Chapter 3

Towards a Sustainable Energy Future for Sub-Saharan Africa

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Additional information is available at the end of the chapter

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Abstract

Current global population is estimated at 7.5 billion with 1.25 billion living in developed countries and 6.25 billion in less developed countries. Africa's population is approximated at 1.25 billion with 1.02 billion in sub-Saharan Africa. Globally, an estimated 1.4 billion people lack access to electricity and 3 billion rely on solid fuels for cooking and space heating. Two thirds of those lacking access to electricity live in sub-Saharan Africa, whereas only about 16% of those in sub-Saharan Africa use modern energy forms as the primary cooking fuel. Lack of access to electricity has adverse socio-economic effects, while heavy reliance on solid fuels has negative socio-economic, health, and environmental impacts. Several initiatives are being undertaken to mitigate the situation; notable are future aspirations for universal access to clean and modern energy expressed in the 2030 sustainable development goals (goal number 7), 2063 African Union Commission Agenda, Paris Agreement, and the United Nations Sustainable Energy for All (SE4A). This chapter discusses the past and present energy situation and presents possible scenarios for a sustainable energy future in sub-Saharan Africa, with a particular emphasis on Southern Africa.

Keywords: sub-Saharan Africa, access to electricity, solid fuels, modern energy forms, sustainable energy future

1. Introduction

It is now, generally, agreed that access to advanced forms of energy is associated with improved and sustainable lifestyles; this has reinforced aspirations for universal access to clean and modern energy for all. Energy access is understood to mean the user's ability to access and utilise both electricity and clean cooking technologies. Achieving this universal access in the developing world especially in sub-Saharan Africa has, however, faced several challenges. Sub-Saharan Africa (SSA) refers to the area lying south of the Sahara desert; it consists of all countries that are fully or partially located south of the Sahara and mainly excludes all countries in North Africa and all countries that may lie in sub-Saharan Africa but belonging to the Arab states. It is highly contended that SSA remains the most energy (modern~) impoverished region of the world. For instance, the International Energy Agency (IEA) says that more than 600 million people do not have access to electricity, and close to 800 million people rely on traditional biomass fuels and unimproved cookstoves in sub-Saharan Africa [1]. In the year 2000, only 22.6% of the population in sub-Saharan Africa had access to electricity, compared with 40.8% in Asia, 86.6% in Latin America and 91.1% in the Middle East [2]. Although it can be argued that this situation has some historical connotations, it is also quite true that it has persisted this long due to variations in national developmental priorities, as well as inefficient governance and sub-optimal resources utilisation. Historically, electricity development in sub-Saharan Africa came about for three major reasons: as an amenity or symbol of modernity for non-African settlers, a source of power for mines and industry, or as a stimulus for industrial development [3]. During the colonial era, African residential areas were systematically and deliberately excluded from connection to grids, since Africans were not considered to have any need for electricity.

Nonetheless, the need to resolve the problem of low or lack of access to clean and modern energy services has been reaffirmed nationally and internationally as expressed by the Sustainable Energy for All initiative [4], the Paris Agreement [5], the 2030 Agenda for Sustainable Development [6] and the Agenda 2063 [7]. In the pursuit for solutions, it is worth noting the consensus, however, that this should be done in a sustainable and environmentally benign manner.

This chapter presents a situational review of the energy sector in SSA and examines possible complementary strategies that could strengthen efforts to attaining universal access to clean and modern energy. Section 2 examines electricity supply; Section 3 explores clean fuels and technologies for cooking, while Section 4 presents a review on biofuels for transportation; and finally Section 5 windups the chapter with conclusion and a way forward.

2. Electricity

Currently, on a global level, more than 1 billion people live without access to electricity, with more than half of them found in sub-Saharan Africa (SSA). Electricity is a clean and efficient source of energy; access to affordable, reliable and sustainable electricity supplies is important for the delivery of clean water, sanitation and healthcare services, as well as for providing reliable and efficient lighting, heating, cooking, mechanical power, and transport and telecommunications services. Lack or limited access to electricity, therefore, has negative socio-economic implications [8].

Electricity supply technologies refer to combinations of primary energy resources, electricity generating equipment and distribution infrastructure; the energy resources maybe fossil (coal, oil, gas) or nuclear (uranium, plutonium) or renewables (solar PV, wind, small and large hydro, biomass and waste, biofuels, geothermal), or any mixes thereof. The distribution infrastructure maybe grid-connected and would include transmission and distribution networks, or maybe based on distributed energy technologies. Distributed energy resources encompass mini-grids, micro-grids, stand-alone systems (such as solar home systems, solar lanterns), energy efficiency and storage technologies.

The first electricity supply power plant in Africa was established in the British southern African settler Cape Colony in the 1880s; in the early twentieth century, electricity generation gradually spreads across the continent. In the decades following the end of World War II, electricity systems evolved into large centralised plants, especially hydroelectric plants, mainly to serve mining interests particularly for refining aluminium [3].

The long-lasting effects of this historical exclusion of indigenous populations continue to be evident to date despite post-independence efforts at national and regional grid roll out and rural electrification. The 2012 World Bank reports show the extent of electricity access in sub-Saharan Africa as indicated in **Table 1**.

