Chapter 3
Prospects for Renewable Energy in Africa

Abstract Not long ago renewable power generation was an expensive choice to be subsidised by industrialized governments to signal an intention to shift to clean energy, however today renewable resources are becoming strategic assets for developing countries too, as the global industry grows stronger and the cost of technology falls dramatically. Their potential is particularly evident in Africa where solar, wind, hydro, geothermal, and biomass resources are abundant. While it is becoming evident that renewables have a major role to play in the electrification process of many countries in the region—including at small scale and off-grid—several challenges remain when it comes to establishing appropriate regulations, attracting foreign investments, and even sometimes simply setting clear targets. After describing the distribution of resources, this chapter looks at the policy frameworks in place in order to point at possible ways forward.

African countries are gifted with a huge—and still untapped—renewable energy potential. Estimates of power generation potential in the continent are 350 GW for hydroelectric, 110 GW for wind, 15 GW for geothermal and a staggering 1000 GW for solar (African Development Bank 2017). Potential for bioenergy is also high, with wood supply from surplus forest estimated at 520 GWh/year (International Renewable Energy Agency 2015). Solar is particularly promising in terms of geographical distribution: albeit with varying potentials, this type of energy could be harnessed virtually everywhere in Africa.

This large endowment of renewables is strategic for the continent, and the prospect of large-scale renewable power production may be a real game changer for several countries. While hydropower has been an option for a long time, other renewable solutions became commercially viable quite recently. Wind and solar in particular are now leading large-scale renewable power production across the continent, competing with fossil fuel alternatives also in terms of costs (Chap. 2).

In general, while many renewable energy sources can be used to produce electricity and/or heat without any combustion process (e.g. sunlight, wind, hydro, underground heat), others need to be burnt in order to release their energy (bioenergy from organic material, or biomass). While biomass is highly versatile—uses include

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Table 3.1 Renewable energy in Africa

Modern renewable energy	Use
Firewood (improved cookstove)	Heat
Charcoal (improved cookstove)	
Ethanol (improved cookstove)	
Residue (industry)	
Briquettes (improved cookstove)	
Solar thermal (buildings and industry)	
Geothermal	Power
Solar PV	
Solar CSP (thermal)	
Wind	
Hydro	
Biomass (thermal)	
Biofuels	Transport

Source Elaborated from (International Renewable Energy Agency 2015)

cooking and heating, transport and electricity—it can be processed and utilized to different degrees of efficiency, cleanliness, and sustainability of the value chain. Unfortunately however, today's reliance on bioenergy in the primary energy mix of SSA (Chap. 2) only reflects the prevalence of rudimentary stoves for cooking with wood and charcoal (see Sect. 4.5).

Talking about *modern* renewable energy means considering ways of producing and consuming renewable energy that are as clean (in terms of particulate and carbon emissions) and as efficient as possible with today's technology (Table 3.1). Hence, modern renewables should replace or step up *traditional* uses of renewables in Africa, first and foremost the direct use of solid biomass.

When it comes to electricity production from renewables, a critical issue is that some of the best solutions (notably wind and solar) depend on a fluctuating source, hence their contribution to power generation is variable and sometimes even unpredictable. This is in contrast with fossil fuels and other renewables that are *dispatchable*, meaning that production can be regulated, initiated and ceased on demand, sometimes as quickly as within minutes, other times within hours. Geothermal, hydropower (reservoir type), concentrated solar power (CSP) enhanced with thermal storage, and biomass generation stand out as dispatchable renewables characterised by different degrees of output flexibility.

It should be noted that hydropower and biomass, unlike other renewables, rely on two critical natural resources—freshwater and biomass—that are increasingly demanded in SSA for multiple, sometimes conflicting uses, and that are subject to climate change impact through reduced rainfalls, higher temperatures, and desertification. Adapting to this reality will mean innovating and optimizing production

Table 3.2 Targets for renewables in selected countries

	Share of renewables in total power generation (%)	Solar (MW)	Wind (MW)	Hydro (MW)	Biomass (MW)	Geothermal (MW)
Angola			100	38	500	
Ghana	10%					
Kenya			636	1,320	44	2,300
Morocco		2,000	2,000	2,280	200	
Nigeria		6,831	292	8,174	3,211	
Rwanda		563	18.5		73	
Senegal	20%					
South Africa		9,600	9,200	75	12.5	
Sudan		716	680	56	54	2,228
Tanzania			100	3,541	100	
Tunisia		1,960	1,755		100	
Uganda				1,285	90	45
Zambia		150		100		

Source RISE website, accessed January 2018

processes, and finding smart synergies (e.g. valorising waste) so as to increase the overall efficiency of natural resource use (de Strasser 2017).

Some African countries are embarking in highly ambitious renewable power projects. Examples that aim at the top of global rankings of installed renewable capacity are: the Noor concentrated solar power plant in Morocco, Lake Turkana wind farm in Kenya, and the Grand Renaissance Dam in Ethiopia (total planned capacities of 500, 310 MW, and 6.45 GW respectively). Although the renewable energy sector is far from mature in most of SSA, today more and more countries are setting up targets for renewables (Table 3.2).

The fact that variable renewables will play a key role in SSA's electrification process highlights the importance of planning for the power system accordingly. While most industrialised countries now face the issue of integrating renewables into existing power grids, in large parts of SSA the opportunity is there to build whole new networks that can directly cope with high shares of variable—and decentralised—renewable power generation.

It is noteworthy that emerging economies—with China and India at the forefront—are effectively leading the global renewable energy transition by showing the boldest commitment to wind and solar development (REN21 2017). This increases prospects for south-south cooperation and trade, which should bring higher availability and affordability of equipment as well as accumulated experience in renewable energy policy and business in the context of developing energy markets. In this context, SSA is set to play a central role as global supplier of raw materials—and rare minerals in particular—which is something that opens up opportunities but also risks, particularly in fragile countries (Box 3.1).

Box 3.1: SSA's Rare Minerals

One of the enabling conditions for variable renewables is storage. Globally, there is quite a lot of uncertainty around the future of utility-scale batteries, however as of today lithium-ion solutions (i.e. the same type that powers smartphones and electric cars) seem to be the preferred solution, even though their appropriateness for grid applications is often questioned (Industrial Minerals 2016). The global boom for these batteries—which is expected to skyrocket as key global economies like China and the EU are taking drastic steps towards e-mobility—is driving demand of the often rare minerals that are required to produce them, like lithium, cobalt, nickel, and many more.

This goes hand in hand with the demand of rare minerals for the production of PV, and even wind turbines. Several analysts predict that the new geopolitics of energy in the era of renewables will be built around these minerals, and point out that the global relevance of SSA production is already evident. Notably, the Democratic Republic of Congo is the biggest cobalt supplier in the world, and Zimbabwe is a key global producer of lithium and copper. In many cases, human rights abuse and environmental damage are common in these mines, and while the problem is well known, the global demand is so high (and for some materials, reserves are so rare) that buyers mostly turn a blind eye on them (Levin Sources 2017).

More initiatives from the demand side are needed (e.g. the Responsible Cobalt Initiative), but it is also critical that African governments themselves take a greater hold of their mineral wealth (including through legislation, and regionally coordinated action) to avoid the draining of SSA's rare minerals in exchange of a little payback.

3.1 Solar

The potential of solar energy in Africa is naturally high. The continent is located between latitudes 37°N and 32°S and spans a vast area that crosses the equator and both tropics. African countries receive a very high number of annual sunshine hours and the average solar irradiation is quite fairly distributed (though areas of Sahara, Sahel, the south-west tip of the continent and the horn of Africa are exceptionally sunny). This means that policy and financial restrictions aside, solar technologies could supply heat and power to virtually everyone, even the most remote communities.

Options for power generation from solar energy include utility-size PV (conventional or concentrated photovoltaic) and CSP (concentrated solar thermal power) as well as small-scale PV systems suitable for off-grid power generation. Figures 3.1 and 3.2 show the distribution of Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) in the subcontinent, respectively. The first one is commonly used as a reference of solar potential in general, as it sums direct and diffuse solar radiation, while the second one (i.e. its direct component) is indicative of CSP potential in particular (Box 3.2). While for PV there is no real lower applicability threshold—the feasibility of a project rather depends on the technology used and the specific design of the installation, in fact PV is also applicable at higher latitudes and colder climates—a CSP plant requires direct sun rays and a clear sky—so for CSP, deserts present ideal natural conditions.

Box 3.2: Estimating the Potential of Distributed Renewable Resources

Since renewable sources are highly distributed in nature (especially solar and wind), there are a number of physical limitations to be taken into account when estimating their technical potential and in turn their economic feasibility. Natural characteristics of irradiation, wind speed etc. can only be taken as a starting point for the evaluation of the suitability of a given technology.

