IRENA
International Renewable Energy Agency

Prospects for the African Power Sector

SCENARIOS AND STRATEGIES FOR AFRICA PROJECT

Executive summary

Electricity has become an indispensable prerequisite for enhancing economic activity and improving human quality of life. Agricultural and industrial production processes are made more efficient through the use of electricity. Households need electricity for many purposes, including cooking, lighting, refrigeration, study and home-based economic activity. Essential facilities, such as hospitals, require electricity for cooling, sterilisation and refrigeration.

Africa currently has 147 GW of installed capacity, a level comparable to the capacity China installs in one or two years. Average per capita electricity consumption in sub-Saharan Africa (excluding South Africa) is just 153 kWh/year. This is one-fourth of the consumption in India and just 6% of the global average. Nearly 600 million people in Africa lack access to electricity. Electricity blackouts occur on a daily basis in many African countries. Faced with this situation, people and enterprises often have to rely on expensive diesel power generation to meet their electricity needs, costing some African economies between 1% and 5% of GDP annually.

To meet its growing demand Africa has an urgent need to raise the level of investment in its power sector. Analysis of a range of country and regional studies suggests the continent will need to add around 250 GW of capacity between now and 2030 to meet demand growth. This will require capacity additions to double to around 7 GW a year in the short-term and to quadruple by 2030. The magnitude of the investments required is such that governments will need public-private partnerships in order to scale up investment in generation capacity. While access rates are improving in some countries, the business environment and policy framework are still not sufficiently robust to attract the level of private investment required to install the additional 250 GW by 2030. Many African countries are burdened by opaque policy frameworks and excessive red tape, while electricity subsidies and government mandated pricing often hinder sustainable business investment. Renewable power generation technologies alone will not meet Africa's energy challenges. For example the policy framework, manufacturing base, social issues related to energy need to be considered as well.

Africa faces a unique opportunity as nearly two-thirds of the additional capacity needed in 2030 has yet to be built. The continent can benefit from the recent global progress and cost reductions in renewable power generation technologies, to leapfrog the development path taken by industrialised countries and move directly to a renewable-based system.

Scenarios and Strategies: The Renewable Scenario

This working paper compares two scenarios:

- The Reference Scenario: This is a continuation of existing economic, demographic and energy sector trends and only takes into account existing policies. Universal electricity access is not achieved and access reaches only 43% in 2030.
- The Renewable Scenario: This scenario examines the impact of policies in Africa to actively promote the transition to a renewable-based electricity system to meet the growing needs of its citizens for electricity, to boost economic development, and improve electricity access. Importantly, this scenario achieves electricity access for all by 2030 and assumes concerted government action in the area of efficiency standards and programmes.

The Renewable Scenario highlights that if the right policies are in place, this could be a future path for least-cost development, particularly for bringing electricity access through renewable off-grid systems to millions of Africans currently lacking access to the grid. It projects that the share of renewables could increase to 50% in 2030, and to 73% by 2050. This scenario assumes that around four-fifths of all new capacity installed between 2010 and 2030 would be renewable, and that virtually all installed capacity after 2030 would be renewable.

The Renewable Scenario estimates an increase in the electricity system costs (investment and fuel) between 2008 and 2030 of around USD 700 billion (USD 32 billion per year), compared to the Reference Scenario. This increase includes the cost of achieving universal electricity access. However, in the long term the Renewable Scenario's undiscounted electricity system costs are USD 1 trillion (25 billion per year) lower than the Reference Scenario. These investment figures mask significant additional macro-economic benefits. If the local content of renewables projects can be raised, it will result in lower absolute costs per kW and improved balance of payments positions, as well as higher economic activity and sizeable job creation.

Barriers to implementation are project-specific and cannot be generalized. For large hydropower the size of single projects still poses a challenge whereas in the case of small hydropower the lack of viable business models is perhaps the greatest challenge. Many countries are lagging behind in the introduction of biomass, geothermal, solar and wind for power generation. However, this paper also shows both established and emerging areas of success. In cooperation with European partners and multilateral financing organizations solar resources in northern Africa are being developed, and a number of countries have started to harness their wind resources, including Egypt, Morocco, Kenya and South Africa. Kenya has also started an ambitious programme to develop its geothermal resources.

Africa: A land of renewable opportunities

Africa is endowed with vast untapped renewable energy resources that can provide electricity for all at an affordable cost. Large hydropower is the least-cost renewable energy solution today. It is followed by onshore wind, biomass and geothermal. Solar is currently more expensive, but has a huge potential and technology costs are rapidly falling.

Hydropower has dominated renewable power investment across the continent, but only generates 5% to 10% of the total technical potential, equivalent to 10% to 20% of the total economically feasible potential. The Grand Inga and Ethiopian hydropower projects stand out as large resources, but other countries in West and Central Africa also have great potential for large and small hydropower. The remaining hydropower technical potential is between 100 GW to 150 GW, but will require significant investment in transmission lines to connect projects to demand centres, and special attention to sustainability aspects.

Solar has by far the largest renewable resource potential in Africa, with high-quality solar resources available everywhere, except in the equatorial rainforest areas. There is large technical potential for concentrating solar power (CSP) and photovoltaics (PV) in Africa, and even under conservative assumptions it could meet demand, and even surpass it in 2050. The key factor holding back the development of solar in Africa is its price and its variability. However, rapid cost reductions are being achieved for solar PV, due to technological developments and an improving learning rate. As a result, annual capacity additions have been growing rapidly. At the same time, PV solutions for rural areas can play a vital role in enhancing off-grid energy access. The CSP market is small compared to the PV market. However, CSP offers interesting cost reduction opportunities and complements PV with the possibility of baseload (by using low-cost thermal storage) power generation.

This paper presents new resource potential estimates for solar and wind. The onshore wind resource in Africa is in the order of 1750 GW, far more than total African demand for the foreseeable future. Its quality varies, but the North-West Atlantic coast, the Red Sea, the Horn of Africa, South Africa and Namibia all have high-quality resources. Total African wind potential with a capacity factor above 30% exceeds 300 GW. This potential is virtually untapped today, as Africa's wind resource is just starting to be exploited. Certain exposed inland sites also show some good wind potential, but better mapping and data is needed. The full use of Africa's wind potential will require significant investments in the transmission system to connect these resources to demand centres.

The CSP, PV and wind resources of North Africa offer the potential for low-cost electricity production within the2050 time horizon. Exports of electricity to Europe, as proposed by the DESERTEC consortium, could help drive developments of renewable electricity in North Africa and provide valuable operating experience and cost reductions. Ultimately, initiatives such as the DESERTEC could result in 100 GW of renewable capacity producing 400 TWh of electricity for export to Europe by 2050.

The availability of high-quality geothermal resources in Africa is limited relative to that of wind and solar. The potential is still in the order of 7-15 GW and is concentrated in the East African Rift, especially in Kenya and Ethiopia. High-quality geothermal resources are an excellent source of low-cost, baseload electricity.

Currently, bioenergy is widely used in Africa for cooking and industrial use, but not for power generation. Power generation using bagasse residues is the largest source of power from bioenergy in Africa and could be expanded. Agricultural residues (e.g. rice husks) represent interesting opportunities, either through gasification (dry biomass) or anaerobic digestion (wet biomass). The co-firing of biomass in coal-fired power plants could also make a significant contribution in southern Africa.

Recommendations to accelerate the deployment of renewable power in Africa

The main goal of the Scenarios and Strategies for Africa Project is to provide insights into the opportunities and costs of a renewable energy development path. This working paper has identified a number of issues and policy areas that require attention, if the Renewable Scenario is to become a reality. In order to accelerate the deployment of renewable power generation, African energy ministers may consider:

- Developing clear and stable policy frameworks that enable the private sector to invest with confidence.
- Exploring opportunities for local manufacturing as a means to reduce capital costs, create local employment opportunities, and improve trade balances.
- Including renewables in economic development strategies, develop long-term energy sector scenarios and strategies, and develop business/entrepreneurship models for renewables and their productive use.
- Assessing the specific technology needs in Africa at the national level, and design strategies and roadmaps to tailor renewable technologies to local conditions and accelerate their deployment.
- Enhancing the mapping of renewable energy potentials (notably small hydro, biomass and onshore wind) and make the information publically available.
- Cooperating in the development of a continental electricity grid of sufficient capacity to connect remote renewable resources, improve security of supply, and to manage higher shares of variable renewable in the electricity mix.

Contents

1. Introduction

1.1. THE AFRICAN ENERGY CHALLENGE

With 5% of global primary energy use and 15% of the world's population, per capita energy consumption in Africa is only a third of the global average. However, the situation is even more serious than implied by these figures; once traditional biomass is excluded Africa's per capita consumption is just a sixth of the global average. The key challenges facing the African energy system are:

- **Access to electricity** needs to be **increased.** In 2009, 587 million Africans were still without basic electricity services.
- **Electricity supply** needs to be **expanded** rapidly and **reliability improved**. Per capita electricity consumption is low and outages frequent. Increasing supply and improving reliability will facilitate economic growth and increase incomes.

In 2009, 587 million Africans lacked access to electricity (IEA, 2011). At the same time, limited and unreliable energy access is a major impediment to economic growth. Unreliable electricity supplies impose direct costs on African economies in terms of lost productive output; while lack of access to electricity imposes significant costs on households and can limit economic, educational and social activities.

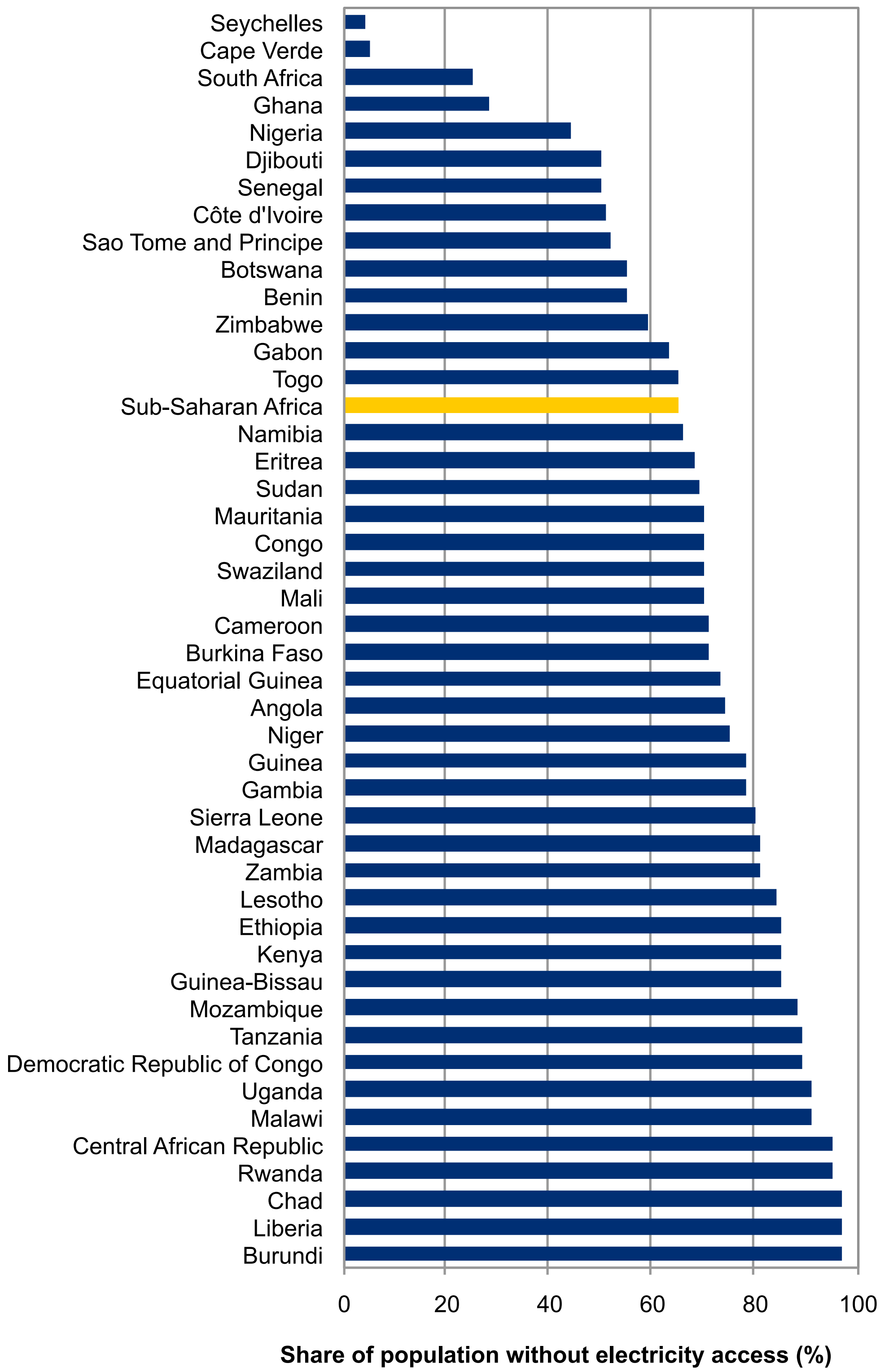
In the coming decades the population of Africa will grow faster than the global average, per capita energy use will increase and the energy mix will have to transition to modern fuels. These three factors will put tremendous future pressure on Africa's already struggling energy supply, but ensuring this transition occurs will be critical if growth in incomes and poverty reduction are to occur.