Traditionally, the electricity supply systems developed into bulk, centralised coal-fired, gas and nuclear-powered plants, hydroelectric dams and large-scale solar power stations and required electricity to be transmitted over long distances to load centres through high voltage (400, 275 and 132 kV) transmission and medium voltage (33 kV, 11 kV, 3.3 kV and 440 V) distribution three-phase systems [9].

In the quest to find solutions to the electricity access problems, several options have been considered including: opening up the energy market to private participation and developing necessary market and regulatory policy framework; streamlining the performance and operation of state owned electricity enterprises; diversifying the energy mix thereby also

% of National population having access to electricity	Number of countries	% of Countries
100	2	4.26
>75	4	8.51
>50	14	29.79
>25	28	59.57
<25	19	40.43
<10	3	6.38

Table 1. Access to electricity in sub-Saharan Africa [3].

integrating distributed energy resources and renewables; promoting sub-continental regional relations and trade in electricity; and developing effective and innovative electricity sector investment financing, and revenue payment and collection systems. The overriding principle behind this paradigm shift is to have efficient, secure and cost-effective electricity services within a framework of market opportunities for competitive business without negating the obligations of national governments to improving access to electricity by unaffording, low income, and quite often rural-based households. Some of these efforts are examined in detail in the following sub-sections:

2.1. Opening up the energy market to private participation

Unbundling of state owned electricity systems can be effected **'vertically'** (e.g. for electricity supply, separating generation, transmission, distribution, metering and supply) and/or **'horizontally'** (separating companies of the same type so there is market competition wherever possible). **Table 2** shows some of the common structures for unbundling of the otherwise vertically integrated and state owned electricity supply system:

2.2. Developing necessary market and regulatory policy framework

Market and regulatory policy frameworks include need for fair and effective sharing and generation of relevant market information and data between stakeholders; addressing difficulties in sourcing investment capital for relatively newer investment markets; the need to develop procedures for resolution of investment, maintenance and operational costs and financial compensation resulting from changes to the power system commercial mechanisms; and provision of long-term market assurances to promote investment and long-term planning.

To this end, most countries have passed legislation establishing national regulation boards with varying mandates to oversee the liberalisation schemes; **Table 3** shows some of the countries that have passed such legislation. **Table 4** shows renewable energy feed-in-tariffs, auctions, net metering and investment incentives adopted by some countries in sub-Saharan Africa.

2.3. Streamlining the performance and operation of state-owned electricity enterprises

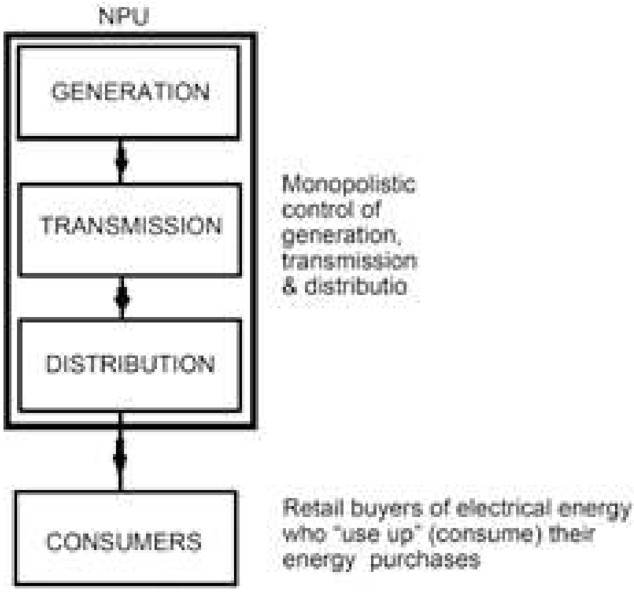
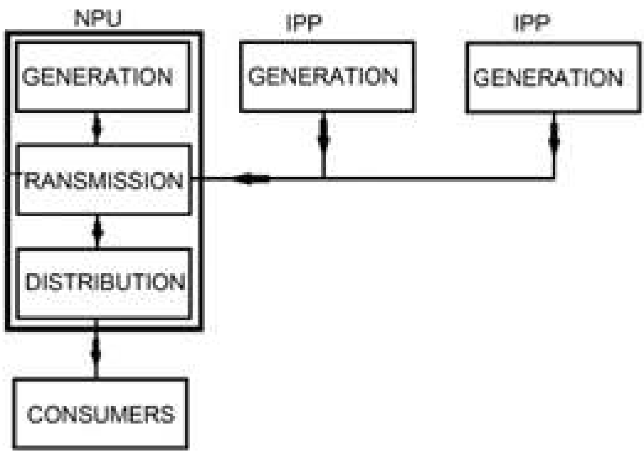
This focuses mainly on the following three aspects:

1. **Lack of system capacity:** in terms of both generation, and transmission and distribution infrastructure; this has adversely affected economic and industrial development resulting in inadequate ability for the sector to reinvest for sustainable and expanding power supply.
2. **Poor sector management:** power sector has consistently failed to reach sustainable operational efficiency for recovery of both recurrent and capital costs.

