CHAPTER 3

Harnessing and Integrating Africa's Renewable Energy Resources

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1. Introduction

Africa's long-term economic growth and competitiveness fundamentally depends on reliable access to energy services, yet the population of sub-Saharan Africa lags far behind the rest of the world in terms of electricity access rates. While the average 2011 rates in Latin America, the Middle East, and developing Asia are 5%, 9%, and 17%, respectively, sub-Saharan Africa ranks lowest, with 68% of its population lacking access to electricity [1,2]. So far investments on the continent have been far below requirements [3,4], explaining why Africa's energy sector has been fraught with deficiencies such as low access and insufficient capacity, poor reliability, and extremely high costs. These and other shortcomings in the power sector have significantly retarded Africa's economic growth and put at risk its long-term economic prosperity.

The grim reality of energy poverty in most African countries, however, is in stark contrast to the continent's rich endowment with renewable and exhaustible energy resources. Africa's reserves of renewable energy 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 [5]. The significant decrease in costs of renewables over the recent years offers huge potential for Africa's power sector; the question remains how best to make use of it.

In this chapter we briefly revisit some of the key issues to consider for successful integration of renewable energy in Africa: Section 2 gives an overview of the contrast between energy poverty and resource abundance in Africa; Section 3 puts Africa in the context of the global energy shift toward renewables; Section 4 discusses some of the key aspects going forward; and Section 5 concludes.

2. Background and context

2.1 Africa's energy challenge

Today, about 600 million people in Africa, roughly 57% of the African population, lack access to electricity. Average annual per capita consumption of power in sub-Saharan Africa is 536 kWh, compared to the global average of 3044 kWh [6]. Electrification rates are correspondingly low (Figure 1): the average rate in sub-Saharan African countries is 32%, with an average of 18% in rural areas; overall only about 32% of the sub-Saharan African population has access to electricity [1,2].

Renewable Energy Integration. http://dx.doi.org/10.1016/B978-0-12-407910-6.00003-X

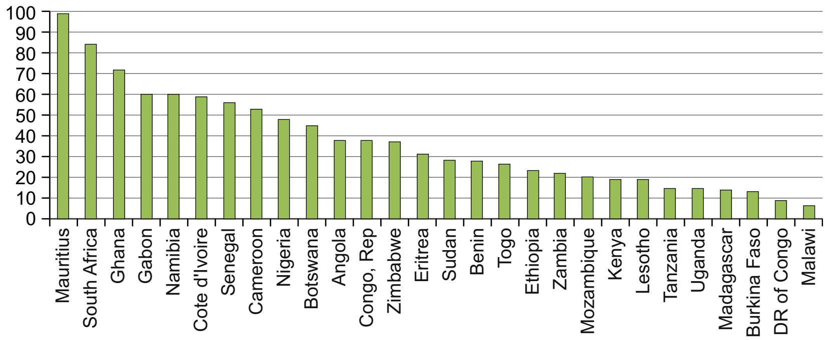

FIGURE 1

Electrification rates of sub-Saharan African countries, 2011 (%).

Refs [1,2].

Africa's current consumption is only about 25% of the global average of per capita energy consumption, its mix consisting of hydropower, fossil fuels, and biomass (predominantly traditional uses) [7].

The African energy sector faces two key challenges: (1) low access to electricity; and (2) insufficient and unreliable power supply. The limited and unreliable access to energy significantly inhibits socioeconomic advancement, which fundamentally depends on reliable access to modern energy services. The lack of it is detrimental to economies not only in terms of lost productive output, but also in terms of the cost it represents to households and the constraints it imposes on quality of life by limiting economic, educational, and social activities, preventing the development of human capital to its full potential.

