-door air pollution, and create small businesses in rural areas. In addition to selling energy services, Devergy also makes and sells modern and aspirational appliances, like TVs and stereos, accessible and available through lease-to-own arrangements. Currently working in all over rural Tanzania, the company planned to scale up its financial model and technologies throughout the continent and eventually the world.

10.5 Private investment model 3: PAYG

Although solar PV technologies are cost competitive against kerosene lighting in terms of lifetime levelized cost, the relatively large upfront capital investment for a solar PV kit, which ranges from \$50 to \$200, remains a challenge to a poor rural household in SSA. Over the past few years, a number of private companies have used a new financing business model that is called PAYG. With this model, a client pays upfront fee at approximately 10% of the total capital cost of the solar PV kit, brings the kit home, and installs it for power generation and use. Afterwards, the client pays affordable installments daily, such as \$0.5 per day. A mobile phone technology-enabled mechanism is installed in the battery of the kit. If the client fails to pay the installments, the technology providing company can shut down the battery and the whole solar kit system. A number of private companies such as M-KOPA, a solar energy company that was founded in 2011, are using the PAYG model while investing in solar PV for the poor in SSA.

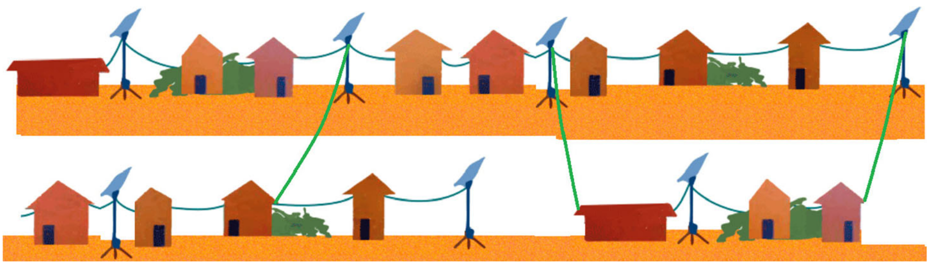

Fig. 4 Model of solar PV-based micro-grid for rural electrification

M-KOPA's core innovation is a market-based financial mechanism rather than solar PV technologies per se. The company acquires solar PV, battery, radio and lighting technologies and equipment from worldwide, mainly from Asia and sell them in a package, which typically contains a solar PV panel, two light-emitting diode (LED) bulbs, an LED flashlight, a rechargeable radio, and adaptors for charging a phone at a loan of about $200 in total. The battery is designed to last at least 4 years, and M-KOPA guarantees all parts for 2 years. A client pays $20 upfront and agrees to make a daily payment of $0.5 for 1 year, after which the asset of system belongs to the client. The package also comes with a control box containing the battery and a SIM card that can communicate with M-KOPA operation centers in the three countries. When a customer has made a payment via mobile phone, the SIM card sends a signal to activate the battery in the package. Then, the battery which has been charged from the solar PV panels will provide electricity to the household of the customer. M-KOPA is giving the poor some collateral and a line of credit, while promoting solar PV energy to them.

Once M-KOPA has a customer, it works hard to sell the customer more products on installment. A couple of weeks before the solar PV package is paid off, an M-KOPA representative calls to offer another product, in exchange for reopening the account and making payments for another few months. Ideally, these too will save the customer money over time. M-KOPA offers fuel-efficient stoves that spare charcoal, a bicycle that cuts transportation costs, a tank that stores rainwater. M-KOPA also sells baby chickens to clients with installation payments $0.50 per day. Many clients raise chickens in their farms or house yards and sell chicken eggs to the market where M-KOPA provides demand and supply information. For richer clients, M-KOPA sells Samsung smartphones and offers loans to pay for school fees.

The financing model has worked well in the three targeted countries. By December 8, 2016, the company has provided the solar PV packages to over 300,000 households in Tanzania alone. Every day, more than 500 new homes in remote poor rural communities in Tanzania are

Fig. 5 Solar PV tower at the back yard of rural households in Tanzania. Source: Devergy (2016)

electrified by M-KOPA. This means that M-KOPA is extending loans of more than $100,000 a day to people who might otherwise not have access to credit and electricity. The company is really taking a bet on anyone who is willing to give the company their mobile phone numbers, their ID number, and a down payment.