3. **High system losses:** both technical losses from the ailing transmission and distribution networks, and commercial losses from poor tariffs collection

2.4. Diversifying the energy mix

The majority of households in many sub-Saharan countries lack grid connection due to the poor state and low coverage of the electricity transmission and distribution networks.

<table>
<tr><th>Name</th><th>Schematic representation</th></tr>
<tr><td>Traditional vertically-integrated power utility; (NPU = National power utility)</td><td>
</td></tr>
<tr><td>Generation competition only. (IPP = Independent Power producer)</td><td>
</td></tr>
</table>

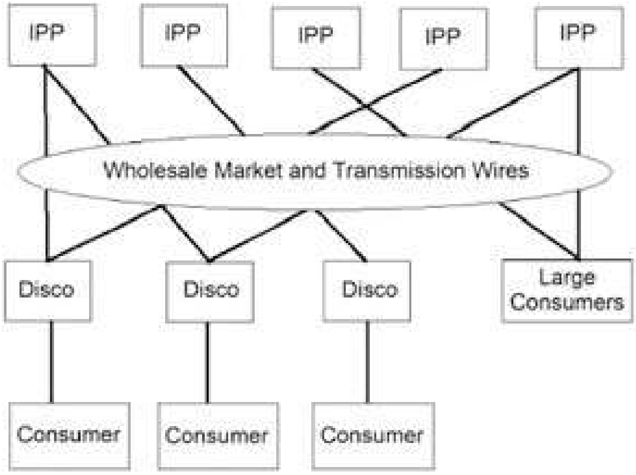
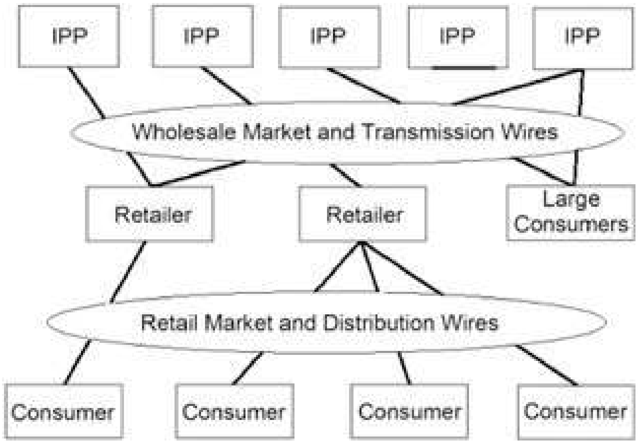
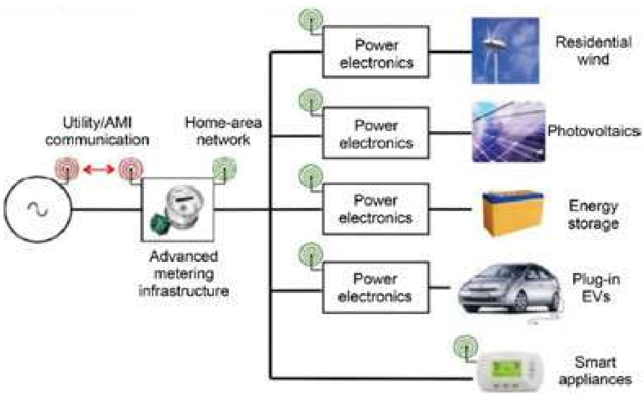
Name	Schematic representation
Wholesale competition only *(DisCo = Distribution Company)*	
Both wholesale and retail competition	
Consumer-owned distributed energy resource possibilities	

Table 2. Electricity supply liberalisation models [10, 11].

Country	Legislation
Kenya	Kenya Energy Act 2006: converted an advisory regulator into a decision making regulator, the Energy Regulation Commission. It also makes the new commission the sole authority over imports and exports of electricity
Mozambique	Mozambique Minister of Energy's directive July 2006 creates a 'strong' advisory regulator, emphasises the need for transparency and public hearings by the advisory regulator. It also entrusts the regulator with the responsibility of monitoring the performance contract between the government and Electricidade de Moçambique (EdM), the state owned power utility
Namibia	The electricity acts of 2000 and 2007 which established the Electricity Control Board that regulates the issuance of licences for electricity generation and related matters
South Africa	The National Energy Regulator (NERSA) established through the 2006 legislation gives the regulator powers to oversee the registration and issuance of licences for the generation, transmission, distribution, as well as the local and international trade of electricity
Tanzania	The Tanzania Electricity Act 2008 provides for the facilitation and regulation of generation, transmission, transformation, distribution, supply and use of electricity; it also makes provisions for regional trade in electricity as well as for the planning and regulation of rural electrification The section on regulation of rural electrification authorises EWURA, the national electricity regulator to: • vary the nature of its regulation depending on the characteristics of the entity performing the electrification; • delegate regulatory responsibilities to other entities.
Uganda	The electricity act of 1999 provided for the creation of regulatory authority to oversee the licencing and regulation of electricity generation, transmission, distribution, sale and use. It also enforces matters pertaining to plant and equipment and safety. It was also entrusted with the responsibility of liberalisation and introduction of competition in the electricity sector
Zambia	The Energy Regulatory Board, established through a legislative act of 1995, gives the board the responsibility of issuing licences for the production and handling of energy and petroleum products

Table 3. National energy (electricity) legislations [12].