Moreover, Africa is undergoing unprecedented growth and is currently the fastest-growing continent in the world. African economies are expanding by an average annual growth rate of 4%. Of the 20 fastest-growing countries in the world in 2012, 13 were in Africa [8]. At the same time, its population is projected to triple over the next 40 years, and its urbanization rates are expected to rise by 20% points by 2050 [7,9,10]. Sustaining such fast growth puts enormous pressure on the continent's energy system and requires a significant upgrade and expansion of generation capacities and power grids to increase energy supply. Demand projections predict average per capita power consumption growth of 120% to 304 kWh/day between 2008 and 2050 [9,10]. The task at hand is clearly a huge and complex one. It involves not only undertaking the necessary investments but also tackling other inhibiting factors such as capital constraints, skill shortages, and weak institutional capacity, as well as making important trade-offs in order to decide on the appropriate energy sources to exploit for power generation. Still, given the costs imposed on African economies by energy poverty, the price to pay for sustaining business as usual is likely much higher than the cost of improving access to and reliability of the energy supply [9,10].

2.2 Availability of natural resources

Africa's low energy consumption levels are in stark contrast to its abundance of renewable energy resource wealth. The continent's reserves of renewable energy resources are in fact the highest in the world, with a renewable energy potential sufficient even to meet its future energy needs [5,9–11] (Table 1, Figure 2).

Table 1 Technical Potentials for Power Generation from Renewables in TWh (Values Subject to ±50% Uncertainty)

	CSP	PV	Wind[a]			Hydro	Biomass	Geothermal
			Total	CF 30–40%	CF > 40%			
Central Africa	299	616	120	16	6	1057	1572	
Eastern Africa	1758	2195	1443	309	166	578	642	88
Northern Africa	935	1090	1014	225	69	78	257	
Southern Africa	1500	1628	852	100	17	26	96	
Western Africa	227	1038	395	17	1	105	64	
Total Africa	**4719**	**6567**	**4823**	**667**	**259**	**1844**	**2631**	**88**

Abbreviation: PV, photovoltaic.
[a]Africa's large wind potential, both on- and off-shore, is located mainly in coastal areas. Eighty-seven percent of high-quality resources with world-class wind resources are located in the northern, eastern, and southern coastal zones [11,12]. The rest of mainland Africa's wind intensity is too low to be exploited for power generation.
Refs [9,10].

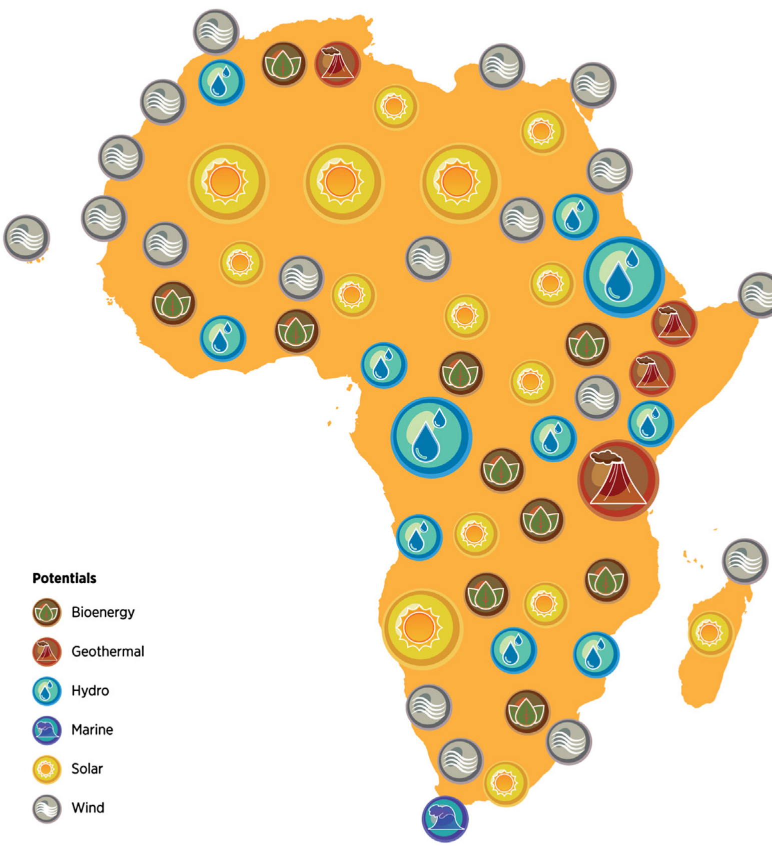

FIGURE 2

Renewable Energy Potential in Africa.