Improving electricity access, supply and reliability in Africa

Energy access is an important issue directly related to income and poverty. Access to modern energy rises from virtually zero for the lowest income quintile to 70% to 90% for the highest income quintile (Monari, 2011). While electrification programmes have improved access in some countries, many rural populations remain deprived of electricity. While northern Africa is virtually entirely electrified, the average electrification rate for sub-Saharan Africa is just 35% (Figure 1). It is especially low in rural areas (below 20%). In 41 countries in Sub-Saharan Africa more than half of the population has no electricity access. In a business-as-usual scenario the average electrification rate will barely rise between now and 2020 (Monari, 2011).

Average electricity use in Africa today is 620 kWh per capita. For sub-Saharan Africa without South Africa it was just 153 kWh per capita in 2009, which will rise to 235 kWh in 2020 in a business-as-usual scenario (Monari, 2011). In comparison, in 2010/11 India will consume 640 kWh per capita and the world average was 2,730 kWh per capita in 2009. Ensuring adequate electricity provision is a challenge for the power generation industry and policy-makers. However, the cost of inaction may be higher than increasing the electricity supply and improving reliability, because of the costs this imposes on African economies. Between 1990 and 2005, the poor performance of the power infrastructure retarded economic growth, reducing per capita GDP growth by 0.11% per year for Africa as a whole and as much as 0.2% in southern Africa (Foster and Briceno-Garmendia, 2010).

In sub-Saharan Africa, 30 out of 48 countries experience daily power outages. These cost more than 5% of GDP in Malawi, Uganda and South Africa, and 1-5% in Senegal, Kenya and Tanzania (Foster and Briceno-Garmendia, 2010). Diesel generators are used to overcome these outages and more than 50% of power generation capacity in the Democratic Republic of Congo, Equatorial Guinea and Mauritania, and 17% in West Africa, is therefore based on diesel fuel. The resulting generation cost can easily run to USD 400/MWh, which is significantly more expensive than most renewable energy solutions. **Reliable and affordable power supply is an essential prerequisite for economic growth. Electricity from renewable sources can play a key role in improving electricity supply in Africa (Holm, 2010).**



Note: Data for West African countries refer to 2010.

Figure 1: Share of population without electricity access in sub-Saharan Africa countries, 2007
Source: UNDP and WHO, 2009; ECREEE for West Africa.

There is good reason to be optimistic about the chances of improving electricity access in Africa, as there are some notable success stories where countries have made good progress in improving electricity access. Ghana has raised overall access from 25% in 1989 to 66% in 2011, with rural access rising from 5% to 40%. In South Africa, urban electricity access has risen from 30% in 1994 to 83% in 2010 and rural access has risen from 12% to 57% over the same period. In Morocco, rural electricity access has risen from less than 15% in 1990 to 97% in 2009 due to a combination of grid extension and the provision of photovoltaic (PV) kits to isolated villages. However, in many countries with rapid population growth, an increasing rate of access to electricity does not necessarily mean a reduction in the absolute level of population without access. Importantly, the success stories are generally closely linked to good governance. Countries suffering from political instability or conflict have fared less well in terms of electrification.

Successful implementation models for electricity access vary. In South Africa, the national utility Eskom has driven a utility-led approach. In Ghana, a self-help community electrification programme has been used, a model based on positive experience in Thailand in the 1970s. Foreign investment can also be important. For instance China is investing USD 700 million in Guinea's rural electricity system. But it should be noted that none of these countries are least developed countries (LDCs). In these very poor countries many are not able to afford electricity. This poverty is the core of the problem in Africa, as it undermines the sustainability of many electrification programmes. In many cases governance also poses a challenge and is a further brake on the rapid expansion of electricity supplies.

The cost of improving access to modern energy sources is large, but not insurmountable. Worldwide universal energy access by 2030 will require an investment of USD 34 billion (bn) per year over and above the baseline investments, with USD 32 bn per year extra for electricity and USD 2 bn for cooking fuels (IEA, 2011). About 60% of these additional investments (USD 20 bn per year) would have to be in Africa just for universal electricity access by 2030. In comparison, total African power sector investment including operation and maintenance is today around USD 50 billion per year (UNECA, 2011).

Today sub-Saharan Africa investments from the World Bank Group alone amount to USD 10 bn per year in the power sector: USD 2.27 bn for grid extension, USD 4.59 bn for grid-connected supply, USD 1.37 bn for off-grid renewable electricity, USD 1.07 bn for policy/regulation and USD 0.76 bn for the efficient use of electricity (Monari, 2011).

The challenges to improving energy access, increasing electricity supply and improving reliability of supply are not insurmountable, but will require co-ordinated effort to overcome the wide range of barriers that exist (Eberhard et al., 2008). Renewable electricity is not a silver bullet to achieve these goals, but it can help to overcome many of the challenges, because:

- Many solutions are modular and applicable even on a small village or household scale. This allows significant flexibility in supply expansion, reduces project lead times and complexity, and reduces the investment cost to smaller manageable increments.
- Decentralised solutions can be implemented in locations without grid access. In fact, renewables are often the most economic solution to expanding electricity access to remote locations. Access to electricity is often a precondition for economic activities, eg to cool agricultural products so they can be shipped to the market. In a separate study IRENA is looking into renewable energy for productive activities in Africa.
- In many cases, renewable solutions are the most economic supply solution even for grid supply. Africa is blessed with high quality renewable resources and continued cost reductions for renewable power generating technologies provide an opportunity to avoid the inefficient, fossil-fuel based industrialisation of OECD countries and leapfrog to systems dominated by renewables.

The renewable power generation opportunities in Africa are so good that in the long-run North Africa could even export electricity to Europe. Up to 15% of European electricity demand, which would be equivalent to 15% of African electricity production in 2050, could be supplied from solar and wind plants. The better quality of renewable resources in Africa creates an economic incentive in both continents for such a scheme.

1.2. GOAL OF THIS WORKING PAPER

The scenarios and strategies project for Africa at IRENA is ongoing. This paper provides early insights for the power sector in Africa. This analysis for Africa's power sector focuses on the period to 2030, with an outlook to 2050 to examine long-term issues that have an impact on investment decisions in the near future. Other IRENA work projects, such as those on renewable power generation costs, are essential inputs into the analysis presented here. Two scenarios are analysed: the Reference scenario and the Renewable scenario. The Reference scenario explores a continuation of ongoing energy sector trends while the Renewable scenario examines the impact of policies in Africa to actively promote the transition to a renewable-based electricity system

The main goal of the scenarios and strategies analysis for Africa is to provide insights into the opportunities and costs of renewable energy development pathways. The scenarios are not intended to be forecasts of what will happen, but rather allow the complex interaction of markets, costs, and other core drivers to be analysed in order to identify key trends, development opportunities and critical technologies or assumptions. This information is vital for long-term planning and investment decisions, as the results of different scenarios can be used to explore the sensitivity of different electricity development strategies to changes in costs, income growth, fuel prices, etc. The insights provided by the scenarios and strategies analysis show the usefulness of the tools. Further analysis and dissemination is planned in order to refine the proposed strategies and to allow feedback from the other IRENA sub-programmes to inform the analysis.

In the IRENA work programme, the analysis of scenarios and strategies is an important project in its own right, but will also feed into the "renewables readiness assessment" project, which will assess policy priorities and best practices in renewable energy policy development. This will in turn be the basis for the IRENA work on financing investment and capacity-building activities. This work will start with detailed renewable readiness assessments for Mozambique and Senegal.

In addition to being used as inputs to these other areas of work, the scenarios and strategies developed are also useful for country planning. This paper discusses results on a technology and a country/regional level. In 2012, the analysis and the tools developed will be rolled out through a set of workshops. Hands-on refinement for scenarios and strategies will help to build understanding and support among policymakers.

[1] *The other main reason is the continued insufficient investment in power supply, transmission and distribution, which has meant that consumers rely on their own diesel generators as backup when outages occur.*

The focus of the analysis in this working paper is limited to renewable energy and renewable energy technologies as a means to overcome the current and future electricity sector challenges Africa faces. Renewables are attractive for a number of reasons, but their use must be seen in the light of competing fossil-fuel energy options.

Given the pressing energy challenges Africa faces today, one may ask why policy-makers should be interested in issues that are many years or even decades away. The reason is that decisions now can entrench technology development paths that are very expensive to change later on due to the long lifespan of power generation assets. Moreover, the energy scene is changing rapidly. Just a decade ago, new oil-fired power plants were built in Africa based on the assumption that the low oil prices at the time would continue. In hindsight, this was a costly decision and highlights that the high dependence on diesel aggregates today is a consequence in part of insufficient energy planning in the past. 1 Scenario and strategy analysis is therefore a very valuable tool that can support the decision-making process and reduce the risk of expensive choices or energy shortages in the future.

Policy-makers need reliable, independent information regarding technology cost, the reliability of equipment, and recent and upcoming technological innovations that may affect their policies. This is important, given the large investment needs for power generation. Poor decisions can cost billions of dollars. **This project aims to provide accurate cost and potential data for renewable power generation, assess the contribution of different renewable technologies in different scenarios and outline the basis for a strategy that accelerates the deployment of renewable energy in the power sector.**

Scenarios to 2050, uncertainty and inputs

It is important to remember that the further out into the future scenarios go, the more speculative they become. The projections for 2050 are inherently very uncertain, especially in a rapidly evolving market such as Africa. The 2050 results that are presented here should be considered in the light of this uncertainty. The main benefits arise from identifying key patterns, the generation mix in different countries, critical assumptions, and the sensitivity of the results, rather than the absolute levels projected. However, despite these caveats, a long-term perspective is needed, because emerging issues and constraints need to be considered in decisions taken today, given that power plants can operate for 30 to 40 years.