There is a growing body of knowledge on the potential use of Geographic Information System (GIS) tools for renewable energy infrastructure planning and—particularly for Africa—electrification pathways. The basic procedure to come up with a geographical representation of renewable potential is the following: first, collecting data on the physical availability of resource (spatial distribution), then excluding zones that are not suitable for building infrastructure (e.g. water bodies, protected areas, etc.), finally determining a maximum limit to the distance from centres of consumption (e.g. cities) and existing grid infrastructure. Additional information of various nature can result in further geographical constraints, the establishment of priority areas (e.g. decentralised productive uses), coefficients to be applied (e.g. efficiency of production, power distribution losses), etc. A similar procedure can be adopted for determining the potential for biofuels but it has to take into account land use with a higher degree of detail.

It should be noted that such procedure is subject to a variety of assumptions and approximations (sometimes due to a heavy reliance on aggregated satellite data), which may result in overestimations or conservative assessments. This means that large scale maps—like those included in this book—need further processing in order to produce accurate estimates or to serve for real project siting. For the purpose of this book we only aim at giving a sense of magnitude of resource endowment, reporting estimates made by international organization such as the International Renewable Energy Agency and the World Bank, and inviting the interested reader to look for more detail in specialized literature.

Other than power, solar energy can be used to produce heat for domestic uses or non-intensive industrial activities (like textile that use low-to-medium process temperatures) as well as cooling (critical for remote hospitals and clinics). Crucially for rural communities, agricultural uses of solar (heat and power) include irrigation, food processing, and storage, and both CSP and PV technologies can bring desalination and wastewater treatment to communities where fresh water is scarce.

All these possible uses make solar technologies attractive for a number of sectors from energy generation, to agriculture, and water supply. The main limitations of solar technologies are relatively high costs—especially for CSP—and access to finance.

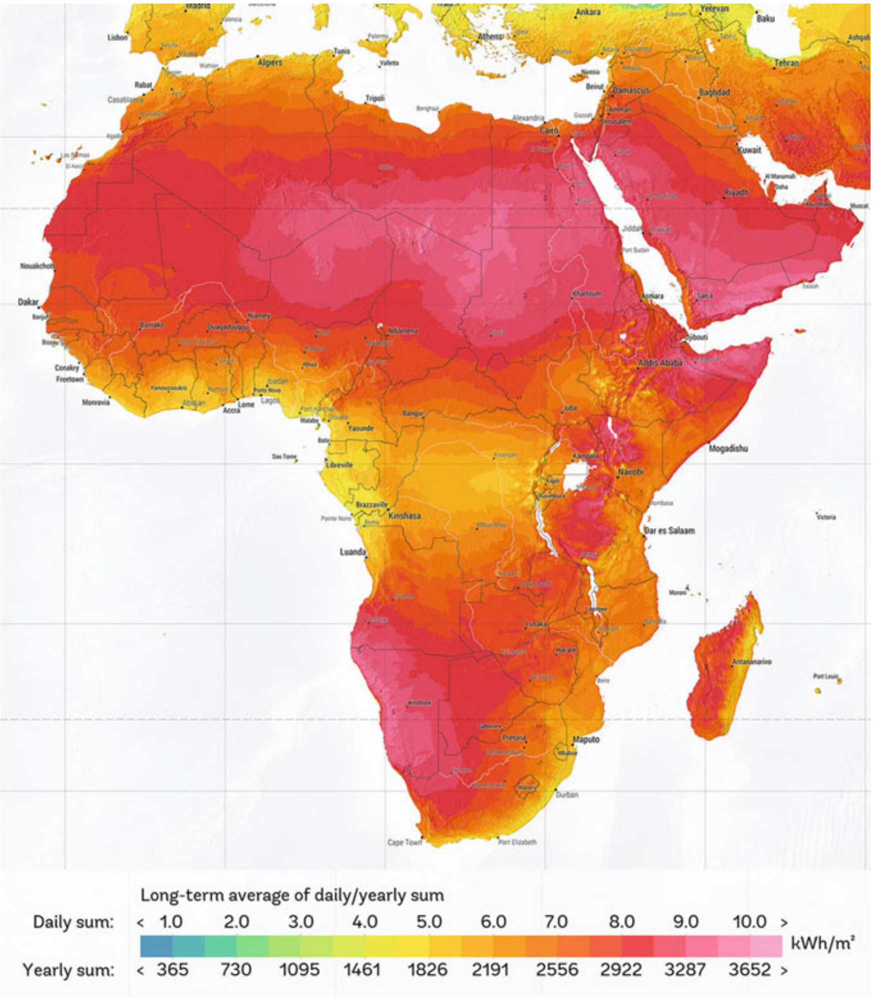

Fig. 3.1 Solar energy potential. Global horizontal irradiation. *Source* Global Solar Atlas, owned by the World Bank Group and provided by Solargis

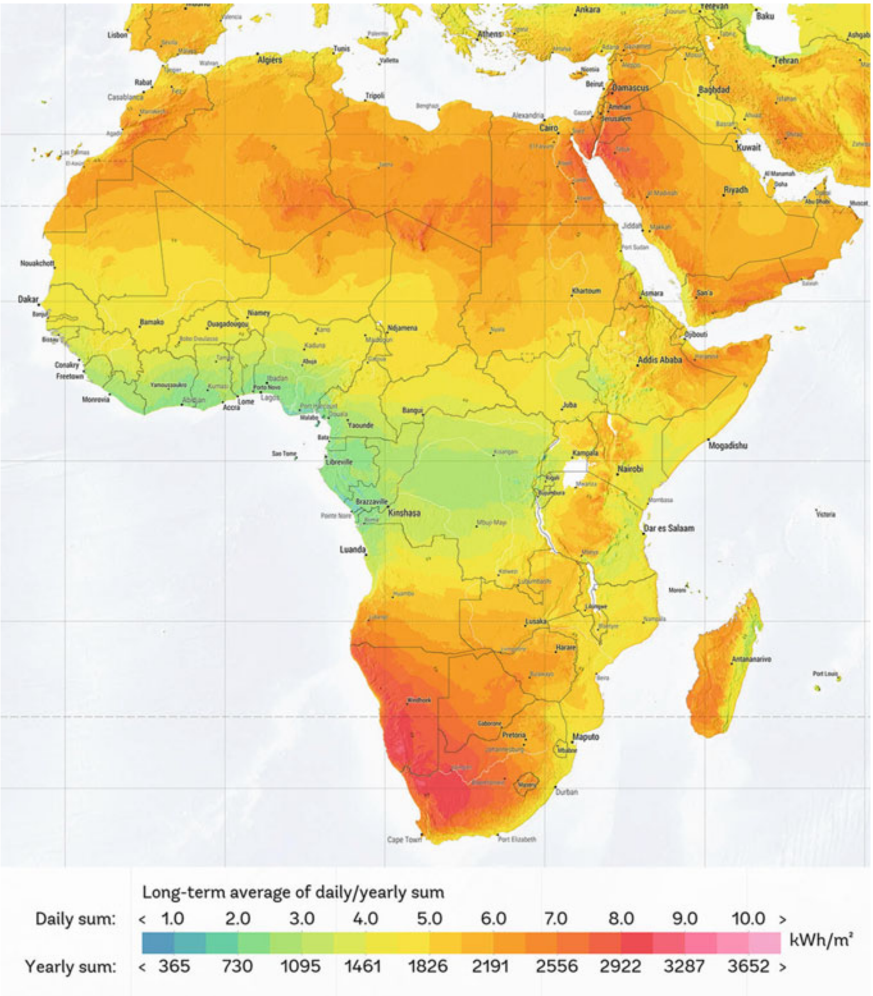

Fig. 3.2 Solar CSP energy potential. Direct normal irradiation. *Source* Global Solar Atlas, owned by the World Bank Group and provided by Solargis

Still, we are already witnessing a non-negligible rise in the deployment of solar largely driven by quickly falling prices of PV equipment.

The power capacity built in the past ten years consists of both large-scale plants (PV and CSP) and small scale (PV) (Fig. 3.3). While the latter represents a small share of the total capacity added, it is important to underline that PV-powered stand-alone systems and mini-grids are becoming the most popular (and cheapest) way of producing electricity far from the grid, and it is expected that off-grid rural electrification in SSA will be driven specifically by this technology (International Energy Agency 2017).