Source: (IRENA 2013).

Hydropower is currently the most important renewable source in Africa. It makes up about 16% of Africa's power generation mix and 94% of the continent's renewable power production [9,10]. The untapped potential for large projects is mainly located in the lower Congo River and the upper Nile. Africa's economic potential of hydropower is only about half of its technical potential, yet it would be sufficient to provide a substantial share of total African power demand [9,10].

Solar energy has significant potential for sub-Saharan Africa, as the continent's solar power radiation intensity is 3000–7000 W/h/m^2, which is higher than required to support average domestic loads. Various solar photovoltaic (PV) applications offer compelling solutions for heating in households as well as commercial sectors in both rural and urban settings. The majority of the PV market (90%) consists of lighting, operation of simple appliances, and residential rooftop systems, with high potential for growth as PV panels are a particularly suitable solution for the off-grid market [7,12]. Other applications include power provision for off-grid schools, health centers, and other social institutions, as well as solar energy in telecommunications and broadcasting [13].

Bioenergy is an important source of renewable power in sub-Saharan Africa. Currently, about 79% of the sub-Saharan African population relies on traditional use of biomass [1,2]. Despite the abundance of biomass residues from agriculture, solid waste, and forest biomass, biomass for power generation has not been widely exploited in most African regions other than in the form of burning of bioresidues, with negative health and environmental consequences [14]. Yet biogas-based technologies offer suitable solutions for areas with availability of sustainable quantities of organic waste in both rural and urban regions, serving a variety of users, from households to municipalities. Cities in particular can benefit from sewages and other organic wastes to produce biogas [7]. Biogas and biofuels can also be used to fuel modern (clean) cooking appliances, improving health conditions and freeing up time for productive activities. Bioethanol and biodiesel can be cost-competitive options for fueling rural transportation as well as agricultural machines.

Excellent geothermal resources with large potential can be found in the East African Rift system, especially in Kenya and Ethiopia. The advantage of geothermal power is that it can provide electricity 24 h a day. It is a cost-effective and reliable baseload technology and the only renewable energy resource without intermittency challenges [11,12].

3. Sub-Saharan Africa in the global energy transition

3.1 Falling technology costs

Sub-Saharan Africa today is in an excellent position to benefit from the momentum of the global paradigm shift toward a cleaner, more sustainable path of energy consumption. Capital costs and the levelized cost of electricity of renewables globally have decreased significantly and continuously over the past decade, driven by a combination of learning effects and incentive schemes [15,16]. Costs are predicted to continue declining in future [17,18], which is why renewables are well positioned to play a major role in the electrification of sub-Saharan Africa. Renewable energy technologies have to a large extent already become competitive with fossil fuel technologies across the continent [9,10,19]. These developments present the African energy sectors with unprecedented opportunities to leapfrog to systems dominated by renewables, avoiding the fossil fuel-heavy path of industrialization.

3.2 A good fit

In light of recent technological and cost developments, renewable energy has the potential to go a long way in solving Africa's two key challenges. For one, it plays an important role in providing access to electricity in remote settings, far from the centralized grid. An estimated 70% of the sub-Sahara African population without access to electricity lives in far-flung, rural areas [15] with a dispersed character and low levels of commercial energy consumption of rural populations [36]. These areas are typically associated with poor-capacity utilization of transmission and distribution utilities and other energy infrastructure involved Onyeji. Despite rapid urbanization, around 40% of Africa's population is projected to still live in rural areas by 2050 [7]; Africa's rural economy and large agricultural sector will continue to play a key role in the continent's economic growth.