The IRENA scenarios build on analysis that has already been undertaken for Africa. A number of energy scenario and strategy studies have been published in recent years and these serve as a starting point for the IRENA analysis. Studies with a continent-wide focus include the:

- Africa infrastructure study (Foster and Briceno-Garmendia, 2010);
- World Energy Outlook (IEA, 2010 and 2011); and
- Energy Revolution study (EREC and Greenpeace, 2010).

There have also been some country-specific studies and reports by regional organisations, including studies of:[2]

- North Africa (OME, 2008, and 2011b);
- South Africa (GSA, 2011); and
- Egypt (OME, 2011a).

These studies have helped to inform the analysis undertaken by IRENA and in some cases have provided guidance on input assumptions. However, these have only been a starting point, as the power sector analysis undertaken for Africa as a whole by IRENA is more comprehensive, detailed and up to date regarding the latest renewables technology insights than any of these other studies.

Many other country-level studies exist, but not all are in the public domain. Some are detailed energy system assessment studies, others are investment plans or technology needs assessments of varying levels of detail. A wide range of other sources of information and analysis has also been used to identify the current state of Africa's electricity system, the renewable resource potential, as well as many other factors that are vital to developing scenarios for Africa.

[2] *An overview of these studies is provided in an earlier IRENA working paper (IRENA, 2011a).*

1.3. THE AFRICAN POWER SECTOR TODAY

African power generation is dominated by fossil fuels (Figure 2). Coal, oil and gas together account for 81% of power generation. Hydropower accounted for 16% and other renewables accounted for 1% of total power generation in 2009.

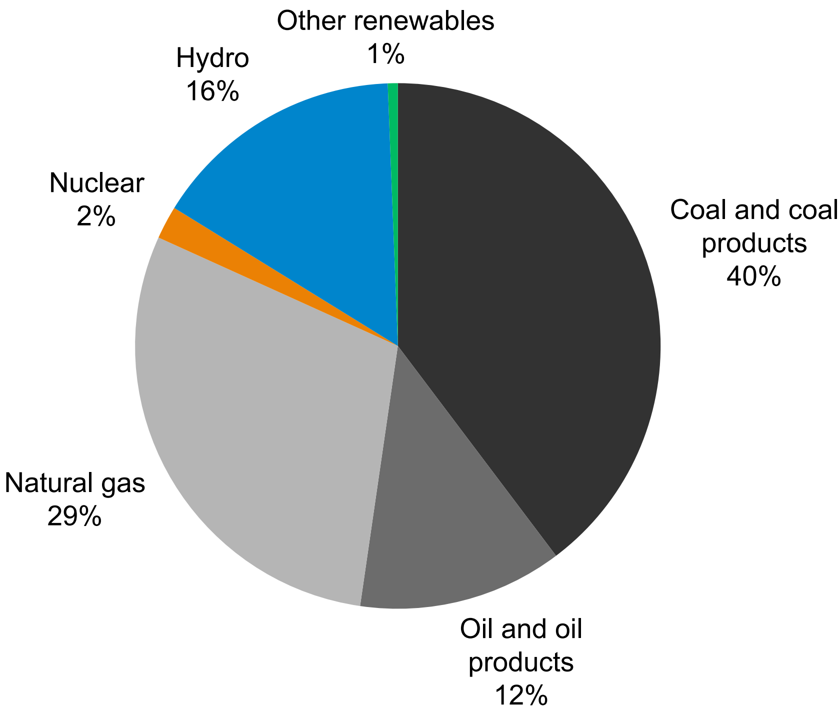


Figure 2: African power generation by fuel, 2009
Source: IEA database.

Africa had 147 GW of power generation capacity as of January 2011 (Platts, 2011). This includes 27.8 GW of renewable energy capacity, with hydropower accounting for 93% (25.9 GW) of total renewables capacity, equivalent to 18% of total power generation capacity (Figure 3). A total of 980 operational hydropower plants have been identified, with an average capacity of 26 MW. About 392 plants have a capacity of 10 MW or more (large hydro) and 588 plants have a capacity of less than 10 MW (small hydro). There are 46 wind farms with an average capacity of 16 MW. Bagasse-fired electricity plant dominates biomass power generation, accounting for 94% of biomass-based power generation capacity (123 plants with an average capacity of 7 MW). Finally, there are 14 geothermal plants with an average capacity of 15 MW.

Oil-fired power generation accounts for 17% of capacity and 12% of generation. This relatively high share, compared with the world average of 5% is partly due to the costly decision made by several African nations in the 1990s to

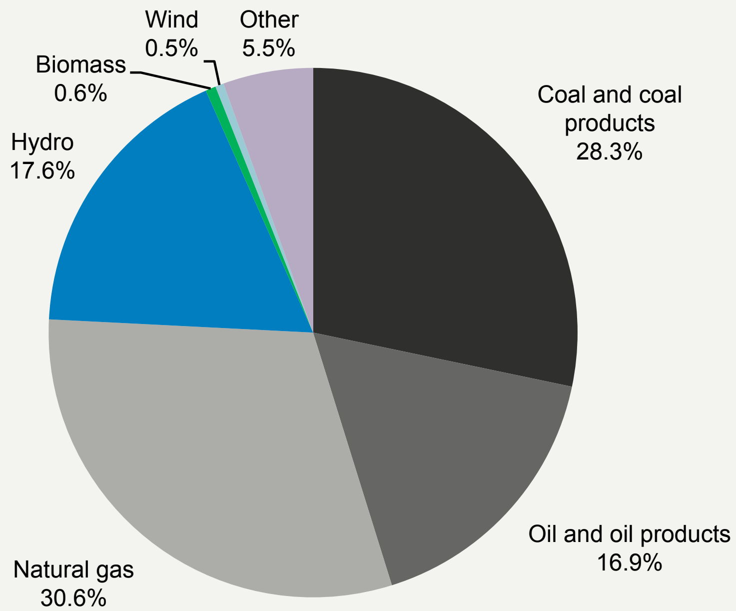
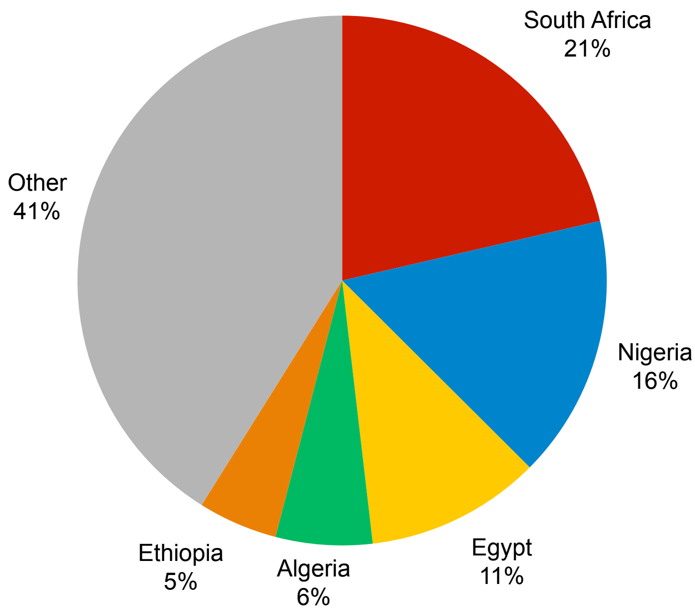


FIGURE 3: AFRICAN POWER PLANT CAPACITY SHARES
SOURCE: PLATTS DATABASE, 2011

build oil-based power plants when oil was cheap. Long-term, realistic price forecasts or scenarios would have shown that this was a very risky decision to make. Unfortunately, history may be repeating itself, as recent decisions to build new coal-fired power plant expose nations to significant risks surrounding future cost developments, particularly for fossil fuel prices and CO_2 price risk, given that the nature and scope of future CO_2 emissions regimes is highly uncertain. These risks may appear small in the short-term, especially for CO_2 prices, but coal-fired plants routinely operate for 40 years or more and much can change between now and 2050.

In the short term, five countries will dominate developments in the African power sector. Algeria, Egypt, Ethiopia, Nigeria and South Africa together account for nearly 60% of African primary energy use (see Figure 4). These five countries are therefore the subjects of in-depth analysis by IRENA (IRENA, 2011a). The energy sectors of the other countries in Africa play just as vital a role in the economic development of their countries, but their impact on total electricity consumption and generation trends is smaller. These countries are pursuing various policy goals. Morocco, for instance is seeking to become self-sufficient in energy, while most sub-Saharan countries are focussing on reducing energy supply problems, increasing electricity access and reducing energy poverty.

FIGURE 4: PRIMARY ENERGY USE IN AFRICA BY COUNTRY, 2009
SOURCE: IEA DATABASE.



1.4. ASSESSING THE RENEWABLE ENERGY POTENTIAL FOR POWER GENERATION IN AFRICA

The development of robust energy scenarios for Africa requires realistic estimates of the renewable energy potentials for each country in terms of installed capacity and energy production for each renewable energy source. The data required for this analysis has been extracted from initial analysis by IRENA of the renewable potential, supplemented by a wide range of external sources. The most detailed resource data available to IRENA has been compiled to provide detailed estimates of renewable energy potentials. These have then been aggregated to the country level. However, for simplicity the resource potentials are generally presented at the level of the five African regions covered in the analysis in this paper. The key sources for the renewable resource potentials used in the scenario analysis are outlined below:

- For **hydropower:** The potential is based on assumptions obtained from the 2010 Survey of energy resources, published by the World Energy Council (WEC, 2010).
- For **geothermal:** The literature provided a wide range of estimates. For the scenario analysis a total potential of 10 GW in the Great Rift Valley was considered feasible[3].
- For **bioenergy:** The potential estimate is based on a range of literature sources. The potentials used in the scenario analysis are possibly conservative, as they represent the lower end of a wide range.[4]
- For **solar** and **wind:** The literature did not provide suitable estimates for the analysis of these highly-distributed resources. The potentials used in the scenario analysis are therefore based on initial IRENA analysis of the highest resolution datasets available. The numbers that are shown in Table 1 reflect 10% of the technical potential[5] that has been identified and take into account competition from other types of land use.

Although point estimates of the energy potential of renewable for power generation are used, in reality, significant uncertainty exists and there is a wide range for the potentials (typically +/- 50%). The average potentials for renewable power generation by region and technology used in the scenario analysis are presented in Table 1. The largest potentials are for solar and wind. It should be noted that these are technical potentials based on a number of criteria and consideration of further limiting factors may reduce them.[6] The economic potential of each renewable technology is likely to be substantially lower than the technical potential in most cases. While these factors will not limit the use of solar (due to the massive resource available) regional limitations may emerge for wind, hydro and biomass in the long term. As for biomass, its potential will evolve over time depending on agricultural productivity and food demand and the outcome is uncertain. For biomass

Table 1: Technical potentials for power generation from renewables (Numbers are subject to uncertainty, typically +/- 50%)

	CSP	PV	Wind			Hydro	Biomass	Geothermal
			Total	CF 30%-40%	CF > 40%			
	(TWh)							
Central Africa	299	616	120	16	6	1,057	1,572	
Eastern Africa	1,758	2,195	1,443	309	166	578	642	88
Northern Africa	935	1,090	1,014	225	69	78	257	
Southern Africa	1,500	1,628	852	100	17	26	96	
Western Africa	227	1,038	394	17	1	105	64	
Total Africa	4,719	6,567	3,823	667	259	1,844	2,631	88

Source: Herman, et al., 2011; IRENA, 2011a.

and for hydropower, the resource potential might be affected by climate change. However, what is clear today is that the renewable power generation potential in Africa is very large compared to installed capacities.