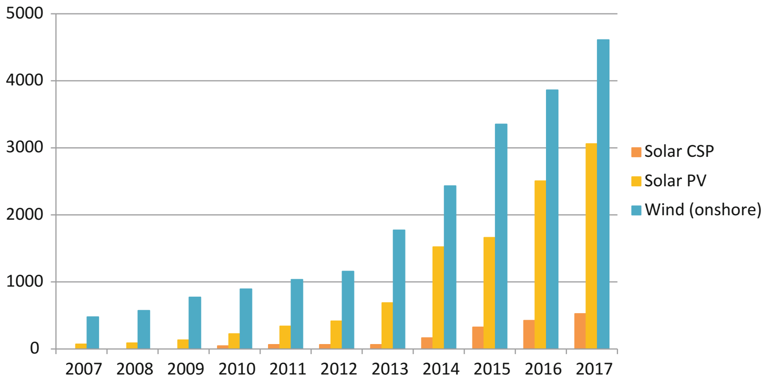

Fig. 3.3 Cumulative solar and wind power capacity installed in Africa (MW). *Source* IRENA database, accessed in April 2018

As of today, the five largest solar markets in Africa are South Africa, Morocco, Algeria, Ghana and Egypt (Tiyou 2017). Not surprisingly, the top of the ranking is occupied by South Africa and North African countries, not so much because of a real advantage in terms of availability of solar resource, but rather due to their strong policy commitment and investments. However several SSA countries are also picking up, with Ghana already an established market, and others increasingly committed, like for example Nigeria that recently issued the first African green bonds (Bloomberg 2017), and Kenya that is leading innovation in the field of micro-grids (TFE Consulting 2017) and stand-alone solar systems (Bloomberg New Energy Finance 2016).

3.2 Wind

Mechanical energy from wind turbines can be used to power a variety of mechanisms, like pumps for irrigation, or to produce electricity. While wind mills can be central assets for rural communities—and indeed they are widely used in some countries—here we talk about wind power turbines because of their potential to accelerate electrification in SSA. This means both large scale projects and small scale installations, which can be an integral part of a mini-grid together with solar PV, for example.

Compared to solar potential, wind potential is less fairly distributed across the continent. The main factor determining the geography of wind potential is wind speed, in turn highly dependent on pressure gradients and the shape of the landscape. Hence the presence of deserts, coastlines, and natural channels, all play in favour of high wind speeds. In Africa, the best wind quality can be found in the rugged regions of Sahara and Sahel (all countries, including the most central Niger, Chad, and Sudan), along the coast, and in mountainous areas of Southern Africa (particularly

South Africa, Lesotho, Malawi, Zambia), and in some parts of East Africa, especially in the horn of Africa and along the Great Rift Valley (Eritrea, Djibouti, Somalia, Ethiopia, Kenya, Tanzania) (International Renewable Energy Agency 2015).

The wind power density (a function of wind speed) showed in Fig. 3.4 is a measure of wind potential at a given height: here 100 m from the ground. As a rule of thumb 150–250 W/m^2 can be considered a fair value of wind power density, 250–350 W/m^2 is good, and over 350 W/m^2 is excellent (Renewable Energy Science and Technology). While this type of map is not suitable for project siting—other factors can significantly change the estimate at higher resolutions and using direct wind measurements—it gives a first indication of the varying potential of wind across the continent.

Similar to solar, we can observe an exponential growth of wind power capacity installed in Africa in the past ten years (Fig. 3.3) and point at the biggest five wind power markets that are driving this growth. They are South Africa, Morocco, Egypt, Ethiopia, and Kenya. Again, it is the strong commitment of these countries to renewable energy policy that is making a difference. Among these, Ethiopia and Kenya are relatively new players, the latter entering the ranks of top African wind producers with one single massive project (the already mentioned Lake Turkana, see Box 3.3), and the first with a number of smaller schemes that aim explicitly at working in tandem with hydropower production, given a lucky complementarity between dry seasons with higher wind potentials and wet seasons with higher hydro potential (Tiyou 2016).

Box 3.3: Lake Turkana Wind Power

Lake Turkana in Kenya is a very ambitious renewable projects: once completed, it will be the largest wind farm in Africa (310 MW of planned power capacity) and the largest single private investment in the history of Kenya (623 million euros) (African Development Bank 2014). However the project is also located in one of the poorest areas of the country. The wind turbines will be built scattered across a vast area (162 km^2 of which 0.02% will be physically occupied by the farm's facilities) that is a dry-season vegetation buffer for pastoralists, and this has sparked significant opposition to the project since its inception, which culminated in a legal lawsuit for lack of transparency in the procedure of land rights acquisition (Kamadi 2016; Critical Resource 2016).

As for the Lake Turkana project, many other potential wind and geothermal sites in Kenya practically overlap with areas that are vital for indigenous people, who are often nomadic and live in "community lands" (forests, grazing areas, and shrines) (Sena 2015). In fact, land tenure issues are a common reality for many large-scale renewable energy projects planned all over rural Africa and it is one that should not be ignored, given the potential conflict they could end up sparking.

The project in Lake Turkana is now moving forward with a particular emphasis on community engagement and consultation (and minimum fencing of land areas) (Lake Turkana Wind Power). The experience from this project shows that the development of large renewable energy projects in SSA put both developers and institutions in front of the need to ensure transparency and accountability—also as a means to manage investment risks.

In Africa, all of the wind power installed is found onshore because offshore solutions are generally more expensive (in fact, almost all of the offshore wind globally installed is located in Europe). However, it should be noted that offshore wind is generally associated with higher yields, and that the global industry is expanding (International Renewable Energy Agency 2016). Though at present there is a relative lack of offshore wind speed data to allow for a geospatial assessment of offshore wind potential in Africa (Mentis et al. 2015), it is clear that this resource is an asset to be considered by coastal countries (see for instance a feasibility assessment for a site in Nigeria (Effiom et al. 2016)).

Other offshore renewable energy technologies could also represent an asset in the future (e.g. wave energy, which theoretical potential in Africa is estimated at 3,500 TWh/year), however for now almost all of the technologies available to harness them are still at a conceptual phase of development and the global capacity installed today is negligible (Lewis et al. 2011). The only exception is tidal energy, which can be harnessed by underwater turbines and indeed one such project has been recently proposed in Ghana (CNN 2017).

3.3 Hydropower

Hydropower plants can be classified by the amount of capacity they produce or by the characteristics of infrastructural components of the single plant. For the sake of simplicity, here we distinguish only between large and small hydropower, meaning projects that give a major or minor contribution to power generation capacity and have a major or minor impact on water flows.[1] In reality, when it comes to water flow alteration, what makes a difference is the presence or absence of a dam or reservoir. Hydropower plants with little or no water accumulation are called run-of river. Most small hydropower plants are run-of river, but also some large ones, as long as they can count on high and stable flows like those of many tropical rivers. A plant counting on one upper and one lower dam can also serve as “pump-storage”, sending water up when there is a surplus of energy and releasing it when needed to supply peak-loads of demand.

Different sizes and types of hydropower plants bring about different issues, but overall large projects that exert a strong control on water and sediment flows have the biggest environmental impact. For very large water flows like those of some

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[1] Technically, a hydropower plant is considered large starting from a minimum of 100 MW, medium between 20 and 100 MW, and small from 1 and 20 MW (and mini, micro and pico for progressively lower capacities).

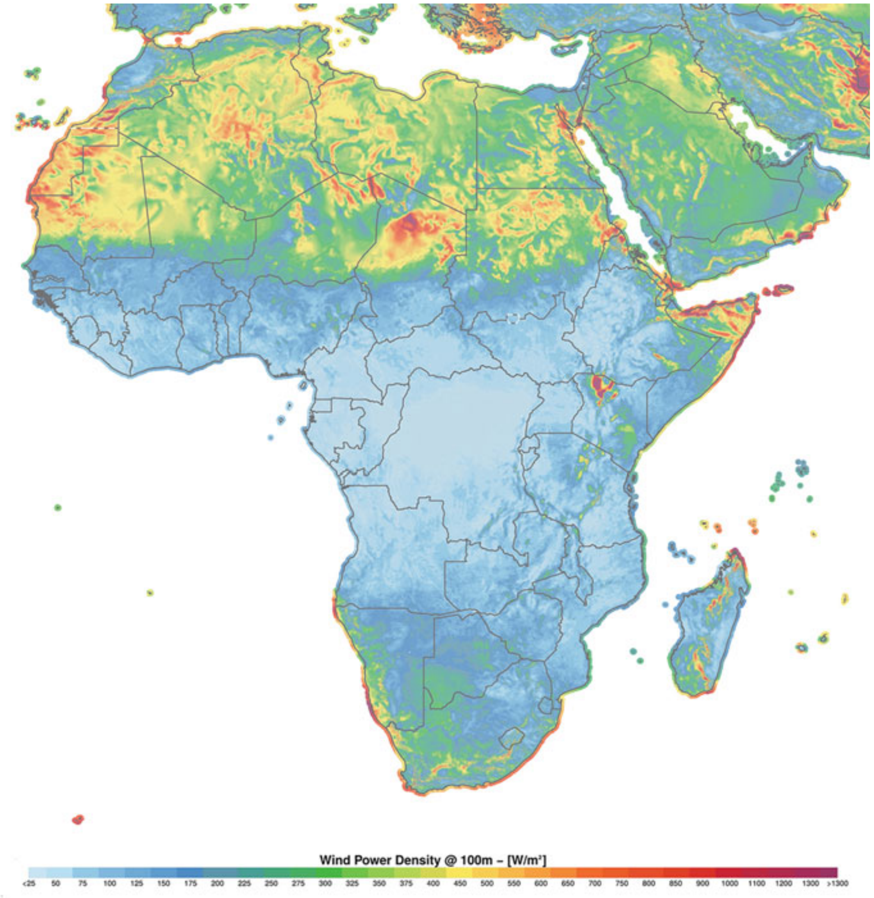


Fig. 3.4 Distribution of wind energy: wind power density (W/m2) at 100 m elevation. *Source* Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP)

African rivers, we are talking about mega projects with capacities of hundreds, if not thousands of MW (i.e. GW). Such projects raise high hopes for broad electrification, but they are also the most controversial and expensive ones.