Decentralized renewable power solutions are particularly well suited to overcome many of these challenges, including high grid extension costs, transmission losses, and low-income segments of the rural population. Off-grid solutions using renewable technologies play a significant role because they allow for greater flexibility in supply expansion and are even applicable at the village or household level. They have the added advantage of lower project lead times. Where grid extension is not (financially) justifiable, the development of mini-grids or, in cases of limited electricity demand of isolated households, individual energy systems fed by renewable power present optimal solutions [7]. By increasing the population with access to energy, particularly in remote areas, and as more people have access to modern energy, renewable energy opens avenues to kick-start businesses and industries. Productive uses of renewable energy include water treatment and supply (desalination, pumping), heating (e.g. food, water), and cooling (e.g. refrigeration of agricultural and medicinal goods and products) [7].

At the same time, renewables have the ability to address the second key challenge of expanding power supply and increasing its reliability, with added benefits that cannot be provided by simply augmenting traditional fossil fuel-based power. Renewable energy resources are indigenous and, hence, enhance energy independence by shielding economies from the volatility of international fossil fuel prices and its negative repercussions on economies. Moreover, energy services based on renewable energy sources stimulate positive environmental impacts and help mitigate the effects of climate change [7,20].

The possibility for renewable energy to contribute considerably toward mitigating some of Africa's major energy challenges is tremendous; yet it begs the question of how best to promote the uptake of renewables on the continent. In the following section we consider some key aspects.

4. The way forward

4.1 Financing

Despite falling technology costs, it remains challenging to bring renewable energy to rural areas, the main reason being large up-front costs associated with renewable energy projects. Local banks could act as crucial facilitators by offering financial products tailored to rural communities' cash profiles, but lack of understanding of technologies as well as issues related to installation and maintenance remain a major barrier [1,2]. Although financial flows related to the energy sector in developing countries are significant, they are still not adequate to the task of delivering energy access to those deprived. The sub-Saharan African region in particular has not been part of the global rise of gross fixed capital formation for electricity and gas distribution in general in the past decade [3]. Comparing financial flows with estimated requirements for extending energy access to those lacking it suggests that significant funding for energy access in Africa will have to be sourced internationally [35]. According to the International Energy Agency, an estimated $34 billion in investments is required annually to achieve global universal energy access by 2030; 60% of these investments ($19 billion a year) is required in sub-Saharan Africa [21]. The cost of the transition to a low-carbon economy and additional associated barriers, such as lack of capacity, make the transition to more renewable energy in Africa unlikely without international support [22].

The main sources available for financing the expansion of renewable energy in Africa are multilateral (World Bank Group and regional development banks, as well as multilateral funds such as Organization of Petroleum Exporting Countries Fund for International Development and Scaling-up Renewable Energy Program for Low-Income Countries) and bilateral sources (mainly from members of the OECD Development Assistance Committee), sources from governments in developing countries, and private sector sources [21]. Bloomberg New Energy Finance estimates the cumulative clean energy investment in Africa by development banks over the period 2007–2012 to be $14.6 billion, of which the African Development Bank (AfDB) was the largest source ($4.3 billion), followed by the World Bank Group with $2.9 billion [17,18]. Power Africa, a 5-year multistakeholder initiative recently announced by US President Barack Obama, aimed at doubling the number of people with access to electricity in sub-Saharan Africa by unlocking substantial renewable energy resources in the region, has already garnered more than $21 billion in financial support, including direct loans, guarantee facilities, and equity investments by its financial partners (including the US government, AfDB, World Bank, African governments, private sector participants, and a number of US government agencies) [23]. International financial institutions such as the Global Environmental Facility, the European Investment Bank, and, more recently, the Clean Technology Fund and the Sustainable Energy Fund for Africa have played a critical role in most of the African power sector's recent activity [22,24].