Country	Wind	Solar PV	Concentrating solar power	Small hydro	Biomass	Geothermal
Kenya	√	√	√	√	√	√
Uganda	√	Auction		√	√	√
Namibia	√	√	√		√	
Zambia (Draft Sep 15)	√	√	√	√	√	√

Source: www.bluehorizon.energy [13]

Table 4. Existing renewable energy feed-in-tariff programs (website: www.bluehorizon.energy [13]).

Diversification of the energy system is one way of resolving this problem. Some factors to consider are as follows:

1. **Dependence on large dams:** the seasonal variability of hydropower output and the impact of prolonged droughts in the region create fragile power systems and increase the financial and climate risks; secondly owing to very high upfront costs, long-term financial viability is not assured.

2. **Dependence on fossil fuels:** the challenges include local air pollution and public health concerns, as well as susceptibility to global fluctuations in fossil fuels prices.

3. **Distributed energy resources (DERs):** the modular nature of renewables such as solar and small-scale hydropower and the improved knowledge and management of energy distribution systems have made DERs an attractive option especially for off-grid applications. Product systems include solar lanterns, solar home systems and solar micro-grids.

4. **Renewables:** offer opportunities for improving and developing energy access as they can be deployed at different levels from small to large systems.

5. **Micro-grids:** a micro-grid is a lower level electricity supply generation and distribution system that delivers electricity to several structures in a village. Micro-grids can supply power to even remote locations because advances in ICTs facilitate demand projecting and pay-as-you-go services. Also, micro-grids do not need huge investments and lengthy construction times—notwithstanding that capital costs are still prohibitive for small- and medium-sized businesses. Initial micro-grids were based on fossil fuels such as diesel; their performance was highly dependent on reliability of fuels supplies as well as fuel prices. However, advancement in renewables has made micro-grids more appealing. An example of a micro-grid is that at a village called Motshegaletau in central Botswana, the village had a population of about 700 as at 1997 projections; the micro-grid consisted of a PV array with an output of 5.7 kW, 48 V dc from 20 x 285 W panels arranged in five parallel rows; two sine wave inverters convert 48 V DC to 230 V AC. Forty-eight batteries rated 2 V DC, 1200 Ah connected in two parallel strings form the battery storage bank rated 48 V DC nominal and 2400 Ah. The grid supplied nine residential houses, a bar, a clinic and a school.

6. **Energy efficiency:** supply side and demand side inefficiencies certainly implicate negatively on improving access to electricity supplies; cogeneration and trigeneration technologies can enhance supply side electricity efficiencies. A successful case of biofuel-based cogeneration has been demonstrated in the sugar industry where the bagasse by-product is used to fire steam generators for heat and electricity production. For instance, Mauritius has been able to meet about half of her electricity needs from bagasse cogeneration plants following reforms aimed at making the sugar industry more attractive for investment. A number of countries in East Africa and Southern Africa have large sugar industrial sectors.

2.5. Promoting sub-continental regional relations and trade in electricity

Regional power pools:

Currently, the sub-continent has four regional power pools; intra- and inter-regional power pools collaborations could help improve performance of the power sector through economies of scale, security of supply from a rich energy mix, and cost efficiency through shared energy storage and improved demand side response management.

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2.6. Developing effective and innovative revenue payment and collection systems such as flexible payment schemes

i. **Pay-As-You-Go (PAYG) business model:** Under this model, consumers can finance off-grid renewable electricity systems such as solar lanterns, solar home systems and solar micro-grids either by paying the full cost upfront or by paying in instalments over time using mobile money mechanisms such as M-PESA and Airtel MTN. Two companies, M-Kopa and Mobisol, have adopted this model and are using it in East Africa where off-grid low-income and rising middle-class customers who are unable to pay a once off full purchase price for solar home systems, have been enabled to access electricity services. The M-Kopa systems consist of 8 W solar panels, LED lights, a rechargeable radio, and a cell-phone charger. As of 2016, M-Kopa had connected more than 300,000 homes to solar power (website: www.pwc.co.uk [14]; website: m-kopa.com [15]) while Mobisol, has to date installed more than 3 MW of solar home system capacity in Rwanda and Tanzania (website: [16] energy-access.gnesd.org) (**Figure 1**).

ii. **Fee-for-Use (F4U) business model**: Under this model, the customer does not buy the stand-alone system, but only pays rent to use it. A solar company retains ownership, ensures that the system is operating properly and is responsible for maintenance. The customer makes a one-time installation payment as well as reoccurring fixed payments based on the size of the system. The M-POWER company offers to Tanzania rural people a solar home system (SHS) which includes: the hardware to generate solar energy (solar panel, storage and wires) and energy using products (EUP) (two lights and phone charger). Customers pay as a pay per period (daily fees). Off Grid Electric maintains proprietorship of SHS and EUPs and develops a network of local artisans/dealers for installation and technical support [17] (**Figure 2**).

The foregoing discussion illustrates that widespread electricity access is achievable as demonstrated by the two countries, Seychelles and Mauritius, with 100% electricity access; it also points to the complexities associated with tackling the problem of electricity access; for instance, three countries have less than 10% access and 50 of the 70 countries recorded have less than 50% access.