With its major river basins (Congo, Nile, Senegal, Niger, Zambesi, Volta, Orange), SSA is endowed with a huge hydropower potential and the Congo basin alone—the largest in terms of water discharge—counts for 40% of the total. Most of the potential is found in Central Africa (Congo, Democratic Republic of Congo, Cameroon), but estimates are also noteworthy in East Africa (Ethiopia), Southern Africa (Angola, Mozambique, Madagascar) and West Africa (Guinea, Nigeria, Senegal).

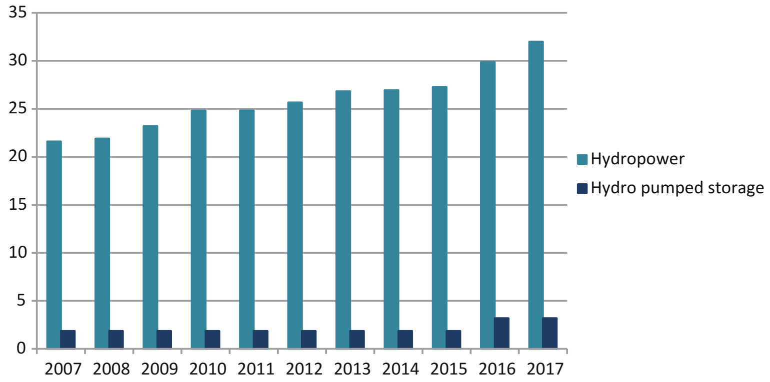


Fig. 3.5 Cumulative hydropower capacity installed in Africa (GW). *Source* IRENA database, accessed in April 2018

There is a huge gap between this potential and actual hydropower production in SSA: of the estimated 280 GW potential capacity, only 10% is currently tapped (International Energy Agency 2014). While Central Africa has the largest technically feasible hydro potential (570,730 GWh/year), it also has the lowest rate of utilization of this potential (3%). For comparison, North Africa has about one tenth of the technical potential of Central Africa (59,693 GWh/year) but produces a higher amount of hydropower.

Still—in Africa like in the rest of the world—hydropower is the most widely utilized renewable energy source. The total hydropower installed capacity in Africa is about ten times that of solar or wind, with new investments advancing with a more or less constant growth (Fig. 3.5) and it is expected that by 2030 hydropower will overtake coal as the fuel with the highest share of power production in the subcontinent (International Energy Agency 2017).

3.3.1 Large Hydropower

It is easy to understand the appeal of large hydropower for African countries that have the potential to develop it (see Table 3.3). Hydropower can produce a significant and steady supply of electricity, using an indigenous and renewable source, and counting on a well-established, low-carbon technology. Working as a baseload power source, it can serve the demand of cities and industrial areas. All of this at a relatively low cost: as of today hydropower still constitutes the cheapest option for electricity production on large scale in Africa (International Renewable Energy Agency 2018). Furthermore, the construction of a dam can serve multiple purposes including water supply, which in some areas is urgently needed to alleviate pressing issues of low access to water, sanitation, and irrigation.

Table 3.3 Hydropower capacity in countries where the total (installed and planned) is higher than 1 GW

Country	MW in operation	MW planned
Angola	1,346	5,639
Cameroon	736	10,784
Congo	287	14,090
Democratic Republic of Congo	2,398	47,361
Egypt	2,866	2,143
Ethiopia	3,812	25,570
Equatorial Guinea	120	920
Gabon	324	1,553
Ghana	1,580	554
Guinea	347	3,138
Ivory Coast	599	1,023
Kenya	818	1,313
Lesotho	73	1,204
Liberia	64	2,593
Malawi	349	661
Morocco	1,795	654
Mozambique	2,181	5,560
Nigeria	2,044	8,990
South Africa	3,554	20
South Sudan	0	2,147
Sudan	1,733	1,965
Tanzania	561	5,489
Uganda	630	2,726
Zambia	1,900	3,505
Zimbabwe	750	3,096

Source Author's elaboration on International Journal for Hydropower and Dams, 2017

All these reasons historically determined the fortune of large hydropower, as can be seen by looking at the number of African countries that rely on it for the biggest part of their generation: in many SSA countries the share of hydro in the electricity generation mix is significant, and can be as high as 99.9%. This is the case of Mozambique, Democratic Republic of Congo, and Zambia. (World Bank) (Fig. 3.6).

Today, the future of large hydropower is rather uncertain. Although it is clear that its characteristics make it perfect, in theory, to reach the twofold objective of increasing large-scale power capacity while balancing an increasing share of renewables, African hydropower developers are facing some practical challenges.

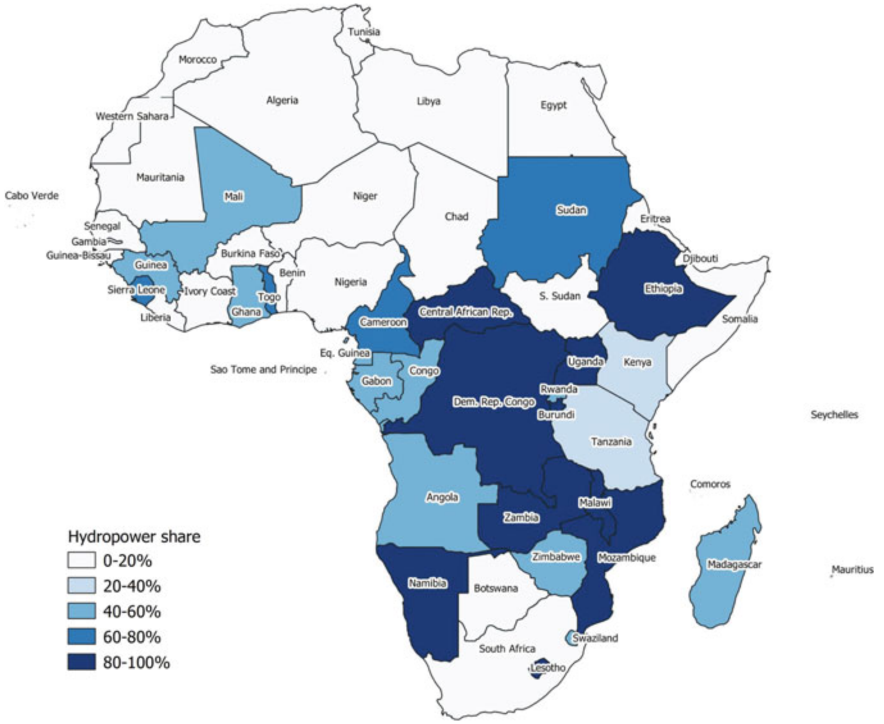


Fig. 3.6 Country dependency on hydropower. *Source* Author's elaboration with data from the International Energy Agency database, accessed in April 2018

The first is that there is an increasing public opposition to hydropower, particularly due to the environmental and social impact of large and mega dams, both on site and at transboundary level. Hydropower dams may require flooding large land areas, potentially displacing communities and reducing temporarily the flow of water available for other uses downstream, such as agriculture. In SSA these issues are particularly pressing: large shares of population count on the direct use of water resources for their livelihoods, and all countries rely to some extent on shared water resources (Grey 2002). It should be noted that the environmental impact of very large projects can be as far-reaching as to compromise ecosystems of global importance, such as the "Congo Plume", a major global carbon sink formed by the discharge of the Congo river in the Atlantic Ocean, threatened by the Grand Inga Dam project.

The second is the adverse impact of climate change, and rainfall variability, on hydropower generation. Several African countries are already experiencing severe power disruption as a result of low water levels in lakes and reservoirs. Major shortages recently hit for instance the huge Cahora Bassa in Mozambique (Bloomberg 2016), the Kenyan Sondu-Miriu and Masinga (Reuters 2017a), and Lake Malawi (Reuters 2017b). Over-reliance on hydropower adds to the weight of rain-fed agriculture in tying the economic performance of SSA economies to changes in rainfall levels (in contrast, for instance, with North African ones) (Barrios Cobos et al. 2008). From this perspective it is clear that not only needs the hydropower sector to adapt to climate change, but also the broader energy system has to diversify (Conway et al. 2017).