While the public sector is responsible for building more enabling business environments, it falls on the private sector to ensure that the continent's abundant renewable energy resources are developed in a sustainable way. Attractive returns are one of the most important drivers for private investors in the African renewable energy space [19]. Asian investors are increasingly targeting African renewable energy projects, and Chinese power generation companies in particular are widely expected to play a larger role in the African renewable energy sector in the future [19]. Calls for augmented African private sector investments in the renewable energy sector are equally becoming louder. Nigerian entrepreneur and philanthropist Tony Elumelu, for example, has made an Africa-wide call to action, promoting the idea of *Africapitalism*—the philosophy that the African private sector has the power to transform the continent economically and socially through long-term investments in key sectors such as infrastructure and power, which not only generate high returns but also help alleviate some of Africa's most pressing challenges [25]. Nonetheless, inadequate financial resources and low skill levels, as well as insufficient technical capacity in African countries, largely still make development finance institutions critical players in matching governments' development goals with the private sector's profit motive [24].

4.2 Regional cooperation: electricity markets, power pools, and grid infrastructure

When considering an increase in the share of renewable power fed into a centralized grid, it becomes imperative to consider implications for grid stability and reliability, as challenges can arise at as little as 10% power supply from renewables. Diversification of renewable resources, electricity storage, and backup capacity all become important options for ensuring grid stability [9,10]. In addition, grid interconnections with neighboring countries are required to profit from a more diversified power generation mix, as well as to balance operations of regional power markets. The Ethiopia–Djibouti interconnector, the first cross-border power connection in East Africa, for instance, connects the grids of the two countries; it enables Djibouti to replace 65% of its fossil fuel-produced power with electricity from Ethiopia's renewables, thereby reducing the costs and polluting emissions related to power generation [7].

Building regional long-distance grids that link abundant resources with centers of high demand enables the expansion of power trading even beyond immediate neighbors. The East African region, for example, has significant renewable energy potential, which in addition to fueling the region's growth can be used to help meet incremental power demand in southern Africa that is currently met largely by unsustainable coal-fired power production [7]. To this effect, the energy project portfolio of the Program for Infrastructure Development for Africa (PIDA)[1] includes the development of four transmission corridors, among other cross-border energy market-enhancing projects. The four corridors include a West African power transmission corridor (from Guinea to Ghana), a north–south transmission link (from Egypt to South Africa), a North African transmission link (from Morocco to Egypt), and a central corridor (from Angola to South Africa) [7,26].

The level of integration for such an undertaking requires high legal, institutional, and technical capacities within regional power pools. There are five power pools operating in Africa: the Southern African Power Pool, West African Power Pool, Central African Power Pool, East African Power Pool, and Arab Maghreb Union. While these pools enable significant cross-border flows of electricity, the increased integration of renewables, especially on a large scale, will require an increase in inter-regional power pooling. Large hydropower projects, such as the Grand Inga Dam in the Democratic Republic of Congo (one of a number of priority energy projects to be implemented by 2020 as part of PIDA), may not be viable considering the demand of one country alone, but may be highly valuable when addressing aggregate demand from several countries. It thus requires bulk inter-regional transmission networks to reap the full benefits of regional power sharing with large-scale projects. Potential benefits to countries dependent on fossil imports, those with less availability of economical renewable resources, or those with small loads hardly able to obtain economies of scale are significant [7]. Moreover, the integration of smart electricity systems could greatly amplify benefits by increasing the accuracy of balancing mechanisms, thereby improving quality and reliability of power and

[1] PIDA is a joint effort by the African Union Commission, the NEPAD Planning and Coordinating Agency, the AfDB, the United Nations Economic Commission for Africa, and Regional Economic Communities to promote regional economic integration by bridging Africa's infrastructure gap [26].

reducing losses and costs, while also offering African countries' energy sectors opportunities to leapfrog traditional power systems [27,28].

In addition, the recently approved new methodology for interconnection between electricity systems for energy exchange by the Clean Development Mechanism board enables cross-border electricity transmission projects to benefit from the sale of Certified Emission Reductions—a significant new source of revenue for countries whose renewable energy resources exceed their national needs and could therefore be exported. These additional revenues would contribute to the financial viability of concerned projects [24,29,30].