This paper is not intended to provide detailed resource potentials by technology, but rather to identify realistic mid-points for a wide range of potentials based on a first estimate undertaken by IRENA. The adopted approach is deliberately conservative in order not to overestimate the potential and to ensure the renewable scenarios presented are robust. Ongoing work by IRENA aims to substantially improve estimates of the renewable resource in Africa by examining in more detail the data available and, as a result, being able to identify the quality and location of the renewable resources more precisely.

For the scenario analysis, it is the relative size of each renewable resource, its geographic distribution and its costs that are the most important factors. These factors have the greatest impact on the mix of renewables that is optimal for each country and region.

Calculating renewable power generation potentials for solar and wind

Given that this paper covers a whole continent, and only a limited amount of underlying data is available, an approach by exclusion zones has been used to simplify the analysis and calculations. Future analysis, based on more detailed spatial data sets, will make an approach by opportunities possible and should provide much more robust estimates.

The data for solar irradiation was provided by Mines ParisTech (with spatial resolution of 0.25 degrees) from the HelioClim-3 database. For wind, the data was provided by the private company Vortex (9 km resolution). IRENA was made aware of the uncertainty and limitations of these datasets by its partners. In particular, these spatial scales do not take into account local effects (micro-climates), which can lead to the actual conditions varying significantly from the potential implied by the data at this level of detail. This is a critical factor in explaining the wide range of uncertainty that must be placed on the current resource estimates.

The specific assumptions made for the exclusions zones were:

- The exclusion of any water bodies, protected areas, forested areas and built-up urban areas.
- In the case of CSP, the exclusion of all areas with a slope greater than 2.1 degrees.
- In the case of PV and wind, the exclusion of land with slopes larger than 45 degrees.
- For wind, only the onshore potential has been examined.[7]
- For solar and wind, any renewable energy potential 200 km or more from a city was excluded, due to the large distances to the consumer.[8]
- Areas with low wind speeds (less than 4 m/s on average) and low solar irradiation (below 1 500 kWh/m2/year for PV and 1 800 kWh/m2/year for CSP) were excluded.
- The spacing factor for solar energy is the ratio between the total area needed for a solar plant park and the area of the collectors alone.

The remaining available areas were converted into technical potentials by considering the possible density of installation, technical parameters and transmission losses. The technical parameters are listed below in Table 2. After all of these factors were taken into account only 10% of the remaining land was finally considered as available.

[3] *The literature suggests a potential of anywhere from 7 GW to 15 GW.*

[4] *For an overview of the data sources see IRENA, 2011a. The lower end of the regional range identified in the working paper has been used. It was assumed that one-third of the biomass potential would be available for power generation. Significant uncertainty exists over the true potential and IRENA has ongoing work to refine this dataset.*

[5] *Except in the case of the high-quality wind resource (e.g. with a capacity factor greater than 30%), where all of this potential has been included.*

[6] *Varying the underlying assumptions in the calculation of the technical potential would yield different results. Thus even technical potentials are highly dependent on the underlying assumptions made, as well as the quality of the available data on the resource (e.g. wind speeds at different heights, solar irradiation, etc.).*

[7] *Analysis of offshore wind is included in plans for future IRENA work on resource potentials.*

[8] *This is a relatively crude assumption and was made, in part, because no data was available to exclude based distance from the electricity network.*

Table 2: Example of the technical assumptions used for the calculation of solar and wind potentials

Solar PV

	Resource Availability	›	Solar cell efficiency	›	Transmission efficiency	›	Spacing Factor	›	Available Area	=	Technical Potential
	(kWh/m²/year)		*(%)*		*(%)*		*(-)*		*(km²)*		*(TWh/year)*
Example	2,000		15		85		3		100		

Solar CSP*

	Resource Availability	›	CSP plant efficiency	›	Transmission efficiency	›	Spacing Factor	›	Available Area	=	Technical Potential
	(kWh/m²/year)		*(%)*		*(%)*		*(-)*		*(km²)*		*(TWh/year)*
Example	2,500		Estimated power curve		85		5-9		100		

Wind energy

	Resource Availability	›	Wind production	›	Transmission efficiency	›	Estimated turbine density	›	Available Area	=	Technical Potential
	(average m/s)		*(MWh/y)*		*(%)*		*(MW/km²)*		*(km²)*		*(TWh/year)*
Example	7		Based on an estimated power curve**		85		14		100		

* Water availability for cooling and the cleaning of mirrors was not incorporated as a limiting constraint, but will be in future analysis.

** The theoretical power curve is based on an average 2 MW turbine with 80 m diameter and 80 m hub height to evaluate wind speeds.

[3] *The literature suggest a potential of anywhere from 7 GW to 15 GW.*

1.5. THE COMPETITIVENESS OF RENEWABLE POWER GENERATION

The cost of renewable power generation varies by technology, resource quality, project details, and site. The capital costs and the levelised cost of electricity (LCOE) of renewables have come down over time and, driven by learning effects, will continue to decline in the future. For each doubling of installed capacity, costs tend to decline by a fixed percentage – the so-called "learning rate". The annual capacity additions for most renewables are very large compared to the installed capacity, so costs are coming down rapidly. For instance, the cost of solar PV modules has declined rapidly in recent years driven by a learning rate of around 18% and a seven-fold increase in installed capacity between 2005 and 2010. This means that cost projections for renewables are not straightforward, as they depend heavily on learning rates and global capacity additions, not just capacity additions in Africa.

It is therefore vital to ensure that the model assumptions are based on the latest cost data available. For example, using estimates from 12 months ago would mean that evaluations would be based on wind turbines costs one-third higher than they are today and solar photovoltaic module costs almost twice as high as today's market price.

Costs for African projects tend to be higher than in other countries due to the need to import equipment, as well as higher internal transportation costs and import levies. There are often gaps in infrastructure, engineering and institutional capacity that can also raise costs. However, where components can be constructed locally, costs can be reduced significantly. For example this is the case for hydropower dams and the foundations and towers for wind turbines. However, when projects are located in remote areas, the cost of extending transmission systems must be added.

Important economies of scale exist in power generation projects. Larger plants tend to be cheaper per unit of capacity. Typically a size increase of one order of magnitude reduces the unit capital cost by half, although above a certain (sometimes low) threshold, this does not always apply to renewable projects.

Equipment from OECD countries tends to be more expensive than equipment imported from China and India. The quality, energy yield and the operation and maintenance costs of equipment may also vary significantly. Given some of the capacity and skill gaps in the operations and maintenance areas, there is an important trade-off to be made.

Increasing the local content of renewable power generation equipment

The drive to increase energy access in Africa has helped accelerate the deployment of renewable energy sources. However, the need to import much of the renewable power generation equipment required and the corresponding high equipment costs are a barrier to more rapid growth and local development opportunities.

Developing local manufacturing capabilities and increasing the share of local content for renewable power generation projects can help reduce costs and contribute to economic development. Some African countries are already taking the first steps towards creating economic value by promoting local equipment manufacturing.

Egypt has already a wind turbine manufacturer and is looking to develop further its local manufacturing plants for CSP and wind. It is expected that the current local content of the value chain will expand as knowledge and expertise improves. In West Africa, Senegal is working to strengthen the activities of SPEC is now looking to meet the demand of neighbouring countries such as Mali, Guinea and Niger. Opportunities to expand local content also exist in other countries such as Algeria, where plans to manufacture solar PV equipment in partnership with a German company could go ahead as early as 2014.

Other opportunities for local content abound in cabling, inverters, miscellaneous electrical components, etc. There are also significant options for greater African content in operations and maintenance, R&D, construction and engineering services. These will be critical to the rapid growth of renewables in Africa, as well as to their continued long-term operation.

A typical measure for cost comparison is the levelised cost of electricity (LCOE). This excludes any subsidies or taxes and treats all electricity as being equally valuable, be it supplied to meet baseload or peak load. It accounts for grid connection, but not the cost of grid integration (e.g. backup or storage capacity for variable renewables). At the same time, the impact of externalities is also excluded. LCOE is only one indicator of electricity cost. Different cost measures or different boundaries will yield different cost estimates.

Finance cost is also a key factor, given the capital-intensive nature of renewables. The scenarios assume a 15% (nominal) cost of financing for renewables although, with high political risk and high inflation, it may be significantly greater. However, concessional loans and risk guarantees can help reduce the cost of capital, which is often critical to the economic viability of renewable energy projects in Africa.

The cost of working capital can also be significant and can drive overall costs higher, particularly for large projects that require substantial infrastructure works and years of construction (e.g. hydropower dams). The longer the time between initial start-up of the project and completion, the higher the working capital cost.

As illustrated in Table 3, large hydropower has the lowest production costs. This is followed by biomass co-combustion (which has a more limited potential). However, this excludes the costs for grid connection, transmission and distribution. If these are added, the decentralised solutions are often as cost-competitive as grid-connected renewables. The LCOE of solar PV and CSP includes the cost of correcting for dust and heat impacts on their performance, as well as for the gradual degradation in equipment over time.

All options listed in Table 3 have costs below those of diesel generators, but most options have costs somewhat higher than for coal- or gas-fired power plants. However, this excludes any estimate of the costs associated with fossil-fuel price volatility, which has been high over a number of years. Renewable generation technologies do not face these risks. The smaller, modular nature of renewable solutions also has advantages. For example, renewable projects are more easily placed close to demand or to existing grid infrastructure, which reduces transmission costs and allows a more flexible expansion of capacity ensuring that plant does not run the risk of being under-utilised in the first years of operation. Another major advantage is that these smaller projects can be fully- or part-funded by households or small communities. Where utilities are constrained by lack of capital, this may be the only feasible way to ensure the expansion of a reliable power supply. Decentralised renewable projects can also be instrumental in reducing the risk of power outages and so help improve security of supply.

Table 3: Typical LCOE of renewable power generation technologies in good African conditions, 2010

	Investment cost	Capacity factor	Fuel cost	Electricity price[1]	Transmission and distribution cost
	(USD/kW)		(USD/GJ)	(US cents/ kWh)	(US cents/kWh)
Solar PV grid connected (85%PR)	3,000-4,000	0.2		24-37	3-7
Solar PV no battery	3,500-4,500	0.2		30-47	
Solar PV with battery (2.4 kWh/kW)[2]	5,000-6,000	0.2		45-65	
CSP grid connected no storage (90% PR)	5,500[3]	0.3-0.4		35-47	3-7
CSP grid connected 8 hrs storage (90% PR)	8,500	0.5-0.7		31-43	3-7
Large hydropower (above 10 MW)	1,000-2,000	0.5		4.5-9	3-7
Small hydropower (0.1 to 10 MW)	2,000-4,000	0.5		9-18	1-2
Pico hydropower Below 0.1 MW	4,000-8,000	0.5		18-36	1
Onshore wind (2 MW)	1,750[4]	0.25-0.40		10-16	3-7
Onshore wind (0.2 MW)	3,000	0.2-0.25		27-34	3-7
Biomass (bagasse boiler)	2,500	0.5	0.5-3	12-15	3-7
Biomass co-combustion in coal-fired power plant	1,250	0.75	1-5	5-9	3-7
Geothermal (high quality resource)	5,000[5]	0.8		14	3-7

[1] *Assumes 15% annuity plus 5% O&M. Excludes inflation and taxes/subsidies.*

[2] *Given a 20% capacity factor, a 1 kW panel produces 1,740 kWh. If half of the electricity is stored, evenly divided over the days of the year, 2.4 kWh of daily storage is needed. If battery discharge is limited to 25%, 10 kWh of battery storage capacity is needed. For deep-cycling lead acid batteries this costs USD 1,500.*

[3] *This compares to the USD 6,000/kW cost for 100 MW Shams-1 plant in Abu Dhabi.*

[4] *This compares to the USD 3,750/kW for the 100 MW Cape Town wind park project in South Africa and USD 2,175/kW for the 300 MW Turkana wind park project in Kenya. This includes all project costs (AFD, 2011).*

[5] *This compares to the USD 7,000/kW cost for 185 MW Olkaria expansion project in Kenya (AFD, 2011).*

Source: IRENA, 2011b and IRENA analysis.