Figure 1. A 100 W solar home system with kit of DC appliances from Mobisol (source: Mobisol, 2017).

Figure 2. A client showing an M-power solar product based on a 'pay-per-period' concept.

It is also noted that several countries are taking measures to deal with the problem of electricity access. Some of these measures include market liberalisation and development of appropriate legislations. Other initiatives are the promotion of sub-regional integration and development of innovative financing capital and client flexible repayment schemes.

3. Clean and improved cooking technologies

Clean cooking solutions or clean fuels and technologies for cooking refer to combinations of clean cooking fuels and compatible improved cooking equipment; as well as the infrastructure for fuel production and distribution. Clean fuels are fuels which during combustion emit little to no pollutants that are harmful to health and the environment. They include ethanol, biogas and jatropha oil; liquid petroleum gas (LPG) and kerosene may also be admissible. Improved cooking stoves are safer to use and have higher energy efficiencies thus consuming less fuel. Examples of equipment for the production of fuel include biogas digesters, ethanol distillation equipment and jatropha oil extracting machinery, whereas examples of distribution infrastructure embrace local selling points for bottled LPG and pump stations for kerosene. Solar cookers and electricity are also considered clean cooking solutions but have not attained wide spread usage in the sub-Saharan Africa region [4]. Current statistics show that 3.04 billion people are living without clean cooking globally. Around 600 million people residing in sub-Saharan Africa, 76% of the populace rely upon conventional solid biomass fuels as their principal energy resource [18].

Traditional fuels produce dangerous emissions which are a health hazard especially when used indoors and under poor ventilation; in addition, these fuels have very low energy efficiencies, and the heat produced is highly difficult to control. Traditional biomass fuels mainly refer to non-processed or semi-processed solid biomass used mainly for generating heat for cooking and for space heating usually in the form of a simple open fire or with basic wood and charcoal stoves. Traditional forms of biomass energy mainly include wood, wood waste, charcoal, animal waste and other agricultural residues. These fuels are characterised by low efficiency, poor handling and storage. **Table 5** shows woodfuel usage patterns in some sub-Saharan African countries.

3.1. Improved traditional fuels and technologies

These are traditional biomass-based fuels that have characteristics of improved efficiencies and/or sustainably produced. They include improved biomass cookstoves, charcoal, fuel briquettes and sustainable woodfuel.

3.1.1. Improved cookstoves

Initial attempts at finding solutions to the inefficient traditional biomass fuels have been to integrate improved cookstoves into the traditional biomass fuels setting. In the absence of a formally agreed definition of an advanced cookstove, it for the most part implies a stove that cooks more effectively than the customary three-stone stove [1]. Potential benefits of adopting use of improved cookstoves are reductions in indoor air pollution resulting from improved combustion rates, and reduced cooking times and fuel requirements. Cookstoves that incorporate forced ventilation are capable of eliminating pollutants all together. Improved cookstove designs vary depending on the fuel being used; fuels used range from solid fuels such as fuelwood, charcoal, coal, fuel briquettes to liquid/gel fuel and gas fuels; as such local specific aspects need to be built into the stoves; in South Africa, for instance, there is wide spread use of coal for cooking and heating; thus necessitating research and development work on clean coal stoves such as those undertaken by the South Africa's council for scientific and industrial research (CSIR) and New Dawn Engineering's Mr. Crispin Pemberton-Pigott (website: www.pciaonline.org [19]). **Figure 3** shows some of the improved cookstoves exhibited at the people energy network **(**PEN) workshop 2009 at University of Johannesburg, South Africa.

Country	Percentage of total population living in rural and urban areas		Percentage of rural, urban and total population dependent on firewood		
	Rural (%)	Urban (%)	Rural (%)	Urban (%)	Total (%)
Tanzania	76.9	23.1	95.6	26.7	77.4
Uganda	87.7	12.3	91.3	22.1	81.6
Senegal	59.3	40.7	89.1	15.9	54.7
Zambia	65.4	34.6	87.7	10.1	60.9
Malawi	85.6	14.4	98.5	69.0	94.3
Kenya	64.1	35.9	88.4	9.6	68.8

Table 5. Firewood usage in some sub-Saharan African countries [18].

Figure 3. Pictures of combustors on exhibit at inaugural PEN workshop 2009. (source: Author).

3.1.2. Charcoal

Perhaps one fuel, among traditional biomass fuel types, requiring special mention is charcoal. It is a porous carbonaceous black solid fuel produced through the pyrolysis treatment of unprocessed solid biomass fuels. In sub-Saharan Africa, it is mainly produced through the slow burning of woodfuel in earth kilns and under restricted air flow. It emits fewer pollutants and has a higher energy density than firewood thus making is less bulk and relatively easier to transport. It has widespread usage especially among the low and middle income urbanites. It is, however, still not considered a clean fuel as it is inefficient and has levels of pollutants not ideal for household cooking. **Table 6** shows charcoal usage pattern in some sub-Saharan African countries.