4.3 Renewable energy support policies

Aside from the key role governments play in the development of renewables by fostering regional integration and cooperation, they play an essential part at the national level. There are plenty of opportunities for governments to encourage advancement toward the widespread adoption of clean energy supply on a national level, notably through implementation of power sector regulations and playing field-leveling policies (e.g. fossil fuel subsidy removal), as well as the creation of attractive investment and financing conditions in the sector. The Renewable Energy Policy Network for the 21st Century (REN21) makes annual assessments of the global renewable energy policy landscape [15]; Figure 3 shows the number of countries in sub-Saharan Africa having implemented individual policy instruments.

In spite of the overall absence of coherent, consistent, and favorable policies targeting renewable energy development in most African countries, a growing number of these policy tools are being

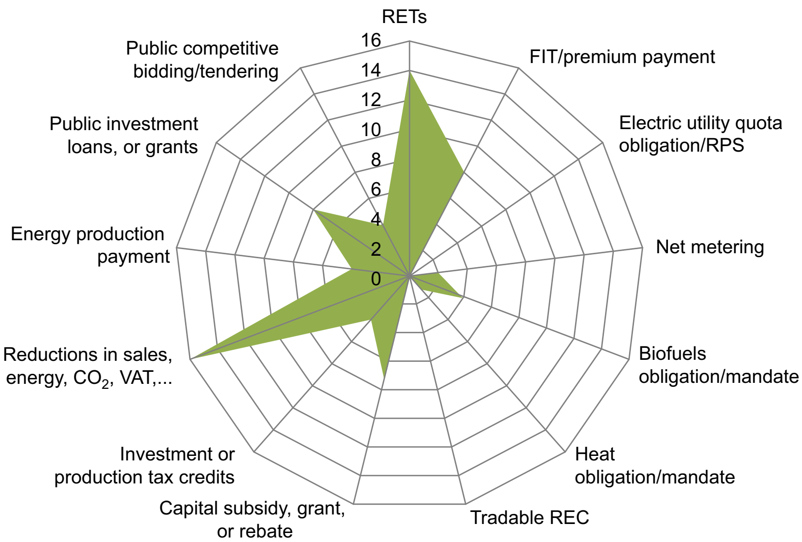

FIGURE 3

Number of Sub-Saharan African Countries to have implemented Renewable Energy Support Policies by early 2013.

Source: (REN21 2013)

adopted on the continent [15]. In early 2012, for example, Nigeria, Rwanda, and Uganda adopted new Feed-in-tariff (FIT) policies, adding to the list of African countries already operating with FITs, including Ghana, Senegal, Kenya, and Tanzania [15]. In the same year the 15 countries of the Economic Community of West African States (ECOWAS), one of the most active regions in Africa with respect to the promotion of renewables, adopted new targets: 10% of the power mix from renewables by 2020 and 19 by 2030 [15]. Among the most implemented policies in Africa are renewable energy targets and reductions in sales, energy, CO_2, value-added tax, or other taxes.

There are a number of examples of policies in respective renewable energy sectors. The South African government set a target of 10,000 GWh of renewable energy by the end of 2013 and contributed to this goal by supporting technologies such as solar water heating or residential heat pumps through schemes that significantly reduce their cost. In Rwanda the government has been promoting biogas as an alternative fuel for cooking and lighting in households and institutions since 2009, encouraging every Rwandan that owns at least two cows to build a biogas plant. The Mauritanian government played an instrumental role in the development of bagasse co-generation in the country by implementing legislation specifically for the sugar industry that improved the business environment and provided tax incentives for investments in power production [7]. Still, overall weak institutional capacity, inadequate technical skills, and financial barriers remain major inhibiting factors, leaving the private sector and lending facilities reluctant to capitalize on the sector.