Table 4 provides an overview of the capital cost projections for the period 2010-2050. Significant cost reductions are foreseen that will make renewables more competitive than they are today. Deployment policies will add more capacity and accelerate these cost reductions through learning effects. The lower end of the price range accounts for supportive policies in Africa and worldwide, while the upper end assumes that Africa only benefits from learning effects in other parts of the world. African governments can also help to reduce costs and promote local economic development by implementing a policy environment that fosters a competitive local industry for equipment supply and for the production of basic materials commodities that will be used in renewable power generation technologies. Costs may be higher than indicated in Table 4 where significant transportation costs for equipment are necessary, such as in landlocked countries. On the other hand recent price data for wind turbines in China suggest that for this technology the cost reduction could be even bigger than indicated in the table.

Table 4: Renewable capital cost projections by technology, 2010 to 2050

(USD/kWh)	2010	2015	2030	2050
Solar PV (utility-scale)	3,000-4,000	2,850-3,000	2,200-2,450	1,800-2,100
Solar PV (home system)	5,000-6,000	4,500-5,700	3,600-4,100	2,200-3,500
Solar CSP (with 8 hr storage)	8,500	6,000-6,500	4,200-5,100	3,000-4,400
Wind (2 MW turbine)	1,750	1,700-1,800	1,400-1,700	1,100-1,300
Biogas engine (incl digestion)	2,000	1,800	1,500-1,700	1,200-1,500
Biomass gasification	2,000	1,800	1,500-1,700	1,200-1,500
Biomass co-combustion	1,250	1,250	1,250	1,250
Hydro	3,000	2,700-2,900	2,300-2,800	2,000-2,700
Geothermal	4,000	3,600-3,900	3,000-3,250	2,400-3,000

Note: Figures do not account for equipment transportation costs to remote locations in landlocked countries or for import tariffs.

2. Status and outlook for key renewable power options

Table 5 provides an overview of existing renewable power generation capacities and the new capacity additions that occurred in 2010. Hydropower clearly dominates, both in terms of cumulative installed capacity and in terms of capacity additions. However, significant future growth is foreseen for wind and solar. Shorter lead times for solar (particularly PV) and wind projects also mean that capacity additions can be ramped up very quickly if the right policies are in place.

Table 5: Existing capacity and capacity expansions in Africa, 2010

	Existing capacity (GW)	Capacity additions (GW)
Hydropower	23.5	2.5
Wind	0.77	0.21
Biomass bagasse	0.85	n/a
Geothermal	0.2	0.04
Solar-PV	0.1	n/a
Solar-CSP	0.064	-
Total	25.62	2.71

Source: GWEC, 2011; Sun and Wind Energy, 2011.

2.1. Hydropower

Total hydropower capacity in Africa in early 2011 was around 26 GW (Platts, 2011). The untapped potential for large projects is mainly concentrated in the lower Congo River and the upper Nile. The total remaining technical hydropower potential is estimated to be around 1,844 TWh, which is 18 times higher than hydropower generation in 2009. About half of this potential would be economic under current economic conditions (100-150 GW). Hydropower can be divided into large hydropower (>10 MW) and small hydropower (<10 MW).[9] A further split is possible into dam-based (with water storage) and run-of-river projects (without water storage [10]).

he Grand Inga project in the lower Congo has a potential of around 44 GW, with just 1,775 MW currently installed. The potential on the upper Nile River is also very large, with a potential of 30 GW in Ethiopia alone. Further potential exists in the other tributaries of the Congo (6 GW in Gabon) and the Niger (10 GW in Nigeria), as well as in Angola (18 GW) and Mozambique (12 GW). Small hydropower potential can be found in many hilly locations in West, Central, East and southern Africa. The economic potential of hydropower is much smaller than the technical potential, but is still enough to allow hydropower to provide a significant share of total African power demand. The dam-based hydropower potential will, through its electricity storage potential, also play a vital role in facilitating the growth in other variable renewables such as wind and solar. In addition, pumped hydro could be used as an option for electricity storage.

Large hydro

The Grand Inga series of projects is a proposed series of hydroelectric dams on the Congo River at the Inga Falls in the Democratic Republic of the Congo (DRC). [11] If completed it could be the largest hydropower project in the world. The first phase, Inga I, was commissioned in 1972 and involved the construction of three power stations in the Nkokolo valley with a total capacity of 351 MW from six turbines. Inga II, with a total capacity of 1,424 MW from eight turbines, was commissioned in 1982. However, due to lack of maintenance these existing plants are currently operating at a capacity of just 875 MW (Le Monde diplomatique, 2011). Repairs and infrastructure enhancements are ongoing, funded by the World Bank (WB) and the African Development Bank (AfDB). However, progress is slow and the renovation of 10 turbines at Inga I and II has twice had to be postponed as the WB has been unable to find sufficient funds. The renovation of all the Inga turbines, originally scheduled for 2012, may now not be completed until after 2016.

The Inga III dam has a proposed total capacity of 3.5 to 5 GW from 16 turbines and is at the project design phase, but if completed would become the biggest hydropower project in Africa and the fifth-largest in the world. High voltage lines will transmit the power generated to Zambia, Zimbabwe, the Republic of South Africa and the Republic of Congo (Brazzaville). The Inga III dam could cost USD 8 to USD 10 billion (USD 1,300 to USD 2,000/kW) although it faces some tough technical choices and the engineers are still trying to decide on the optimal design (Reuters, 2011).

[9] *Small hydropower systems less than 0.1 MW are sometimes referred to as "pico hydropower" systems.*

[10] *It is also possible for dam-based systems to have very little storage, with the possibility of shifting flows only over several hours.*

[11] *The Grand Inga falls have a flow of 26,400 cubic metres per second. The fall height is 102 metres (m) and the water head height is 150 m.*

The proposed Grand Inga dam is at the feasibility assessment stage, but current plans are for a generating capacity of 39 GW from 52 turbines of 750 MW capacity. This is would make it significantly larger than the Three Gorges Dam, which is currently the largest energy-generating project ever built. The project would cost as much as USD 80 billion to complete (assuming USD 2,000/kW)[12] and would supply more electricity than the DRC could use, and significant amounts of electricity could be exported. To complete Inga III by 2020 and the first phase of the Grand Inga projects by 2025 (initial capacity 6 GW, rising to a potential 44GW), the Congolese government needs to raise USD 22.1bn. DRC and South Africa have recently signed a Memorandum of Understanding establishing a partnership between the two countries for the phased development if Grand Inga.

The Grand Inga hydropower projects offer enormous opportunities for Africa. The scale and stability of flow of the Congo River make it one of the world's most favourable hydropower sites. The number of people currently living in the project area is remarkably low. There are also many possibilities for associated development, particularly the use of the water for irrigation. At the same time, if the projects can meet sustainability objectives, their stepwise development offers an excellent opportunity for Africa to acquire and retain the hydropower expertise it currently lacks.

The second largest hydropower potential is on the Nile River, with 30 GW of hydropower potential in Ethiopia alone. However planning is much more complicated because of downstream water scarcity. The Nile is the only large freshwater source for Egypt and the Sudan and upstream Nile countries have recently unilaterally re-written a Nile water-sharing contract dating back almost a century and giving Egypt the right to the lion's share of the Nile river water. [13] This is a potential source of conflict and the value of hydropower energy plays an important role in driving this dispute.

In February 2010 Ethiopia inaugurated a USD 360 million, 300 MW (four 75 MW Francis turbines) Tekeze project that was built with Chinese help. It has the tallest arch dam in Africa at 188 m, used a double curvature concrete arch design to minimise the amount of concrete needed, and created a reservoir 70 km in length. A 230 kilovolt (kV) double-circuit transmission line 105 km long was constructed through mountainous terrain to connect the project to the Ethiopian national grid.

Ethiopia has decided to finance its largest hydropower development to date, the 5.25 GW Millennium Hydro Power Project, on its own. The dam will be built in the lower catchment of the Nile River basin and will cost about USD 1 000/kW, or USD 5.25 billion.

In addition to this project, the state-run Ethiopian Electric Power Corporation (EEPCo) is building, or has plans to build, at least five other hydropower projects in the country. The Gezhouba Group Company and Sinohydro Corporation have agreed to build two of these hydropower projects: the USD 408 million Genale Dawa III hydropower project and the USD 555 million Chemoga Yeda hydropower project.

An important prerequisite for these ambitious developments has been the creation of the Addis Ababa-based East African Power Pool (EAPP), whose main aim is to build shared grid interconnections to enable the flow of power from areas of abundance to deficit areas.

Small hydro

Small hydropower installations account for around 10% of total global hydropower potential. Multi-purpose schemes combine electricity production with other water uses such as irrigation, flood control, recreation and drinking water supply. While such schemes can be more complex, they can also help make projects economically viable and acceptable to local communities.

Africa has 588 small hydropower plants of less than 10 MW in operation (Platts, 2011) with an average size of 2.5 MW (a total of around 1.5 GW). Significant

[12] *A pre-feasibility study by Aecom and Electricite de France (EDF) is expected by the end of 2011.*

[13] *Egypt's control of the Nile waters began in 1929 with a colonial-era treaty with Britain. The subsequent 1959 deal with Sudan gave the two downstream countries more than 80% control of Nile waters. A reduction in the Nile water flow will hasten the date when population growth will outstrip water resources, now projected to be as early as 2017. Under the original deal, Egypt is entitled to 55.5 billion cubic metres of water a year, the majority of the Nile's total flow of around 84 billion cubic metres.*

hydropower potential remains in Africa, with around 4.7 GW of potential in 13 West African countries where surveys have been conducted (Table 6). The cost of small hydropower in Africa varies widely although on average project costs in Africa are high. For example, they are about twice as expensive as projects in China because of the high materials and transportation costs for equipment.

Generally, the smaller the installation, the higher the specific investment cost. The cost of four small hydropower projects in Rwanda (two 100 kW and two 200 kW turbine projects) was in the range of USD 2,300 to USD 3,000/kW (UNIDO, 2010a and 2010b). This includes transmission and distribution and an awareness programme. Other bilateral projects have cost USD 4,000/kW for small hydro and as much as USD 7,000/kW for pico hydro (small hydropower systems less than 0.1 MW). Some hydropower projects are based on man-made lakes that require a dam, others are run of river systems. Whether a dam is needed or not makes a big difference to costs and depends on the water flow fluctuations. However, a dam can make economic sense where water storage enables irrigation in the dry season. These factors are very site-specific and need to be evaluated on a project-by-project basis. In terms of the cost breakdown a typical European project requires about 60% of total investment cost for the hydro-technical construction, 25% for the turbines, 5% for the buildings, 10% for electrical equipment and 0.5% for exploitation (EREC, 2010).