3.1.3. Fuel briquettes

Fuel briquettes are made from powdery or granular industrial waste such as coal dust, charcoal dust, saw dust and wood shavings, waste paper and pulp, or bagasse, and so on. This powdery waste material is normally mixed with a binder; this is followed by moulding under pressure. It is then either simply dried or subjected to carbonisation process that is exposed to intense heat under limited airflow. The environmental performance and combustion efficiency of fuel briquettes are highly dependent on the type and source of materials used in its manufacture.

3.1.4. Sustainable woodfuel

Woodfuel is cultivable. One idea that is normally considered is that of sustainable woodfuel, implying that the forest stock used as fuel is replenished through tree planting thus contributing carbon neutrality of the type of fuel.

3.2. Modern fuels and technologies

Modern cooking fuels are so referred and distinguished from traditional cooking fuels on account of ease of handle ability and controllability during use, higher energy efficiency and clean burning with little or no harmful emissions and as such possessing health and

Country	Rural (%)	Urban (%)	Total (%)
Tanzania	3.6	52.9	16.7
Uganda	7.0	66.8	15.4
Senegal	1.8	12.1	6.6
Zambia	9.5	52.1	24.3
Malawi	0.4	15.5	2.5
Kenya	6.0	20.8	9.7

Table 6. Level of charcoal use for fuel in selected African nations [18].

environmental benefits. Both LPG and biogas are considered examples of gaseous clean fuels while ethanol and jatropha oil are examples of liquid clean fuels. The discussion also covers electricity and solar thermal for cooking, two clean cooking fuels that have not been successfully adopted in the region; kerosene is also discussed as it is considered relatively cleaner that the traditional fuels [20].

3.2.1. Kerosene

Kerosene is a fossil fuel produced as a distillate mainly from crude oil refineries. It is not considered a clean cooking fuel but considered a slight improvement on traditional biomass fuels in that its combustion does not produce as much harmful pollutants, and that it is easier to handle, transport, store and control during use. It is widely used in the urban areas of sub-Saharan Africa. It is predominantly used in two types of combustors, wick type and pressurised cookstoves.

3.2.2. Jatropha oil

Jatropha curcas is a small bush-like plant. The oil from jatropha seeds has a wide range of useful applications. It is traditionally used for medicinal purposes and could find some ground in the pharmaceutical industries. It is widely used for biodiesel production. Further advancements in biofuel stoves technology are needed in order for jatropha to become attractive as an alternative to traditional biomass fuels.

3.2.3. Biogas

Biogas is a clean gaseous fuel suitable for household cooking. It is a gaseous mixture rich in methane gas, produced through anaerobic digestion of biodegradable domestic waste, landfill/municipal waste or agricultural residues; it can also be used for lighting or at larger scales for electricity generation. However, its widespread uptake has been constrained by lack of reliable and adequate availability of feedstock such as in areas where farmers practice free range livestock keeping, as well as socio-cultural factors such as the acceptance of human excreta as feedstock.

3.2.4. Liquefied petroleum gas

Liquefied petroleum gas (LPG) is a mixture of hydrocarbon gases mainly propane and butane. Despite being a fossil fuel, LPG has low carbon content and a high calorific value of around 50 kilojoules per gram; it burns clean and completely with a blue smokeless flame, producing fewer soot particulates. It is also safe, nontoxic and considered relatively affordable. It is potentially a better substitute for traditional biomass fuels.

3.2.5. Ethanol and gelfuel

Several countries in Africa are currently distilling ethanol which is mainly used as an additive in transportation fuels. Ethanol is very well suited as a household cooking fuel. Ethanol production is a matured technology, though there are several controversies surrounding the use of food crops (cassava, sorghum, maize, wheat, etc.) for biofuels. Further conversion of ethanol to gelfuel is thought to improve its handle ability and reduce risks associated with burning ethanol for household cooking.

3.2.6. Electricity

Ideally, electricity would be the fuel of choice. It is a clean and highly efficient energy suitable for cooking; but sub-Saharan Africa's grid network is so underdeveloped and the installed capacity so low, the majority of households cannot access electricity supply.

3.2.7. Solar cooking

Solar cookers use sunlight for cooking, drying and pasteurisation. Solar cooking offsets fuel costs, reduces demand for fuel or firewood, and improves air quality by reducing or removing a source of smoke.

The simplest type of solar cooker is the box cooker. A basic box cooker consists of an insulated container with a transparent lid. These cookers can be used effectively with partially overcast skies and will typically reach 50–100°C.

Concentrating solar cookers use reflectors to concentrate solar energy onto a cooking container. The most common reflector geometries are flat plate, disc and parabolic trough type. These designs cook faster at higher temperatures (up to 350°C) but require direct light to function properly.

An example of a concentrating technology is that known as the Scheffler reflector. This technology was first developed by Wolfgang Scheffler in 1986. A Scheffler reflector is a parabolic dish that uses single axis tracking to follow the Sun's daily course. These reflectors have a flexible reflective surface that is able to change its curvature to adjust to seasonal variations in the incident angle of sunlight. Scheffler reflectors have the advantage of having a fixed focal point which improves the ease of cooking and are able to reach temperatures of 450–650°C. The world's largest Scheffler reflector system is found in Abu Road, Rajasthan India and it is capable of cooking up to 35,000 meals a day. A number of pilot solar cooking systems have

Figure 4. A collection of solar cookers at international conference on solar cooking, Kimberley-South Africa 27-27 November 2000 (source: Author).