Last but not least there is the issue of funding, as these projects require large sums of upfront capital. Domestic markets may be too small to justify large investments, and at the same time poor regional interconnections remain a major impediment to the possibility of export. Nevertheless, since large hydropower remains a strategic resource for many countries, the sector is capable of mobilizing massive funds from a multitude of global, regional, and local investors. Notably the African Development Bank—i.e. the executing agency of the Programme for Infrastructure Development in Africa PIDA—explicitly supports hydropower as part of regional grid expansion projects aimed at the improvement of regional power pools.

It should be noted that due to often limited availability of public money, the hydropower sector receives significant funds from foreign lenders (most importantly China). In SSA, they may have a competitive advantage over multilateral development banks, who are bound to increasingly strict requirements that make them less reliable and more expensive than other lenders (this is the case of the World Bank that, after more or less a decade of stall in the 90s re-engaged with large hydropower in Africa but only after updating their standards and guidelines on social and environmental impact) (International Rivers 2013).

The most discussed mega projects in Africa today are the Great Renaissance Ethiopian Dam (GERD), under construction—which is already increasing transboundary tensions with Egypt—and the proposed Grand Inga on the Congo river—which, if built in its entire extent, would establish itself as the largest centre of power production in the world, in terms of capacity twice as big as the Chinese Three Gorges (see Box 3.3).

Box 3.3 Grand Inga

The big hydropower story of SSA is certainly represented by the Grand Inga Dam, a proposed hydropower dam complex on the Congo River at Inga Falls, in the Democratic Republic of Congo. This project, first envisaged by the Belgians in the 1950s, would alone have a capacity of 44 GW—a potential game-changer of the overall SSA's electricity scenario. Under the dictatorship of Mobutu Sésé Seko, the first two phases of the complex (Inga 1 and Inga 2) were constructed, totalling a combined capacity of 1.7 GW that still today represents a large share of the country's total installed capacity (2.5 GW). Over the last decades, the country has sought to further advance the Grand Inga Dam project. However, the project has systematically been delayed. Most recently, the government has fast-tracked the advancement of the third dam of the complex (Inga 3, with a projected capacity of 4.8 GW). In 2014, the World Bank approved a USD 73-million grant for the technical preparation of the project. However, it suspended this grant in 2016, as a result of a 'different strategic direction' taken by the government (World Bank 2016). The choppy development of the Grand Inga Dam project is an illustration of how difficult it is to advance large hydropower projects in SSA.

3.3.2 Small Hydropower

Small hydropower can be a key element of local development, because its production is stable enough to supply an industrial activity for the benefit of surrounding communities (notably in terms of irrigation and electrification). Of all off-grid options small hydro has the lowest electricity generation price, and it is probably the easiest to design, operate, and maintain. While not comparable to that of mega dams, the environmental impact of small hydropower is not negligible. Together, numerous small installations can bring major hydro-morphologic alterations to river courses as well as changes to habitats and land use, making production unsuitable to protected and biodiversity-rich areas.

Africa as a whole has an estimated small hydropower potential of 12,197 MW and some countries are particularly rich of it, namely Kenya, Ethiopia, Mozambique, Ghana, Angola, Cameroon and Nigeria (Fig. 3.7). Less than 5% of this potential (580 MW) is exploited and the countries with the highest utilization rates are once again South Africa and the North African region (UN Industrial Development Organization and International Center on Small Hydro Power 2016).

Small hydro infrastructure from the time of the colonies can still be found in several countries, although very often such schemes have fallen out of use due to aging, unaffordability of maintenance costs, or lack of interest from institutions (Othieno and Awange 2016).

3.4 Geothermal

Geothermal plants convert heat into electricity, using steam that is naturally stored underground. While deep heat resources are available everywhere, in some areas—near volcanoes, geologic rifts, and hot springs—they are more easily accessible. From the perspective of power generation, this technology has the key advantage of being dispatchable, which makes it a good complement to intermittent renewable power. Having said that, thanks to its low variable costs, geothermal is typically used to provide base load power.

Africa's known geothermal potential is concentrated in the East Africa, in the geologically active area of the Great Rift Valley, which extends from Djibouti to

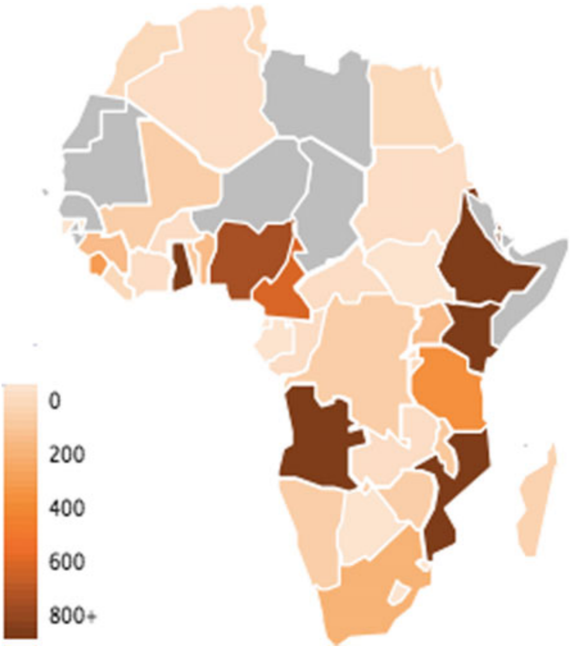
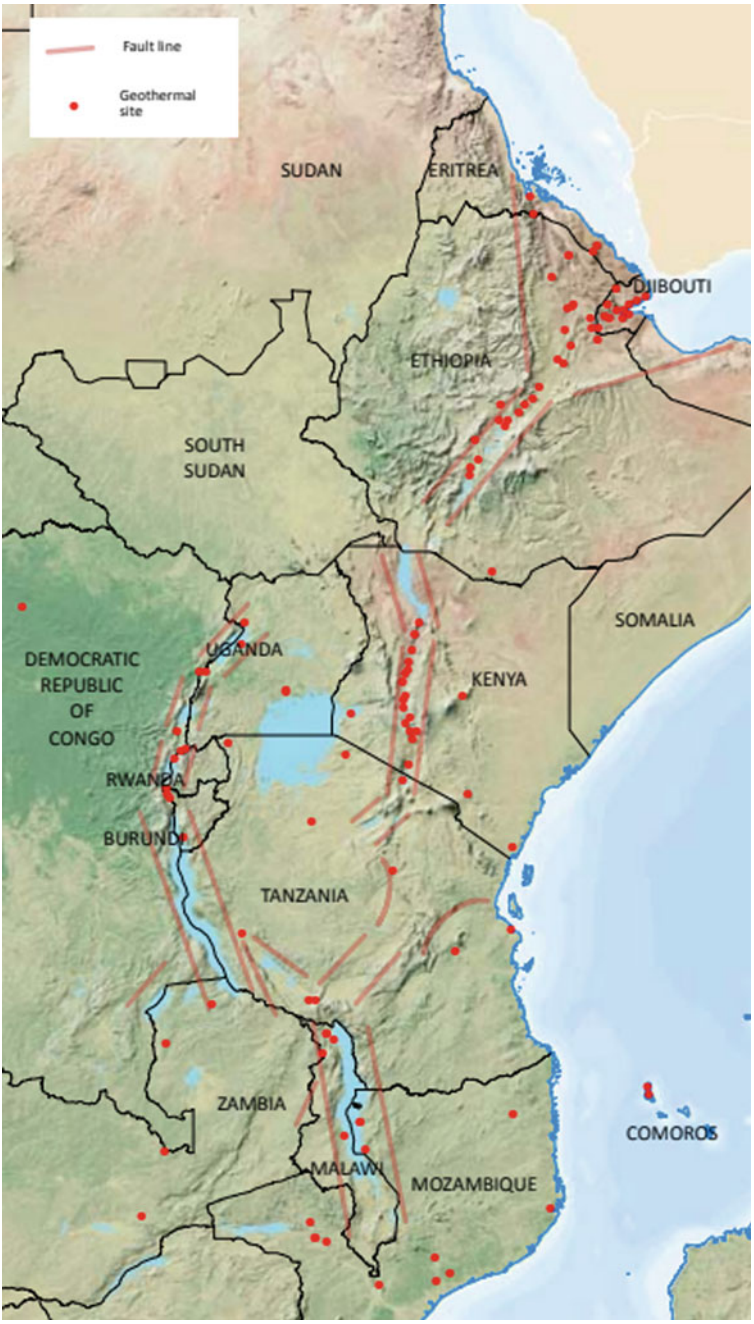


Fig. 3.7 Map of small hydropower potential (MW). *Source* The World Small Hydropower Development Report 2016. UN Industrial Development Organization and International Center on Small Hydro Power 2016

Mozambique (Fig. 3.8). The total potential geothermal capacity in Africa is estimated to be around 15 GW, of which only 0.6% is currently exploited. Almost all of the geothermal power installed is found in Kenya (600 MW) that grew in the past decade to become a global leader in the sector (REN21 2017; Think Geo Energy 2017). It is noteworthy that becoming the predominant source of energy in the country, geothermal has significantly increased the drought resilience of the Kenyan power sector, once over-reliant on hydropower.