Micro hydropower generally refers to plant below 1 MW and is ideally suited to the development of mini-grids. The key to these community-scale projects is creating the correct enabling environment, rather than relying only on subsidies for the investment costs. Policies need to be in place to allow access to resources and any required licences, as well as access to long-term financing and loan guarantees. Complementary policies to develop and retain a competent operations and maintenance capacity are critical to ensuring the long-term performance of these small-scale projects. However, due to the remote areas and the limited financial resources of the communities where electrification is achieved by micro hydropower, at least some public support for the initial investments will be needed (GTZ, 2010).

Table 6: Identified small hydropower potential in West Africa

Country	Potential (MW)	Installed (MW)	Remaining capacity (MW)	No of sites	Remarks
Benin	1,045	0	1,045	85	Mini hydro <1MW: 83 sites 47 MW
Burkina Faso	139	0	139	70	None have been developed
Ghana	8	0	8	69	Mini hydro <1 MW only
Liberia	1,000	0	1,000	40	
Mali	115	0.3	115	15	Nine sites have been properly surveyed
Niger	273	0	273	7	Old studies
Nigeria	734		723	274	Based on a partial survey of the country
Gambia, Guinea--Bissau, Guinea, Mali, Mauritania and Senegal	1,140	0	1,140	9	All are international development projects. Includes projects >10 MW
Sierra Leone	38	0	38	6	Total hydro potential 1 GW. Refers only to sites below 10 MW size
Togo	224	0	224	39	Mini hydro <1 MW: 33 sites 1 MW

Source: ECREEE; UNIDO, 2010b.

The United Nations Industrial Development Organisation (UNIDO) has a programme on small hydro that highlights some of the challenges with small-scale hydropower in Africa. For instance, only a small proportion of the plants that have been installed is still operational today. Maintaining adequate operation and maintenance regimes is clearly a challenge, partly because trained operators often leave for better-paid jobs. Another problem is that community-based systems often run into problems collecting the revenues needed for maintenance (UNIDO, 2010b).

2.2. Wind

Total installed wind capacity in Africa amounted to 0.9 to 1 GW in 2010 (0.5% of global capacity) (GWEC 2011; WWEA, 2011). Egypt has the largest installed capacity (550 MW), followed by Morocco (286 MW) and Tunisia (114 MW). These three countries account for 98% of Africa's total installed capacity. Cape Verde has 26 MW installed. Of the 213 MW added in 2009, 95% was added in the three countries mentioned which have ambitious plans to continue recent growth. Egypt aims to install more than 7 GW of wind power by 2020, while Morocco has a target of 1.44 GW by 2015 and 2 GW by 2020.

South Africa could become the leader in wind energy in southern Africa as a result of the introduction of a bidding system. In December 2011 South Africa approved 28 bids for a renewable-energy tender, including 634 MW for wind developments, from 8 MW installed capacity in 2010. The government is holding five tenders to allocate an additional 2,209 MW renewable capacity over the next two years that will include more wind projects. In addition Eskom is developing two 100 MW wind projects. The integrated resource plan calls for 8.4 GW wind power capacity by 2030.

Wind resources in Africa are very large, but they are not evenly distributed geographically. Initial analysis by IRENA suggests that the total technical potential could be 3,800 TWh (Table 1), equivalent to approximately 1,750 GW. However, 87% of high quality resources are located in the northern, eastern and southern coastal zones. In these areas the wind resource is world-class and wind will probably be the cheapest renewable power generation technology, if there are no large hydro resources nearby.

One of the key challenges in Africa for the large-scale development of wind will be operations and maintenance. Revenue streams for operations and maintenance must be available and local expertise must be developed and retained. This is also true for hydro, but critical for wind, given the higher maintenance regimes required compared to hydro and some other renewable power generation technologies.

The wide distribution of wind resources ensures that it will also have an important role in rural electrification. Special policy attention should therefore be given to small-scale and hybrid wind systems for rural electrification so that hundreds of millions of Africans in areas without electricity will eventually benefit from modern electricity services.

2.3. Solar

Solar photovoltaic (PV) and concentrated solar power (CSP) are two very different technologies. Solar PV accounts for more than 95% of the solar power generation market while CSP accounts for less than 5%. Around 90% of the PV market is accounted for by residential rooftop systems. Africa has one utility-scale PV plant at this time (7.5 MW in Cape Verde) and the total installed PV capacity in Africa is not known with any certainty, but thought to be in the order of 160 MW (EPIA/Greenpeace, 2011). However, although installed capacity in Africa is currently low, the potential for growth is good given that PV panels are a very good solution for the off-grid market. The use of PV for off-grid electrification will be where most growth can be expected.

The potential of PV and, to a lesser extent, CSP in Africa is very large. The technical potential for solar PV could be as high as 6,567 TWh and that of CSP 4,719 TWh. The solar PV resource is more evenly distributed, while the CSP potential is concentrated in the desert areas of the north, east and south.

PV and CSP compete to some extent for utility-scale applications. However, the two technologies are very

Table 7: Comparison of CSP and utility-scale PV

	PV	CSP
Annual capacity additions	>15 GW/yr	<1 GW/yr
Generation timing	Good match for peak load (air conditioning)	
Energy storage	Electricity storage is costly	Thermal storage is possible, small impact on LCOE
Solar resource	Sunny conditions	Only in desert climates (dry air required)
Cost-reduction potential	Very large, continues along learning curve	Significant, but no learning curve available yet
Water requirements	No cooling water needed	Needs cooling water (or costs go up for air cooling)
Project size	Modular (from 1 kW to <25 MW in general)	Bulky projects (>50 MW) with lower transaction costs
Residual heat	None	Can be used for desalination
Hybridisation	With solar thermal for domestic hot water	Can be combined with gas (integrated solar combined cycle)
Local manufacturing	Manufacturing requires specialised production facilities, better opportunities for BoP	Up to 60% local content
Location	Anywhere	Flat land needed, except for dishes
Economies of scale	Modular; limited economies of scale >10 MW	Significant economies of scale up to 200 MW

Note: BoP = balance of plant.

different in some respects and it is likely that they will coexist (Table 7) since they have the potential to complement one another.

Policy support for PV remains limited in Africa, partly due to high investment costs. However, PV can compete on an equal footing for off-grid applications and, with battery storage, to replace diesel generators and provide back-up power supply where the grid supply is unreliable. Onerous administrative procedures and complicated grid-connection requirements can be an impediment for utility-scale projects (EPIA/Greenpeace, 2011). However, with the right policies and continued rapid cost reductions, PV could play a very large role in Africa's energy supply by 2030, with estimates of between 15 GW and 62 GW of solar PV by 2030 in Africa (EPIA/Greenpeace, 2011).

CSP development of is only just beginning. So far the emphasis in Africa has been on gas plants with solar

Table 8: Existing and planned CSP projects in Africa, 2010

Country, project and promoter	Existing (MW)	Planned (MW)
Morocco (ISCC)	22	
Egypt (Kuraymat ISCC)	20	
Algeria (Hassi M`Rel Thermosolar)	20	
Sudan (ISCC, Euromed)		150
Sudan (Fresnel, Euromed)		100
South Africa (Solar tower, Eskoms)		100
Algeria (AlSol)		2

Source: Sun & Wind Energy, 2011.

assistance, commonly referred to as integrated solar combined cycles (ISCC) (Table 8). However, this is changing and recent attention has focussed on dedicated concentrated solar plant. Desert locations are ideal for CSP plants, because they require dry air and direct solar light.

In addition to the specific projects in Table 8, some countries have laid out ambitious long-term goals to increase CSP capacity. Egypt has plans for a 140 MW CSP plant in Kuraymat. Tunisia has plans to develop 40 solar power projects between 2010 and 2016. Morocco has earmarked USD 9 bn for the development of 2 GW of CSP by 2020. Algeria is planning to supply 10% of its electricity from solar by 2025 (IRENA, 2011a).

An even more ambitious long-term goal for renewables is that proposed by the DESERTEC Industrial Initiative (DII), a German-led industry initiative that includes 12 European companies and was launched in 2009, and various similar plans under French or European aegis. The DESERTEC vision is to import 15% of EU electricity by 2050 from 100 GW of renewable capacity located in North Africa via high-voltage direct current (HVDC) undersea lines to Europe. This capacity is two-thirds of total African power production capacity today. The capacity would be primarily solar (PV and CSP), but also with significant wind. The investment volume would be in the order of USD 540 bn. The first stage of the project is anticipated to start in 2012 with the construction of a 500 MW CSP plant in Morocco costing USD 2.8 bn (The Guardian, 2011).

In the longer-term, the combination of solar energy with desalination in North Africa could become particularly interesting. With current trends of rapidly-growing populations and continuing pressure on water resources, desalination needs will increase very rapidly in North Africa. Desalination accounted for about 0.3% of global electricity demand in 2005 and accounted for 5% of the world desalination capacity (around 500 million m^3 per year) was in North Africa. Desalination in this region could grow 20-fold by 2030, especially as Egypt reaches its maximum drawdown of Nile water. The electricity needed to meet the need for desalination in 2030 would be in the order of 70 TWh, which would equal around 15% of the total Reference Scenario electricity demand in the region. Both PV and CSP can be used for desalination (thermal and osmosis processes, respectively). Desalination is an ideal use of renewables, because intermittency is not a problem due to the fact that water can be stored easily and relatively cheaply.

2.4. Geothermal

The use of geothermal energy for electricity generation is a renewable, cost-effective, reliable, baseload technology. The contribution of geothermal to Africa's electricity generation is currently modest, with around 210 MW of installed capacity. However, excellent geothermal resources exist in the East African Rift system and the potential is large, particularly in Kenya and Ethiopia. However, there are technical challenges in some areas such as Djibouti, where the high corrosiveness of the geothermal fluid is an issue.

Africa's geothermal resources are not evenly distributed and most of the potential lies in East Africa. The total geothermal energy potential in the East African Rift Valley is estimated to be between 7 GW to 15 GW, but could possibly be more (AUGRP, 2010).[14] The total technical electricity generation potential for Africa is 88 TWh, all of which is located in East Africa (Table 1).

The 4,000 km long and on average 60 km wide East African Rift System is the largest crack in the continental crust of the Earth and consists of two branches (Figure 5). The eastern branch extends from the southern end of the Red Sea (the Afar triangle) to Tanzania. The western branch extends from Uganda to Mozambique. Volcanic activity is most intense in the eastern branch, giving Ethiopia and Kenya highly promising geothermal resources.

Hydrothermal systems in volcanically active regions along plate boundaries can have fluid temperatures above 200°C. The direct use of the produced steam for power generation is possible. The key factors that influence the design of a geothermal power generation project are:

- reservoir temperature;
- flow rate, which depends on the permeability of the rock; and
- chemical composition of the fluids/steam.

Due to the modular nature of geothermal power plants, projects can be planned in stages, thus reducing working capital requirements and facilitating the development of geothermal expertise and development capacity in a region. Investment in geothermal power plants is often economic, especially where the resource is of high quality and stable regulatory frameworks and financial incentives exist.

Although there are extensive geothermal resources in the East Africa Rift region, only Kenya has started to exploit their potential on any scale. Currently, the Kenya Electricity Generating Company Limited (KenGen) and ORMAT, an independent power producer, together produce a total of about 205 MW (Simiyu, 2010 and KenGen, 2011), primarily at the Olkaria geothermal field. Geothermal power plants account for about one-fifth of Kenya's total electricity generation capacity (RoK, 2011). A further 320 MW is planned or under construction (Simiyu, 2010), while by 2018 KenGen expects to add 1,500 MW of geothermal power to its current portfolio (Simiyu, 2010) and by 2050 a total of as much as 5,000 MW (Steam, 2011).