Going forward, it is important for African governments to remove financial barriers, one of the key obstacles being the high cost of equipment for renewables. Facilitating access to renewable energy technology can play an important role in the continent’s development process. Since most African countries rely on imports of equipment, it is vital to reduce the tax burden on renewable energy technology imports, which could significantly boost respective sectors. Efforts should be made simultaneously to further develop local equipment manufacturing capacities, which would help reduce costs further. Emphasis should also be placed on the removal of bottlenecks in the approval process for setting up micro-renewable energy ventures, as these are complementary solutions to grid extension not only in the short term but also in the long term and, moreover, are vital for the achievement of universal energy access.

Finally, it is essential for the successful integration of renewables that governments focus efforts on human capacity building. In general, African countries are short of technical skills. Some of the consequences when it comes to renewable technology are the poor maintenance of imported systems and lack of adequate after-sales services [31]. Governments have a key role to play in creating an institutional environment that fosters the development and strengthening of relevant skills, knowledge, and experience, which in turn can support the components of innovation systems, including tertiary education or international links between local businesses, universities, and international technology experts [29,30]. The public sector itself equally lacks adequately skilled personnel to undertake effective decision-making, monitoring, and evaluation exercises. Emphasis on human capacity building is essential as the integration and (commercial) sustainability of renewable energy in African countries crucially depends on a skilled work force and a high level of institutional quality [31].

4.4 Innovative business models

Even with often unfavorable local conditions, there is increasing recognition of the huge potential offered by the opportunity to provide millions of energy-deprived households in the low-income segment, the so-called bottom of the pyramid (BoP), as well as deprived businesses with modern energy services. While the public sector is largely responsible for creating an enabling environment for the investment in and widespread adoption of renewables, it remains the private sector's task to figure out viable and sustainable ways of financing and actively delivering sustainable energy solutions across Africa.

Recently emerging business models have come up with innovative strategies of catering to local contexts, specifically targeting low-income segments. These include: (1) creating unique products, services, and technologies to meet BoP needs; (2) localizing value creation, e.g. through franchising or agent strategies involving local networks of vendors and suppliers; and (3) sachet marketing, i.e. offering products and services in single-use or other small units to make them affordable to the BoP [32]. An example of a business model including these strategies is pay-as-you-go solutions made possible by mobile money for purchase of small solar home systems. These leasing models target the aspect of affordability with consumer financing that allows customers to pay in small increments, e.g. on a daily or weekly basis, until the products are paid off and ownership is handed over to them [33]. The model deals with the aspect of remoteness of the rural BoP by using technology that enables consumers to pay remotely and operators to control (switch on and off) systems remotely. Another common strategy is for businesses to engage in partnerships, such as public-private partnerships, partnerships with nongovernmental organizations (NGOs), and partnerships with microfinance entities [32]. Examples include businesses collaborating with governments and NGOs to develop distribution networks for clean cook stoves. Other businesses partner with microfinance institutions (MFIs) to expand the energy product lines they offer, focusing on microloans for small solar and improved cook stoves, which are financed by the aggregation and sale of resulting carbon credits produced by products bought through MFI loans [34].

Local and international entrepreneurs will be essential for African countries to provide all of their populations with access to modern energy services. Much more private sector investment will be necessary to scale viable models. With demonstration of market success come falling risk profiles, new opportunities for higher profits, and more commercial investment in the low-income sustainable energy sector. In the meantime, government and aid agencies can play an important role in supporting market sectors that the private sector is currently unwilling or unable to invest in Ref. [34].

5. Conclusion

Africa has a momentous opportunity to leapfrog to modern renewable energy. Despite the general recognition by African governments that renewable power provides huge opportunities given the continent's enormous resources, the lack of coherent, consistent policies; technical skills; institutional capacity; infrastructure; and financial incentives remains a major barrier for widespread adoption. Coordinated efforts, including government leadership at the national and international level, support from the international community, and increasing entrepreneurship in the sector, will go a long way in guiding Africa towards a cleaner, more sustainable energy future.

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