Figure 5. Preparing meals using SK12-Improved version of SK14 Kimberley-South Africa 27-27 November 2000 (source: Author).

been constructed in sub-Saharan Africa, such as those installed in Botswana and South Africa. A company called Rural Industries Innovation Centre (RIIC) made six installations of a $7m^2$ Scheffler cooker in Botswana in the late 1990s; 16 units of smaller version cooker, SK14, were also distributed to families in the mining town of Jwaneng in Botswana [21]. **Figures 4** and **5** show solar cookers on exhibition and in-use, respectively.

From the preceding discussion, it is evident that a diversity of improved and clean cooking technologies is available in varying formats and mixes for different parts of the subcontinent. Barriers to effective adoption of these technologies are quite wide-ranging and include lack of technological support (localised technology manufacture and maintenance, localised fuels production and distribution networks), higher costs and lack of flexible purchase and repayment schemes, as well as lack of information and awareness. Some efforts are being undertaken to address these barriers; for instance, the Global Alliance for Clean Cookstoves, an initiative hosted by the UN Foundation in support of Sustainable Energy for All, a public-private partnership that seeks to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions; the alliance has a goal of enabling an additional 100 million homes to adopt clean and efficient stoves and fuels by 2020 (website: www.unfoundation.org [22]).

4. Biofuels for transportation

Transportation energy technologies refer to all forms of energy and corresponding infrastructure for facilitation of mobility of vehicular objects. As such they include fossil based fuels technologies, biofuel-based technologies, electricity based technologies and nuclear energy-based propulsion technologies. Clean transportation fuels technologies refer to various fuel-technology combinations in the transport sector characterised by reduced or no greenhouse gas (GHG) emissions. Electrically powered transportation in the form of electric trains and ships has been in existence for centuries, from the 1830s when the Scottish, Robert Anderson invented the first crude electric carriage to the (website: www.pbs.org [23]) to the futuristic notion of all-cars-electric by 2040 (website: news.nationalgeographic.com [24]); numerous efforts for electric automobiles are currently under consideration or development by several technology and manufacturing companies. Efforts for replacement of fossil fuels by biofuels have also been widely explored.

Biofuels are liquid and gaseous fuels produced from biomass, used in the transport sector. Biofuels can be classified into conventional and advanced forms [25]:

- Conventional biofuels (also referred to as first generation) are well-established technologies that are, currently, under commercial production; they include ethanol (processed from corn, sugarcane, wheat, sugarbeet, cassava, etc.), biodiesel (from rapeseed, soybean, oil palm, sunflower, etc.) and biogas (produced via anaerobic digestion of energy crops such as maize silage and waste such as bio-waste including manure).

- Advanced biofuels, also referred to as second generation biofuels, are to a larger extend still at developmental stage, and are mainly produced from non-edible biomass such as cellulose (plant stalks), non-food crops such as jatropha and tobacco, and bio-waste or by-products of food industries such as molasses from sugar processing. Third generation (biofuels from algae) and fourth generation (microbial biotechnology) are still at conceptual stages.

Bioethanol and biodiesel are the most common types of biofuels. The use of bioethanol and biodiesel as transport fuels is very attractive due to reduction of combustion emissions, accessibility from renewable resources, and biodegradability [12, 18, 26]. Over the past decade, the production of bioethanol and biodiesel has been extensively investigated worldwide and their production methods have proved successful in the USA and Brazil [4, 18, 27]. However, in sub-Saharan Africa (SSA), large-scale industrial production and commercialization are stagnant. This section provides a brief review on the potential for biofuels as a transportation fuel in SSA [4].

Access to reliable and affordable transportation infrastructure and services, although, and probably justifiably so, not considered as critical as access to electricity and/or clean cooking technologies, has a greater bearing on any meaningful developmental initiatives, including on the development of infrastructure for adequate provision of electricity and clean cooking. Access to affordable and reliable 'fuel' cannot be divorced from transportation and in turn to socio-economic development. Many countries, in SSA, face insecure fuel supplies due to fluctuating fossil fuel prices, inadequate distribution networks, civil wars, as well as lack of foreign currency. A well-developed biofuels industry will contribute to solving the transportation problem; in addition a number of spin-off benefits to be gained from a well-developed biofuels industry will include:

- ensuring availability of affordable fuel to rural communities for household electrification, powering farming machinery, and transportation;
- stabilising the sub-continent's energy supply and diversifying its fuel options and reducing the burden on oil importing countries;
- creating opportunities for exports of biofuel feedstocks to industrialised countries by African farmers;
- providing many employment opportunities to African people and boost the continent's economy; and
- assisting industrialised sub-Saharan Africa countries, such as Egypt, Nigeria, and South Africa that are among the leading carbon emitters in the continent in mitigating carbon emissions.