Neighbouring Ethiopia also started harnessing its geothermal potential and is aiming at reaching 1 GW capacity in 2021 (Reuters 2017c), while others are more or less actively pursuing geothermal exploration and drilling. This is an expensive and economically risky process that has much in common with oil and gas exploration, in the sense that the exact potential of a geothermal site can only be known once the drilling has taken place (although unlike with oil and gas, electricity generation needs to happen on site because the steam cannot be stored and transported, potentially adding to the cost of project the element of long-distance transmission lines). This means that geothermal developers need significant support in terms of risk management from governments and donors (ESI Africa 2016).

As for solar, geothermal energy can also be used directly in industries that need heat at low temperatures (e.g. the flower industry in Kenya) although it is clear that in most places such direct uses may not be viable, and too complex. Geothermal can supply heat pumps for residential cooling and hot water production—and the current technology can potentially evolve into off-grid power generation (Richter


Fault line
● Geothermal site
SUDAN
ERITREA
DJIBOUTI
ETHIOPIA
SOUTH SUDAN
SOMALIA
DEMOCRATIC REPUBLIC OF CONGO
UGANDA
KENYA
RWANDA
BURUNDI
TANZANIA
ZAMBIA
MALAWI
MOZAMBIQUE
COMOROS

◂**Fig. 3.8** Geothermal potential sites in East Africa. *Source* Atlas of Africa energy resources (African Development Bank et al. 2017)

2016). Although these technologies are not yet widespread in Africa, it is easy to imagine that these could sustainably supply the increasing demand for heating and cooling of East Africa's growing cities.

3.5 Modern Bioenergy: Efficiency, Waste Valorisation, and Biofuels

Bioenergy can refer to heat, power, or a combination of them (Combined Heat and Power: CHP) produced from biomass. The initial feedstock can be processed to various degrees into usable solid, liquid, or gaseous fuels (e.g. pellets, charcoal, biofuels, biogas), however in Africa it is still overwhelmingly combusted directly, either for cooking purposes (and concurrently for heating and lighting) or, to a lesser extent, for industrial processes.

Figure 3.9 shows the percentage of tree cover on African land. During the past century, the consumption of wood has been steadily increasing in Africa and it is expected to keep on doing so, despite the efforts being made to reduce it. This adds pressure to forests that are often already threatened by deforestation due to urbanization and expansion of agricultural land (Africa Renewable Energy Access Program (AFREA) 2011).

As discussed (Chap. 2) the problem of widespread, inefficient use of solid biomass in households is linked to a number of factors, among which poverty and the geographical remoteness of rural population are only the most evident, hence the challenge of switching to efficient, clean, and environmentally sustainable[2] biomass use is not trivial. A multitude of opportunities exist and there are virtuous examples of innovation in Africa, though they are most often limited to local entrepreneurship instead of being part of wider, modern bioenergy policies. For wood and charcoal, the primary policy objective (besides fuel switching) is twofold: increasing the efficiency of combustion on the user side, and building sustainable value chains on the production side. The potential here is huge but policy efforts need to play out at many different levels, from the support to local markets for efficient cookstoves and high-efficiency fuels, all the way up to sustainable forest management. Considering that the wood and charcoal market in Africa employs tens-to-hundreds thousands of people, such policies could have a massive impact on rural development (Africa Renewable Energy Access Program (AFREA) 2011; GIZ 2014).

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[2] Establishing the sustainability of biomass production is necessary to be able to determine if biomass can be considered "renewable". Statistics are inaccurate however, and this forces analysts to take arbitrary assumptions, like considering industrial uses of biomass as sustainable as opposed to traditional cooking with solid biomass (International Renewable Energy Agency 2015).

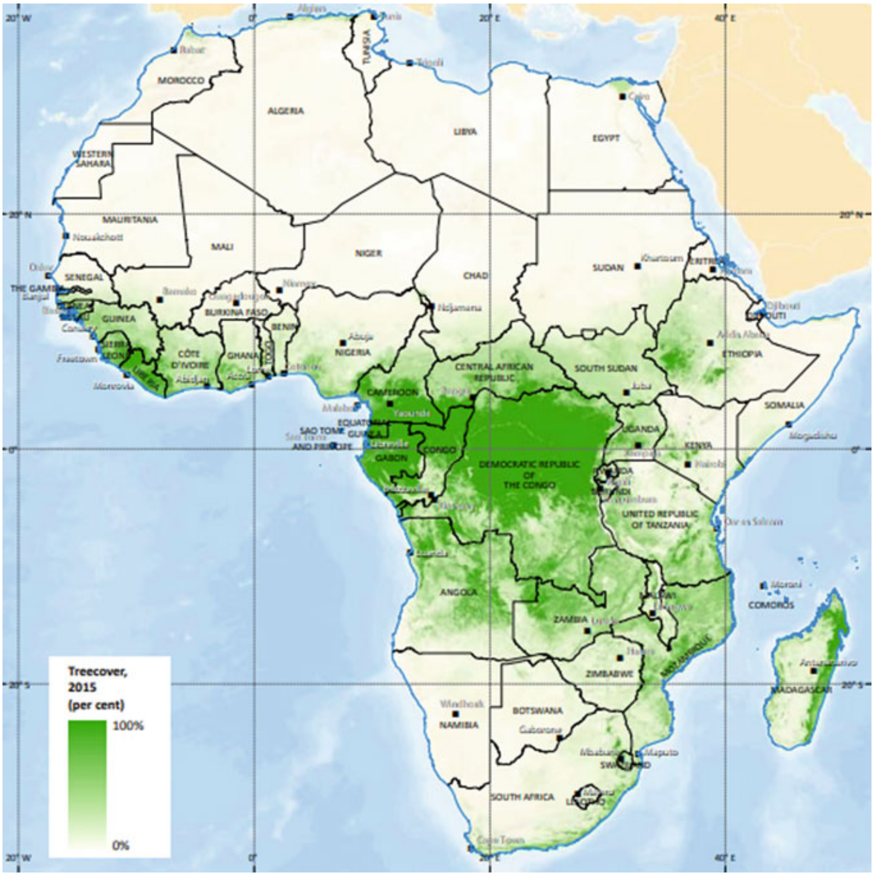


Fig. 3.9 Percentage of tree cover in Africa. *Source* Atlas of Africa energy resources (African Development Bank et al. 2017)

A large potential for bioenergy comes from waste and residues of various nature. Biomass and waste already provide around 30% of the thermal energy used in African industry (the rest coming from fossil fuels) but only 8% of this can be considered "modern"—in the sense that it is processed from residues that would otherwise be disposed of. In SSA, bagasse (i.e. the main byproduct of sugarcane processing) is the most commonly utilised feedstock for CHP production. Indeed, for sugarcane producing countries (e.g. Mauritius, South Africa, Egypt, Sudan, Kenya, Swaziland and Zimbabwe) bagasse can be really valuable as the cases of Mauritius and South Africa show, where sugarcane producers already produce more electricity than needed to cover their own industrial demand, selling their surplus to the national grid. CHP production holds significant potential also when it comes to the residues of wood processing and logging (IRENA estimates a total of 20 GW of potential power generation capacity from this sector), however this type of bioenergy is not yet widely adopted and there are only a few wood based power plants (about a dozen) scattered across the continent (International Renewable Energy Agency 2015).

When it comes to municipal waste, the potential in SSA is massive and so far basically unexploited. On large scales, valorising waste is not only a means of advancing renewables and energy efficiency, but also a clever way of solving the huge problem of waste disposal. Ethiopia seems to be leading the way, having recently announced the construction of the first waste-to power plant in the continent (UN Environment Program 2017). Considering the speed of urbanization in Africa it is clear that this type of solution will have a role to play in the future of many countries.

There are several open questions around the sustainability of bioenergy and its potential as a global climate mitigation solution. However, when it comes to SSA specifically, at least two considerations appear to be quite straightforward. First, as African forests are severely threatened, modernizing the bioenergy value chain (and adding value to the sector) could significantly contribute to better protect them. Second, given the importance of African forests as global carbon sinks, there are opportunities to value bioenergy efforts in the context of the UN Reducing Emissions from Deforestation and Forest Degradation (REDD+) support program—provided that they reduce pressure on forests or contribute to increase forested areas (Bertzky et al. 2012). Such opportunities could be further enhanced by appropriately recognizing REDD+efforts as carbon credits in international carbon markets (Bosetti et al. 2011).