Figure 5: East African Rift System (Kraml, 2008)

[14] *The East African Rift valley encompasses 12 countries: Burundi, Comoros, Djibouti, Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia.*

Table 9: Existing and planned geothermal power generation plant in Kenya, 2011

Power plant	Current capacity (MW)	Number of units	Under construction/ planned (MW)
Olkaria I	45	3	70-140
Olkaria II	105	3	
Olkaria III	48	2	50
Olkaria IV			140 (2 x 70)
Oserian	4	2	
Eburru pilot	2.5	1	
Menengai			420 (3 x 140)
Bogoria-Silali			800 (8 x 100)

Sources: Simiyu, 2010 and KenGen, 2011.

Menengai will be the next geothermal field in Kenya to be developed. The Geothermal Development Company (GDC), established by the Government of Kenya (GoK) to develop geothermal resources, has completed drilling two wells, with two others underway. A three-stage project could see three 140 MW plants built at this field.

The GDC is also assessing the Bogoria-Silali geothermal prospect and plans to develop 2 GW of geothermal power generation capacity in four phases. The first phase would involve the construction of eight 100 MW plants. The total cost of the project is about USD 3.2 bn (USD 4,000/kW) including feasibility studies, rig procurement, infrastructure development, drilling test wells, well testing, development of the steam collection system, drilling the production wells and purchase of the power generation units. Half of the investment cost is for the power plant, the other half for the wells and the steam field (RoK, 2011).

A total of six drilling rigs will be needed to complete 200 wells for the Bogoria-Silali development, and the GoK has already bought two. The African Development Fund (ADF) will fund another two to be supplied by the end of 2011, and the ADF will provide funding to buy the last two. This strategy is cheaper that hiring rigs in the international market, as strongly fluctuating prices for oil and gas rigs often do not reflect costs, but the scarcity of rigs. Kenya has acquired the necessary skills in drilling and operation geothermal plant and Kenyan experts are now also providing training to other countries.

Kenya's peak power demand stands at about 1.2 GW and is projected to increase more than ten-fold to 17 GW by 2030. Kenya aims to install 1.6 GW of geothermal capacity by 2020 and 5 GW by 2030 (RoK, 2011). This would represent a third of the projected installed capacity by 2030. These plans will make Kenya the leading African country for geothermal power development.

Another key country in the geothermal context is Ethiopia where the proven potential is around 0.7 GW, all of which is located in the Ethiopian Rift area. However, the actual potential may be much larger if the region stretching from the south-east to the north-west of the country is included (Wolde-Ghiorgis, undated). Installed capacity is just 4 MW, but this could grow. The

Tendaho geothermal site (Afar Triangle) is currently in the final stages of a pre-feasibility assessment and future development of this site is envisaged.

Tapping the geothermal potential in the East African Rift could significantly contribute to the improvement of local livelihoods in the countries involved, as well as help with industrial and socio-economic development. Unlocking these resources is a task for governments, the private sector and the international community.

KfW, the German Development Bank, recently launched the Geothermal East Africa Initiative (GEAI), which provides a risk mitigation fund for geothermal developments to the private and public sector. The GEAI encourages drilling operations and rewards developers with grants and soft loans. The fund is politically and technically closely linked to the Department of Infrastructure and Energy of the African Union Commission in Addis Ababa, Ethiopia. The German development corporation financially supports the Geothermal Facility with EUR 20 million (about USD 27 million), the EU Infrastructure Trust Fund has expressed interest in topping up the fund with an additional EUR 30 million (about USD 40 million).

The UNEP and WB will also encourage geothermal development with the African Rift Geothermal Development Programme (ARGeo), which will target the East African countries of Djibouti, Eritrea, Ethiopia, Kenya, Tanzania and Uganda (AUGRP, 2010). The technical assistance component (provided by UNEP) was launched in early 2011 and includes geo-scientific investigations, the promotion of public-private partnerships, awareness raising and dialogue. The WB will assist private investors in exploratory drilling operations through a risk mitigation fund (funds of USD 17.75 million are available).

The key to attracting private investors at an early stage is to have a facility to cover the development risk, particularly with regard to wells that are dry, or perform poorly compared to the indications given by appraisal wells (necessitating additional production wells). The risk guarantee schemes established by KfW and the WB will help overcome these barriers, while the UNEP technical assistance programme will help improve geothermal appraisal and therefore also reduce risks.

In addition to these international donor efforts, East African countries are looking to work together to help develop their geothermal resources. The declaration on geothermal energy issued at the regional meeting in Addis Ababa on June 10, 2009 recommended that:

- The African Union Commission (AUC) launches a joint regional programme that will engage in the promotion, exploration, development and utilisation of the geothermal energy resource of these signatory countries.
- The AUC establish a “Geothermal Energy Development Agency” with the task of supporting the above activities.
- The AUC convenes a permanent Regional Forum with the participation of these countries in order to institutionalise their involvement in the activities of the proposed Agency.

2.5. Bioenergy

Bioenergy is an important source of renewable power in the world today. The combustion of pulp industry residues (black liquor) and sugar cane bagasse are an important source of electricity and are often very economic sources of power. Bagasse is the most important source of bioenergy power in Africa, accounting for 94% of the 860 MW of installed bioenergy power generation capacity in 2011. The technical potential for the use of bioenergy for power generation is estimated to be 2,631 TWh, with 60% of this potential in Central Africa.

The expansion of generation from bagasse will depend on trends in the sugar cane industry, but the use of other agricultural wastes will often also be economically attractive. An emerging trend in developed countries is the co-combustion of biomass in coal-fired power plants. This technology could be relevant in South Africa. However, the drivers for co-combustion in developed countries – waste management and climate change policies – are less relevant in the African context, unless some future mechanism (post-CDM) is developed to incentivise its use. However, lower bioenergy feedstock costs in Africa compared to other world regions could act in favour of this option. Given current levels of coal use, 5 GW co-firing would be feasible.

Biogas and landfill gas are widely used for power generation in many parts of the world, but not in Africa, where only 4 MW biogas capacity is identified. This option deserves more attention, especially for remote locations. However, the availability of sufficient quantities of feedstock to make biogas production attractive is an issue, given that large-scale farming is still relatively rare in Africa.

Biomass gasification is successfully applied in India and rice-husk gasification is a widely deployed technology. To produce electricity, piles of rice husk are fed into small biomass gasifiers, and the gas produced is used to fuel internal combustion engines. The operation's by-product is rice-husk ash, which can be sold for use in concrete. Several equipment suppliers are active and one, Husk Power Systems (HPS), has installed 60 mini power plants that power around 25,000 households in more than 250 communities. These systems have low investment costs (USD 1,000 to USD 1,500/kW) and have overall efficiencies of 7% to 14%, but are labour-intensive in maintenance and operation.[15] One of the keys to their success has been the recruitment of reliable people with a vested interest in the ongoing operation of the plant.

The International Finance Corporation (IFC), the private sector arm of the WB, has formed a partnership with HPS and is looking to expand into Kenya and Nigeria. IFC will provide an investment grant of up to 29% of the capital cost for biogas power generation projects, with the balance to be met by commercial loans. GIZ (Germany) is also focussing on the promotion of biomass gasification for combined heat and power (CHP) generation in decentralised settings as an economic alternative to grid extension in remote areas of Benin. The potential is large, with 766 MW of capacity possible from agricultural waste in Benin alone. GIZ plans to install one or two small pilot units of between 25 kW and 100 kW in a low-voltage mini grid to gain experience.

The critical factors for these gasification systems are the reliability of the gasifier and the cost of the biomass supply. While feedstock may be free when the first plant begins operating, prices can quickly rise if the technology takes off and competition for feedstock arises. This often places a limit on the potential of waste-based power generation.

For wet biomass, anaerobic digestion is a better option than gasification. A kilo of cow dung can produce 30 litres of biogas, so 30 cows produce the equivalent of a kilo of LPG every day[16]. This biogas can then be used for cooking or power generation and can soon become an important power source. For instance, Germany derived around 3% of its total power generation from biogas engines in 2010, with a feed-in tariff of USD 0.11 to USD 0.13/kWh.

Senegal, Mauritania and Burkina Faso are looking into biogas for power generation while interest is also increasing in East Africa and in southern Africa. Estimates suggest that South Africa could generate 5% of its electricity from biogas (Pretorius, 2011). The major obstacle for households or villages is the high initial cost. To overcome this barrier, Senegal has introduced a National Biogas Programme that strives to implement subsidies, ranging between 35% and 50% of the initial cost, to help produce electricity from biogas. In Kenya, biogas has been tried for half a century, without much success. Operation and maintenance challenges are the main problem (ETC, 2007). With biogas from animal effluent, the number of animals needed for power generation at any scale poses a challenge under most African conditions and, as a result, large-scale power generation from biogas only makes economic sense on large farms or in community-wide systems.

2.6. Power pools, interconnectors and systems integration

The cost of power generation technology generally represents only part of the total cost of providing electricity. If a centralised grid is used, transmission and distribution can add significantly to the total supply cost. As the share of variable renewables connected to the grid rises, it also becomes important to consider the impact on grid stability and reliability. Much depends on the network and the power generation system, but

[15] *This compares to 16% to 19% for wood fuel gasification systems in combination with Otto cycle engines*

[16] *In terms of energy equivalent, one cubic metre of biogas equates to 1.5 kWh of energy*

local stability issues can arise when renewables account for as little as 10% of total generation.

Diversification of renewable resources, spreading their location over different climate zones, grid interconnections with neighbouring countries, electricity storage (e.g. pumped hydro storage) and backup capacity (typically gas turbines) can all play an important role in ensuring grid stability. Typically the cost for such system integration, once it becomes necessary, adds USD 0.01 to USD 0.02/kWh to the real cost of variable renewable electricity. However, the actual costs vary significantly depending on the specific situation. It is also possible that in certain circumstances renewables can help reduce grid costs and improve stability. For instance, the ability to economically place modular amounts of small capacity in areas where the local distribution or transmission grids are at times heavily constrained can help improve grid stability at very low cost compared to other options.

There is a range of concrete developments in place to create new interconnections and significant interest has been shown in improving current grid interconnection in Africa in order to provide security of supply and facilitate the development of large electricity generation projects. The southern African Power Pool (SAPP) is an effort by the national electricity companies of 12 countries in Southern Africa to improve cooperation through grid connection. Similarly, the Economic Community of West African States (ECOWAS) West Africa Power Pool (ECOWAPP) includes all the ECOWAS countries. The Central African Power Pool includes 11 utilities and is a specialised body of the Economic Community of Central African States (ECCAS). The Arab Maghreb Union has a set of interconnections, with relatively low capacities, that connect the countries of North Africa. However, at present, these power pools are not connected to one another.

The East African Power Pool (EAPP) should be operational by the end of 2011 and will allow interconnected member countries to share power to avoid or ease shortages. Seven East African countries – Burundi, DR Congo, Egypt, Ethiopia, Kenya, Rwanda and Sudan – are currently members and Tanzania, Uganda, Djibouti and Libya have been invited to join. The "Zambia-Tanzania-Kenya" interconnector is a separate, USD 860 million plan to transfer electricity from Zambia to Kenya through Tanzania.

Obvious interconnectors that could enhance renewable energy access would link the Grand Inga hydropower project with South Africa and/or Nigeria. At the same time, the connection of the wind potential in the Northwest to the demand centres in West Africa or from East Africa to southern Africa could be considered, although it would require the construction of transmission lines over distances of up to 2,000-3,000 km. This is only likely to make economic sense after the current untapped national resources, notably hydropower, are fully exploited. However, China has shown that this type of development is possible, as HVDC lines of similar length have been built to connect the hydropower plants in the West of China to demand centres in the East.