11 Assessment of cost-effectiveness

In this paper, the authors use the levelized cost of electricity (LCOE) to undertake the assessment of cost-effectiveness. The LCOE is defined as the net present value of the unit cost of present value of electricity over the lifetime of a power generation asset. It is often taken as a proxy for the average price that the power generation asset must receive in a market to break even over its lifetime. It is a first-order economic assessment of cost-effectiveness of a power generation system by incorporating all costs over its lifetime including capital investment, operations and maintenance, the cost of fuel, and the cost of disposal of the technology. Mathematically, it can be expressed as follows:

$$LCOE = \frac{\text{Sum } of \ cost \ over \ lifetime}{\text{Sum } of \ electricity \ generted \ over \ lifetime} = \frac{\sum_{t=1}^{t=n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{t=n} \frac{E_t}{(1+r)^t}}$$

I_t: Capital investment in year t ($)
M_t: Operations and maintenance costs in year t ($/year)
F_t: Fuel costs in year t ($/year)
E_t: Electricity generated in year t (kWh)
r: Discount rate (%). The discount rate in this paper refers to the rate that is used to determine the present value of future cash flows. This discount rate takes into account not only just the time value of money, but also the risk or uncertainty of future cash flows. The greater the uncertainty of future cash flows, the higher the discount rate.
n: Lifetime of the power system (years). Typically, the LCOE is calculated over the design lifetime of a plant, which is usually 10 to 20 years for solar PV technologies.

It should be noted that the external costs of fossil fuel generation have not been accounted in the above equation, due to the lack of carbon prices in the African market. Carbon pricing charges fossil fuel consumption for their carbon dioxide (CO_2) emissions. That charge, called a "carbon price," is the amount that must be paid for the right to emit 1 t of CO_2 into the atmosphere. The authors will discuss this issue in another section on this issue.

In this paper, the authors have only undertaken cost-effectiveness assessments for three scenarios: (1) business as usual, (2) PAYG, and (3) using diesel power. There are two reasons for it. First, the AfDB's New Deal on Energy for Africa is mainly for electrification of the urban or township areas where an upfront connection fee of $1000 is required. The New Deal may not be applicable or compatible with the private-investment based financing model. Second, Devergy's solar PV-based micro-grid electrification model started recently. The total capacity of all served customers of the

Devergy is less than 100 kW as of December 2016. There is not sufficient information to undertake cost-effectiveness assessment for this financing model. As such, the AfDB's New Deal model and the Devergy's micro-grid model are not listed in the following cost-effectiveness assessment.

The following assumptions are made for the three different scenarios (business as usual, pay-as-you-go, and diesel power) while their cost-effectiveness is undertaken:

1. Discount rate: $r = 10\%$
2. Lifetime of the power system; $n = 12$ years. The assumption incorporates three factors. First, it is reasonable to assume the lifetime of 12 years for a diesel engine powered generator in the rural area. Second, the lifetime of a solar PV battery is 4 years; three kits of the solar PV will have a total lifetime of 12 years. Third, after 12 years, the whole 630 million people in SSA should have access to electricity.
3. Business as usual scenario: A household does not invest capital in energy, but it spends about $0.75 a day on energy, or $272 a year, including $164 on kerosene, $36 on charging their mobile phones, and $72 on electric torches and radio batteries. The kerosene price is $0.85 per liter at the constant price of 2016. The household uses a total of 191 l of kerosene per year. CO_2 emission factor of kerosene is 2.685 kg per liter, and carbon emission from kerosene consumption is thus 513 kg of CO_2 per household per year. In terms of quality of lighting, kerosene lamps cannot compare with solar PV powered LED lamps in terms of lumens. For the reason of comparison, the authors assume that the lighting efficacy of kerosene lamps is equal to the solar PV LEDs in the solar PV kit as described in the next scenario. In other words, the kerosene lamps are virtually assumed to provide 30 kWh electricity per year to a household in lighting, although they are not as bright as LEDs.
4. PAYG scenario: A household pays $20 as capital investment at upfront to lease the solar PV kit; it makes accumulated annual payment of $182.5 in the first year, and no payment for the second, third, and fourth years. The lifetime of the battery is 4 years. The authors assume that the household changes the whole solar PV kit after 4 years. This means that the household will pay $20 as capital investment and pay the accumulated annual fees of $182.5 in year 5. Then, the second solar PV kit will last another 4 years and so on. In a total of 12 years, the household needs to buy three solar PV kits. The solar PV kit works 8 h and generates 80 watt hours of electricity per day. The annual power generation is approximately 30 kWh.
5. Diesel power scenario: A rural household also uses 30 kWh of electricity from the micro-grid. The household pays $3 per kWh in 2016 and the tariff increases at 10% per year (the same as the discount rate) due to inflation and increasing costs of the micro-grid operations. According to the IEA (2015), the mission factor of a diesel power generation is approximately 0.725 kg/kWh.

Using the aforementioned methodology and assumptions, the authors carried out the assessments for the three scenarios and the results are listed in Table 3. Of the three scenarios, business as usual, namely using kerosene and candle lamps, is the least cost-effective. It costs more than $9 to obtain 1 kWh electricity equivalent for lighting, while emitting 3.8 t of CO_2 in 12 years per household. The most cost-effective business model is "pay-as-you-go"; it costs $1.77 per kWh, and it does not emit any CO_2. The diesel power model is in between, costing $3 per kWh and emitting 163 kg of CO_2 in 12 years per household.