The potential of using biofuels (e.g. bioethanol and biodiesel) in the transport sector of SSA countries is also significant. Biofuels can be first-generation, if the feedstock comes from crops that in some way end up competing with food production (e.g. vegetable oils, sugarcane), otherwise they are second- (e.g. bagasse, wood, waste) or third-generation (i.e. algae). As anticipated, estimating the potential of biofuels (particularly first-generation) is not an easy task: it is clear that the production of fuel crops in SSA, where malnutrition is widespread and food insecurity sometimes translates into famine, can be a very sensitive topic. Still, the potential can be estimated taking into account land competition. Methodologies may vary but some assessments are quite encouraging. IRENA estimates for instance that by 2050 liquid biofuels could meet and even exceed the fuel demand from the transport sector of Ghana, Mozambique, Nigeria, South Africa and Uganda, provided that dedicated policies are set up (International Renewable Energy Agency 2017a). All in all, the employment of biofuels as transport fuels would require a considerable effort from the side of policy makers because they compete with oil (and to a certain extent gas) that is a much better established and often subsidised (hence more competitive) option.

Finally, a special mention should go to biogas, as it valorizes waste-type feedstock and is highly versatile on the user side, hence it can be safely used for cooking. A product of the anaerobic digestion of organic materials, it can be produced from a variety of free (or low-cost) sources such as animal manure, agricultural residues, wastewater sludge, and municipal waste. Depending on the size, digesters can serve industrial uses as well as residential complexes. Once compressed, biogas can also be used for transport. In SSA, the technical potential of domestic biogas for cooking in rural households and for agro-industrial uses is substantial, and small-scale biogas production is already starting to take ground across the continent, particularly in Kenya and Ethiopia (REN21 2017).

3.6 Upscaling Renewables

This chapter so far showed that the potential for renewable development in Africa is as high as diversified, but also that harnessing it requires a dedicated effort. Given the potential renewable power and the broader benefits that electrification brings (Chap. 2), the next paragraphs look specifically at the challenges of upscaling renewables in the power sector. Considerations on upscaling clean cooking solutions are more scattered throughout the book, including at the end of Chap. 5.

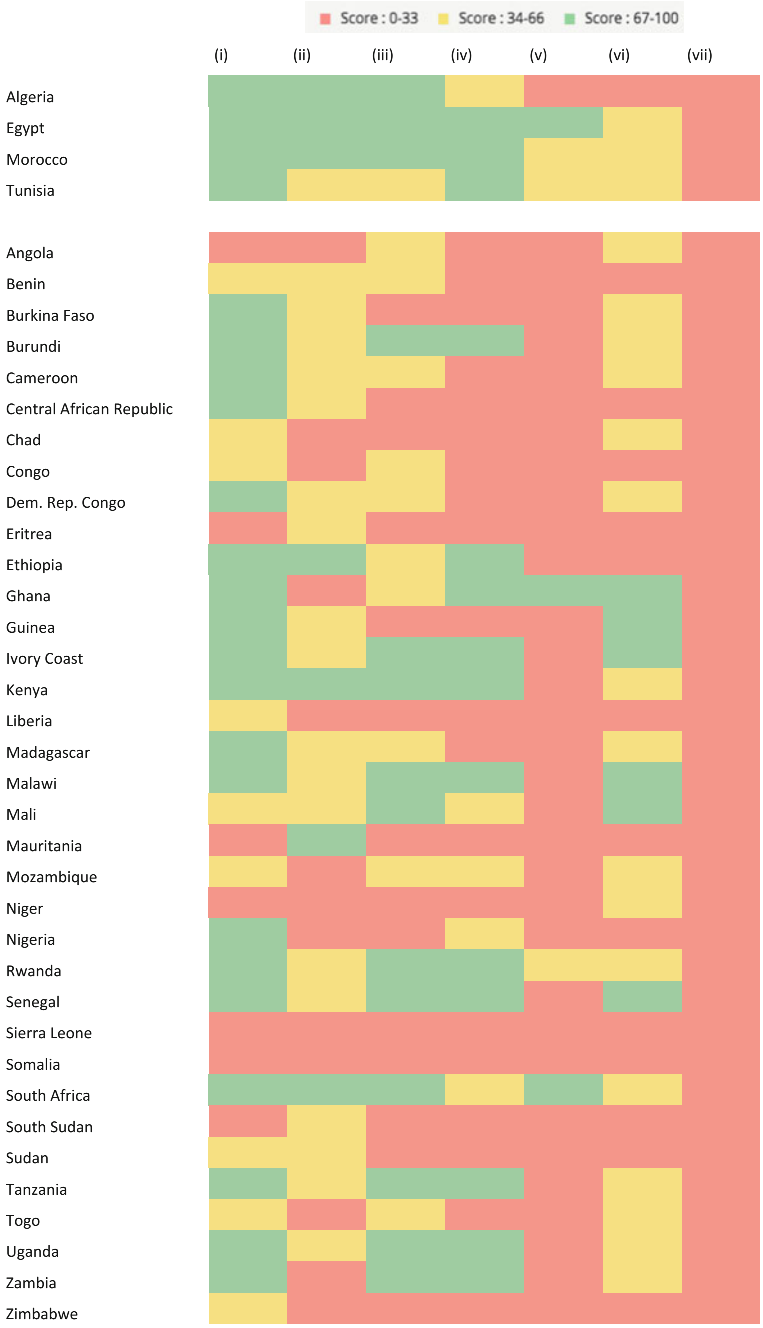
Not all countries can count on the same renewable sources, and some of them are unpredictable, or highly variable over time (e.g. daily, seasonally). This means that the development of renewables has to be planned in a way that maximises generation where the single resources are available, balancing at the same time their variability at the level of the grid.

The variability of renewable loads can be forecasted and subsequently managed by acting on the supply side (i.e. building up a reliable mix of technologies, introducing storage, or designing hybrid power plants) as well as on the demand side (e.g. through appropriate pricing schemes), while being able to respond fast to sudden interruptions at the source or unexpected peaks of demand—to avoid blackouts—may require a certain sophistication of grid management. Smart meters and fast-responding batteries may have an important role to play in this sense, although their uptake in SSA is currently constrained by the costs of equipment. As storage solutions make their first appearance (particularly for off-grid installations) and experts try to develop business models tailored to SSA utilities and users (Tsagas 2017), betting on hybrid solutions and matching complementary technologies can already go a long way to manage the variability of renewables on large scales.

One clear advantage of renewables is that they are widely distributed, which opens up opportunities for decentralised production of heat and/or power. To a certain extent, solutions can be developed fast by local entrepreneurs even without explicit governmental support for a specific technology, particularly at small scale, however it is fundamental that countries set up the most appropriate and effective policy frameworks to enable a systematic transition to modern renewables.

Comparing the experience of countries all over the world it is clear that there is no one-size-fit-all policy approach, and while the presence of some kind of framework is a prerequisite for renewable development, this may succeed or fail depending on a multitude of factors. The World Bank developed a tool called RISE (Regulatory Indicators for Sustainable Energy) to monitor specifically the status of policy frameworks to advance access to modern energy, and renewable energy in particular. Table 3.4 shows how African countries score based on a rather extensive list of aggregated indicators, namely:

Table 3.4 RISE country score for renewable energy policy framework, selected indicators (0–100)



🟥 Score : 0-33 🟨 Score : 34-66 🟩 Score : 67-100

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
Algeria	🟩	🟩	🟩	🟨	🟥	🟥	🟥
Egypt	🟩	🟩	🟩	🟩	🟩	🟨	🟥
Morocco	🟩	🟩	🟩	🟩	🟨	🟨	🟥
Tunisia	🟩	🟨	🟨	🟩	🟨	🟨	🟥
Angola	🟥	🟥	🟨	🟥	🟥	🟨	🟥
Benin	🟨	🟨	🟨	🟥	🟥	🟥	🟥
Burkina Faso	🟩	🟨	🟥	🟥	🟥	🟨	🟥
Burundi	🟩	🟨	🟩	🟩	🟥	🟨	🟥
Cameroon	🟩	🟨	🟨	🟥	🟥	🟨	🟥
Central African Republic	🟩	🟨	🟥	🟥	🟥	🟥	🟥
Chad	🟨	🟥	🟥	🟥	🟥	🟨	🟥
Congo	🟨	🟥	🟨	🟥	🟥	🟥	🟥
Dem. Rep. Congo	🟩	🟨	🟨	🟥	🟥	🟨	🟥
Eritrea	🟥	🟨	🟥	🟥	🟥	🟥	🟥
Ethiopia	🟩	🟩	🟨	🟩	🟥	🟥	🟥
Ghana	🟩	🟥	🟨	🟩	🟩	🟩	🟥
Guinea	🟩	🟨	🟥	🟥	🟥	🟩	🟥
Ivory Coast	🟩	🟨	🟩	🟩	🟥	🟩	🟥
Kenya	🟩	🟩	🟩	🟩	🟥	🟨	🟥
Liberia	🟨	🟥	🟥	🟥	🟥	🟥	🟥
Madagascar	🟩	🟨	🟨	🟥	🟥	🟨	🟥
Malawi	🟩	🟨	🟩	🟩	🟥	🟩	🟥
Mali	🟨	🟨	🟩	🟨	🟥	🟩	🟥
Mauritania	🟥	🟩	🟥	🟥	🟥	🟥	🟥
Mozambique	🟨	🟥	🟨	🟨	🟥	🟨	🟥
Niger	🟥	🟥	🟥	🟥	🟥	🟨	🟥
Nigeria	🟩	🟥	🟥	🟨	🟥	🟥	🟥
Rwanda	🟩	🟨	🟩	🟩	🟨	🟨	🟥
Senegal	🟩	🟨	🟩	🟩	🟥	🟩	🟥
Sierra Leone	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Somalia	🟥	🟥	🟥	🟥	🟥	🟥	🟥
South Africa	🟩	🟩	🟩	🟨	🟩	🟨	🟥
South Sudan	🟥	🟨	🟥	🟥	🟥	🟥	🟥
Sudan	🟨	🟨	🟥	🟥	🟥	🟥	🟥
Tanzania	🟩	🟨	🟩	🟩	🟥	🟨	🟥
Togo	🟨	🟥	🟨	🟥	🟥	🟨	🟥
Uganda	🟩	🟨	🟩	🟩	🟥	🟨	🟥
Zambia	🟩	🟥	🟩	🟩	🟥	🟨	🟥
Zimbabwe	🟨	🟥	🟥	🟥	🟥	🟥	🟥