In closing the discussion under this section, it suffices to point out that sub-Saharan Africa presents greater potential for development of a strong biofuel industry. There are several ongoing and commenced initiatives regarding biofuels development in sub-Saharan Africa. **Table 7** shows some of such initiatives:

Country	Biofuel initiatives
Burkina Faso	A Dutch funded government project, Fondation Fasobiocarburant (FFB) has promoted planting of 70,000 trees of jatropha oil seeds in 2009.
Ghana	Ghana's bioenergy policy aims at attaining 20% blend of biofuels with petroleum fuels by 2030. Initial production of ethanol has been from cassava and sugarcane. Other feedstocks considered are maize and jatropha oil seeds.
Mali	an NGO, Mali-Folkecenter Nyetaa has developed an innovative project whereby the local farmers of Garalo village, in the vicinity of the centre, have grouped themselves into cooperatives for growing of jatropha, intercropped with other cereals; the jatropha seeds are pressed into oil that is supplied to the centre; in turn the centre operates a 300 kW installed capacity plant with a 15 km mini-grid supplying electricity to the 10,000 inhabitants of the village.
Malawi	Bioethanol for fuel is produced by two captive distilleries at Dwangwa and Nchalo sugar estates at annual capacities of 15–20 million litres and 12 million litres, respectively. The fuel grade bioethanol is blended at 20% (v/v) with petrol by the petroleum industry. Local farmers are also involved in the sugarcane production under out-growers schemes; local farmers have also been engaged to grow over ten million jatropha trees under a 5 years project.
Mozambique	Mozambique Government has implemented a 5–10% (v/v) blend for bioethanol with petroleum. Ndzilo plant delivers close to two million litres of ethanol from cassava. Biodiesel is produced from jatropha oil seeds by two companies, Petromoc and SunBiofuels.
Nigeria	Five big companies distil about 134 million litres of ethanol every year in Nigeria. Biodiesel is produced by companies such as Biodiesel Nigeria Limited in Lagos State, Aura Bio-Corporation in Cross River State, and the Shashwat Jatropha in Kebbi State.
South Africa	Government plans to reduce fossil fuels imports by substituting it with biofuels. It has thus passed legislation that requires a mandatory 2% blend for all petrol and diesel products as of 2015; with plans to increase the blend proportion as the biofuels industry grows. A few companies have been issued licences for the production of bioethanol and biodiesel. Biomethane, bioelectricity and biohydrogen are also under consideration for incorporation in the mix for clean fuels for transportation.
Tanzania	Seven companies and NGOs include Diligent Tanzania Ltd., Kakute Ltd., ARI-Monduli, MVIWATA, Kikuletwa Farm, Jatropha Products Tanzania Limited, and Tanzanian Traditional Energy Development and Environment Organisation are involved in jatropha tree planting and production of biodiesel

Table 7. Biofuel initiative in sub-Saharan Africa [28].

5. Conclusion and a way forward

Lack of access to clean and modern energy, including energy poverty, is quite prevalent in sub-Saharan Africa, with the majority of the population relying on traditional biomass fuels. Traditional biomass fuels are associated with low energy efficiencies, difficult to control and are a health hazard. Electricity supply and connectivity is far outstripped by demand and is beyond the means of the majority poor people. It is widely acknowledged that access to affordable, reliable, sustainable and modern energy for all is a common necessity for socio-economic development as espoused by the sustainable development goal number seven (SGD 7).

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More than half of all Africans have no access to electricity; regrettably, this also represents more than half of all people without electricity globally. The traditional electricity system in most countries evolved as large, centralised, fossil fuel or large hydropower systems operating on a monopolistic, state-owned, vertically-integrated model characterised by inefficient management and poor performance. Some of the efforts aimed at redressing this situation include liberalisation of the electricity market, development of market and legal frameworks, streamlining the performance of state-owned electricity utilities, promoting sub-regional electricity trade, as well as development of innovative financing and revenue repayment and collection mechanisms.

Improved traditional cooking technologies include improved cookstoves and higher energy-content traditional fuel forms. These, generally, do not meet the requirements clean, modern cooking technologies. Modern fuels and cooking technologies include cleaner fossil fuels (kerosene and LPG), biofuels (jatropha oil, biogas and ethanol), and electricity and solar cooking. Lack of awareness, lack of technological support and higher costs are the main barriers to the widespread adoption of modern cooking technologies.

Biofuels for transportation are at different developmental stages with bioethanol and biodiesel being the most advanced and commercialised globally. In sub-Saharan Africa, however, the biofuel industry remains largely underdeveloped, although isolated significant developments have been recorded. Substantial potential for the biofuel industry is substantial and so are the potential benefits.

As an ending to this chapter, it worth noting the following:

- There is no 'One-Size-Fits-All' or 'Cut-and-Paste' solution to the problems of energy access and poverty in Sub-Saharan Africa; each scenario requires a unique solution apt to its details; that is, the stakeholders (users included), available energy resources, level of socio-economic and industrial development, and so on.
- Lessons can be learnt from success stories such as the 100% electricity access in Mauritius and Seychelles, LPG roll out program in Senegal (website: stoves.bioenergylists.org [29]), Free Basic Electricity (FBE) scheme in South Africa (website: flash.co.za [30]).
- Notwithstanding the merits of a competitive and profitable energy model, it remains governments' obligation to develop systems that ensure universal modern and sustainable energy access is availed to those that cannot afford.

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