Table 3 Highlight of the assessment results of the three scenarios

Scenarios	Capital investment ($)	O&M cost or payment	LCOE ($/kWh)	CO_2 emissions (kg/12 years/household)
1. Business as usual	0	$272/year	9.08	3837
2. Pay-as-you-go	20	$182.5/1st year; and $0 for other 3 years	1.77	0
3. Diesel power	0	$90/year	3.00	163

12 Conclusions and policy implications

As of August 2017, over 630 million poor people in SSA could not access to electricity. With continued growth of population in SSA, under business as usual, this number will likely grow up to 1.3 billion by 2050. It is not financially and environmentally feasible to electrify these people by diesel-power generation. Rather, the SDGs and the Paris Agreement require to electrify those people with low-carbon or zero carbon emission pathways over the next one and a half decades.

The AfDB's New Deal on Energy for Africa aims at mobilizing an additional $40–70 billion annually from 2016 to 2025 to provide electricity to these people. This is equivalent to spending $642–$1102 in electricity per household. This scheme may be applicable to urban households but cannot be affordable to rural households in SSA. Economic reviews show that rural households in SSA have limited income, approximately $2 per capital per day. Without capital investment subsidies, the poor in rural communities can hardly afford connection with a conventional power grid. Consequently, other energy resources, technologies, and financial models should be developed and used.

Renewable energy, particularly solar PV, with a lease-to-own financial model can be a solution. The solar PV technology under the PAYG financial model is most effective. It has been initiated and developed by a number of private companies. With the current development and scaling up speed, by 2030, all rural communities in Kenya, Uganda, and Tanzania will likely be electrified with solar PV kits under this financial model, and this financial model could become applicable and scaled up in all SSA with government new policies. It will help mitigate 3.8 t of CO_2 per household or over 500 million tons of CO_2 in SSA from 2017 to 2030.

It is high time that national governments in SSA develop new energy policy to transform existing energy supply systems. This new energy policy should widely cover scopes of energy production, technologies, finance, market, and relevant sectors that are beyond the energy sector, including the banking sector and the information technology sector.

Regarding energy production and technology policies, governments in SSA should encourage renewable energy particularly solar PV technologies. This is due to several reasons. First, renewable energy technologies are increasingly becoming competitive against fossil energy technologies in the forthcoming decade. Second, off-grid solar PV technologies are particularly suitable and flexible for remote rural communities with low population density and low-income households. Third, world commodity prices are low but with high volatility. Electrifying the poor in SSA with imported or domestic fossil energy carries high risk, which could be mitigated by increasing the share of solar PV technologies in the energy system.

In terms of finance and renewable energy market development, a variety of energy policies should be applied in different countries with different renewable energy resources. For example, feed-in tariff and feed-in premium policies should be continually encouraged in countries or provinces where there is rich hydro energy. These policies may not be favored by some national governments of countries where grid-connected solar PV technologies are becoming dramatically cheaper and cheaper.

Innovative government energy policy and regulations may extend beyond the energy sector. For example, the development of mobile banking and credit systems in the West and South SSA is urgently needed to boost private investments in micro-solar PV kits for the remote and poor communities. Energy policies, banking policies, and credit regulations should incorporate one another, so that countries will be able to establish a reliable and sound energy payment and credit monitoring systems that will remove barriers for private investments in RE.

Cross-border financing should be encouraged by government policy in SSA. This policy will benefit small and landlocked countries, while providing opportunities for RE investment for their neighbors. SSA national governments should streamline and standardize procedures across the SSA region in RE technologies for environmental considerations and local manufacturing.

With continued cost reduction in new renewable energy technologies, the government and the private sector are adapting new energy policy and financing models in addressing climate change while developing their economies and business in SSA. First, these new policy and financing models will facilitate rural electrification with affordable new renewable energy technologies. Today, in SSA, M-KOPA Solar is selling solar PV kits including with battery storage and appliances at the cost of one US dollar per watt (Lazat 2017). This cost is competitive against what the rural households are paying for their basic energy needs including lighting and mobile phone charging. With the new energy policy and financing models, rural poor households in SSA will be able to use new renewable energy technologies to replace existing fossil energy technologies without paying additional costs. This replacement will greatly reduce fossil fuel consumption, increase national energy security, and reduce carbon emissions. Second, the new policy and financing models will facilitate government energy tax reforms. In most SSA countries, there are energy subsidies favoring the consumption of fossil fuels due to many historical reasons. Wide use of new renewable energy technologies in rural communicates will significantly help governments to stop fossil energy subsidies. Third, the new energy policy and financing models will spur new renewable energy technology development and innovation on a large-scale throughout the local communities in SSA. It will promote innovation and business for the low-carbon transition locally in SSA, which will fill potential skill gaps through education, training, and labor market policies. The technology localization, innovation, and education will have a long-term impact on climate mitigation and adaptation. Forth, it will also likely enhance international trade and the low-carbon transition. Governments' policies on import duty exemption for new renewable energy technologies can remove trade barriers that undermine climate objectives. To sum, the new policy, new renewable energy technologies, and innovative financing models are shaping contemporary climate strategies that facilitate investment in clean energy, spur community economy, enhance national energy security, and improve global environment.

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