Source World Bank, RISE website, accessed in December 2017
Note This list does not include a number of countries, for which data is not available

(i) Legal framework for renewables (existence of a legal framework for renewables; legality of private sector ownership of generation);
(ii) Planning for renewable expansion (existence of renewable targets and plans; extent of renewable energy in planning for generation as well as transmission; resource data and siting);
(iii) Incentives and regulatory support for renewables (existence of financial and regulatory incentives; transparency of legal framework; extent of grid access and dispatch);
(iv) Attributes of financial and regulatory incentives (predictability, efficiency, and long-term sustainability);
(v) Network connection and pricing (connection cost allocation; network usage and pricing; renewable grid integration);
(vi) Counterparty risk (payment risk mitigation; public financial statements; utility creditworthiness);
(vii) Carbon pricing and monitoring.

At a glance, it is clear that Africa, and particularly SSA, still lags behind when it comes to renewable policy (although it should be noted that the worst performing indicator indicating the absence of carbon pricing mechanisms (vii) is not particularly telling, as it simply reflects the global situation outside the OECD area).

Columns (i) and (ii) indicate that some countries lack quite basic requisites, such as the existence of a legal framework for renewable power producers, the availability of detailed natural resource assessments, or the presence of a clear renewable energy policy direction. For these countries, showing policy commitment by establishing clear targets and concrete plans for implementation is the very first step that needs to be taken to give a positive signal to investors.

Given the massive costs required to increase power generation capacity in Africa (see Chap. 5), the ability of governments to catalyse private funding for renewable energy projects is crucial. As much as renewables are increasing in competitiveness, private investors willing to develop renewable projects face significant costs and risks, and this is true for small-scale installations as well as for projects of regional significance. The challenge of governments is therefore to increase the confidence of investors through policy and financial de-risking measures. The existence and effectiveness of such measures can be seen in columns (iii), (iv), (v) and (vi).

For on-grid projects, setting up power purchase agreements (PPAs) with power generators by ensuring that they will have access to the grid as well as a fixed long-term price guaranteed for the power they will produce is considered a “cornerstone” on which further policy and financial de-risking measures can build upon (Waissbein et al. 2013). Essentially, this can be achieved with feed-in tariffs schemes (FITs) or through auctions. The main difference is that tariffs are pre-fixed by policy makers in the first case, while they are the result of a competitive bidding from the side of investors in the second. Both approaches have multiple declinations and while each one carries its own advantages and disadvantages, they can also co-exist, suggesting that there is ample room for manoeuvre in the design of a country strategy.

Especially in SSA, the final cost for users is a critical element that can compromise the long-term sustainability of energy investments, and renewables are no exception. This means that the presence of targeted subsidies, and cross-subsidies in particular, is necessary, and as this is in turn a fiscal burden for taxpayers, it becomes vital to uncover least-cost solutions.

So while FITs have driven the first wave of renewable energy investments in Europe, auctions are enjoying more popularity in developing countries and emerging economies all over the world (International Renewable Energy Agency 2013). Compared to FITs, they stimulate competition and in turn push forward the most cost-efficient projects (Fowlie 2017). African examples of countries that successfully implemented renewable energy auctions are South Africa, Morocco, and Zambia (International Renewable Energy Agency 2017b). One of the main risks of auctions is that they tend to favour larger and well established players, potentially compromising market efficiency in the long term. While this should not be a deterrent for their implementation (it is clear that in the context of SSA the priority is to increase renewable power generation capacity) it is important that such schemes are not only carefully designed, but also monitored and, if necessary, corrected.

If auctions are proving more effective in stimulating large-scale renewable energy investments, small-scale projects seem to find better backing in FIT schemes that do not require the investor to undertake expensive tendering procedures. This is particularly important for specific target groups that have little capital but a clear motivation to produce energy, such as farmer cooperatives or small industries. It is still possible to stimulate competition among small-scale investors by topping up FIT schemes with auction-based premium payments. In Uganda for instance, the latter is assigned on the basis of technical, economic, social, and environmental performance of the company (GET FiT Uganda).

The policy support required for off-grid renewable investments and mini-grid in particular can be even more complex than for grid-connected projects. While the final goal of an enabling policy is the same—boosting private investments in the sector—in this case the market is less mature and there is much less accumulated experience of successful policies to draw from. It seems too early to expect a private sector- led growth in the mini-grid sector, and yet it is already urgent to move away from donor-led, demonstration projects that do not stimulate entrepreneurship (UN Industrial Development Organization 2017). This requires explicit government support. In general, the subsidization of mini-grids can be strategic due to the positive social impact that they can have, but it is particularly reasonable when they actually represent the least-cost electrification option (TFE Consulting 2017).

For decentralised energy the willingness and ability of consumers to pay becomes a precondition for project feasibility, which puts productive uses—industry in particular—in a key position. In mini-grids, they can guarantee a long-term purchase of power to the generator or even decide to become power producers themselves. Still, the main purpose of off-grid solutions is to accelerate access among the poorest in rural areas, and it is important to make sure that investors manage to effectively address this need elaborating targeted pro-poor business models. In this case, policy makers should aim at building up an environment where entrepreneurship can flourish and, once again, setting up the appropriate legislative frameworks and enabling access to credit are critical moves. Today, the most popular models are distributed energy service companies (DESCOs) for mini-grids, pay-as-you-go (PAYG) for stand-alone, and microfinance in general, including for the provision of cookstoves (REN21 2017).

Being able to set up renewable energy policies and the related frameworks of implementation requires a great effort of governance. While it is important to maintain a whole-sector perspective to energy development—particularly when it comes to rural development, bioenergy, and waste recovery—renewable energy needs to be championed by appropriate institutions that have its development at the core of their mandate (i.e. Renewable Energy Authorities). As their task is both ambitious and socially significant, these organizations need to aim high in terms of objectives but also pursue transparency and accountability in the implementation of their agendas.

Good governance is also the fundamental prerequisite to get the bilateral and multilateral funding needed to develop large infrastructure projects. Especially when it comes to hydropower, international agreements will be needed to underpin water allocation agreements and, potentially, to define the roles of each country in financing and managing infrastructure. In general (independently form the technology) regional cooperation involving inter-state agreements can make large projects viable by aggregating demand to the level necessary for a viable commercial case for investment. It also offers opportunities to share the output and benefits among countries to address electricity supply deficits and support economic development.

In the long term, the possibility of manufacturing renewable energy equipment in the African continent for local and/or regional markets should be seriously considered (the cost of importing technology from overseas is significant, if not prohibitive for some countries) as well as strategic investments into assembling, operation and maintenance, and research and development (UNIDO 2017). It is important to underline that manufacturing of renewables does not refer to PV panels and wind turbines only: there is also an important unmet demand for less expensive equipment for biomass thermal power units, hydro turbines, and even clean cookstoves. Building a stronger renewable sector is also instrumental to the uptake of technological innovation. An interesting example is advanced thermal storage using molten salt batteries, an option that is particularly suitable for solar CSP and that is already a reality in South Africa and Morocco (Deign 2017).

African universities and research institutions are best positioned to develop the most appropriate technologies for the realities of the African continent. Because of its potential to stimulate local employment, the research and development of renewable energy technologies and the promotion of public-private initiatives should be strongly promoted by governments, national and international development agencies and financial institutions.

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