A 400 MW interconnector already exists between Morocco and Spain. The capacity of this interconnector could be increased to enable the export of wind and solar resources to Spain. However, for the time being the electricity flows largely from Spain to Morocco. New interconnectors between North Africa and Europe have been proposed, some as part of the DESERTEC Industrial Initiative.

2.7. Off-grid solutions

Off-grid solutions using renewable technologies can play an important role in providing access to electricity in remote areas or those far from the current centralised electricity grid. Unfortunately, there are no detailed statistics available regarding the deployment of off-grid and mini-grid solutions in Africa, so the scale of today's deployment of these solutions is not known.

Off-grid systems based on solar or wind require electricity storage to make them truly useful. Various electricity storage systems exist or are under development, but they are expensive and tend to be more suited to large-scale applications. For small-scale systems, standard lead-acid batteries are the technology of choice.

Redox flow batteries represent an emerging option, but they are not yet commercially available. Capacitors are an emerging technology, but are more suited to very short-term electricity storage.

Also small wind is emerging as a solution. The scale of a wind turbine is typically for a number of households or for a small village.

Lead-acid batteries are the oldest, most widely applied electricity storage technology and are a proven option. Car or truck batteries are sometimes used because they are the cheapest option, but they are not designed for use with power generation technologies and have a short lifespan (as low as 50 cycles). Deep-cycle lead-acid batteries are a proven option, with much longer lifespans than car batteries, and they will last even longer if the discharge rate is kept low. For instance, limiting the discharge to 20% or less can allow the battery to last for 10 years. The trade-off is higher initial costs, as 5 kWh of battery storage is needed for every 1 kWh of electricity used from storage.

In sunny African conditions a 1 kW PV system can supply 1,500 kWh per year (4 kWh/day). Assuming half of this energy is needed in the evenings this means 2 kWh of useful storage is needed, requiring 10 kWh of battery storage if battery life is to be optimised. This represents an investment of USD 1,500 (USD 150/kWh), to which a battery charge controller must be added if this is not included in the PV system. The addition of storage, assuming the PV system costs around USD 3,000/kW, therefore adds 50% to the PV system cost (total USD 4,500/kW).[17]

Other battery options include lithium-ion (Li-ion) or sodium-sulphur (NAS) batteries. Their cost is higher than for deep-cycle lead-acid batteries at USD 550 to USD 600/kWh. However, NAS is a new battery technology and global production capacity is less than 150 MW per year, so cost reductions are likely. NAS batteries are currently large-scale storage solutions, and a single NAS battery in the capacity range of several MW will weigh ten tonnes, or more. Production of smaller NAS batteries is beginning and they could soon be used for mini-grid, village or small city-size storage solutions. In the longer term, NAS battery costs could come down significantly, as they have been designed to use cheap and abundant materials. Li-ion batteries are small-scale, and today usually power laptop computers, and may therefore be better suited to highly modular small-scale off-grid solutions if costs come down. Other options, such as redox flow batteries, are still at a developmental stage and their practical feasibility is not yet proven.

Off-grid systems compete with centralised grids. Centralised grids require substantial investments in high-voltage transmission lines, transformers, as well as medium- and low-voltage distribution systems. The cost per unit of energy delivered depends heavily on the length of the system and the demand density. While a centralised grid may be the cheapest solution for a large city, an off-grid or mini-grid system will usually be more economical for a remote dwelling or community. For instance, as a rule of thumb, the grid cost will on average be of the same order of magnitude as the level of investment required for the power supply units, effectively doubling the investment needs. So, although the unit cost of fossil-fuel based generating plant is low, it is offset by the grid costs, potentially making off-grid solutions with renewables the most economic approach today.

Kenya plans to raise the share of renewables in 12 isolated mini-grids with a total capacity of 11 MW by installing 3 MW of solar and wind to complement the existing diesel generators in these grids. The GoK also plans to construct 27 new isolated mini-grids with a total installed capacity of 13 MW. The total cost for the 16 MW of additional generating capacity and the grid costs of the 27 new mini-grids is USD 68 million. The average cost is USD 3,000/kW for power generation and USD 1,300/kW for the mini-grid development (Table 10).

In 2007 the WB conducted a cost comparison of off-grid, mini-grid and grid electrification technologies (ESMAP, 2007). They concluded that off-grid solutions have a LCOE of USD 0.11 to USD 0.60/kWh. For mini-grids the supply cost ranges from USD 0.05 to USD 0.50/kWh, while for grid connected power plant the cost ranges from USD 0.04 to USD 0.15/kWh, with the cost of expanding the transmission and distribution

[17] *This analysis is in line with 100 W off-grid systems for sale in South Africa that cost around USD 5,000/kW.*

Table 10: Projected costs of the Kenyan mini-grid programme

	Million USD	USD per kW
Equipment (16 MW)	49.5	3,000
Grid (13 MW)	16.5	1,300
Other	2.0	
Total hybrid mini-grid systems	68.0	4,300

Source: RoK, 2011.

system typically adding another USD 0.05 to USD 0.10/kWh.

If demand is limited to a few basic functions (predominantly lighting) in rural areas, off-grid solutions can be cheaper than grid connection. However, the operation and maintenance needs for off-grid solutions are high and often not adequately provided for in the long term. This is one of the major factors that explain why there is a tendency to move to grid-connected solutions when the opportunity exists and the costs are affordable. However, the reality is that while 70% of the population is still without access to electricity, off-grid solutions will remain an important solution for many years to come and they can act as an important stepping stone to grow demand and improve the viability of grid connection at a later date.

3. Drivers of future African electricity demand

The population of Africa is growing fast (2.3% per year). At the same time, per capita income levels are rising and Africa is urbanising. These three trends will drive energy demand growth and consumption patterns in the coming decades.

Africa's population was 1.031 bn in 2010 and is projected to grow to between 2 bn to 3 bn by 2050 (UN Population Division, 2008). The current urbanisation rate ranges from 18% in Ethiopia to 50% in Nigeria, but it is well above 70% in some North African countries (UN Population Division, 2009). In Africa today, 34% of population lives in cities and 66% in rural areas.

Figure 6 provides a breakdown for sub-Saharan Africa of the population distribution by settlement type. The trend is towards a 20 percentage point increase of the urban share by 2050. This means that more than half of the sub-Saharan population will live in cities and the urban population will more than double.

African economies have been growing at an average rate of around 4% in the last few years. If this trend continues GDP will increase 2.9-fold between 2008 and 2030 and 6.7-fold by 2050. If growth were to accelerate to the levels seen in China and India in recent times, GDP levels could rise even further. The GDP growth rate assumptions in this study vary by region (Table 11), but are slightly higher on average than recent growth rates. These differences – in conjunction with today's variations by region in electricity generation mix, electricity consumption levels and renewable energy potential – will drive the renewable energy outlook by country and region in Africa.

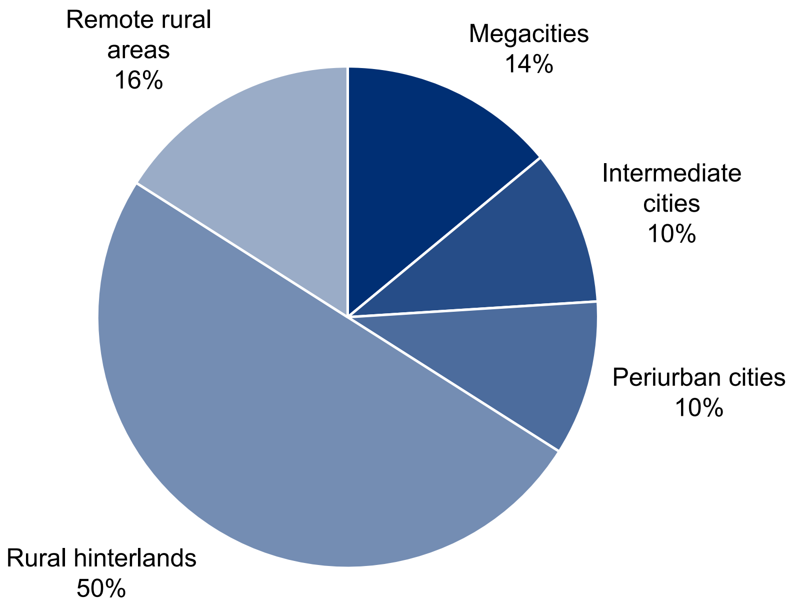


Figure 6: Sub-Saharan population distribution by settlement type
Source: Foster and Briceno-Garmendia, 2010.

Table 11: GDP growth projections

GDP Growth rate		2008-2015 (%/year)	2015-2030 (%/year)	2030-2050 (%/year)
Central		8.0	7.0	6.0
East		6.0	5.0	4.0
North		6.0	5.0	4.0
South		4.0	3.5	3.0
West		8.0	6.0	5.0
Total Africa		5.8	5.0	4.3
GDP Index	**2008**	**2015**	**2030**	**2050**
Central	100	185	511	1638
East	100	142	295	646
North	100	142	295	646
South	100	117	196	354
West	100	185	444	1177
Africa	100	139	289	674

Source: DB, 2010 and IMF, 2010.

Electricity demand growth

In developing countries, electricity demand tends to grow at least as fast as GDP. The demand modelling assumes that, given the low starting point, demand in the Central and Eastern regions will grow at the rate of GDP growth plus 2% (so more than 7% electricity demand growth per year between now and 2030), while in the West it will grow at 1% above GDP growth. In southern Africa it is assumed that electricity growth will match the rate of GDP growth (so not more than 3-4% electricity demand growth per year), while in North Africa, electricity demand is assumed to grow at a slower rate than GDP, given the relatively high electrification rate and electricity consumption, and the larger industrial base.

The other key factor that needs to be considered in the demand analysis is the impact of changing lifestyles. The most prominent feature in the African context is the urbanisation trend (Table 12). Urbanisation rates are projected to rise by about 20 percentage points by 2050. Almost two-thirds of Africans will live in cities in 2050, compared to less than 40% today. This has consequences for a successful renewable power strategy, as over the period to 2050 the emphasis will shift from off-grid solutions to large-scale grid-based systems with significant daytime peak demands.

Table 12: Projected share of urban population for different African regions, 2008-2050

(%)	2008	2015	2030	2050
Central	39	44	53	66
East	22	25	33	47
North	53	55	62	72
South	44	47	55	66
West	44	48	57	68
Total	39	42	50	62

Source: UN Population Division, 2009.

Consumers' ability and willingness to pay for electricity will also be key factors in determining electricity demand growth. Surveys held in Mali concluded that the willingness to pay for electricity in rural areas averaged USD 15/month, ranging from USD 9.3 to USD 22.4/month. In Senegal, most rural households already spend USD 2 to USD 24/month on kerosene and dry cell batteries to meet their lighting and small power needs, and hence are likely to be willing and able to pay for electricity use at least up to this level. In Guinea, rural surveys obtaining data on avoided costs found that the willingness to pay for basic electricity services was just USD 1.6/month, which would cover the cost of 12 kWh/month at the average tariff of the sub-Saharan region (USD 0.13/kWh) (WB, 2010). Any form of electricity is a major expense under such conditions. In the scenarios, the willingness to pay is assumed to increase over time with incomes, resulting in electricity consumption per capita growing at least as fast as incomes.

Fossil fuel prices

The fossil fuel price assumptions are consistent with the latest World Energy Outlook (IEA, 2011). In the Reference Scenario the world market oil price is projected to increase from today's level (around USD 100/bbl (barrel) average import price) to USD 140/bbl in real terms in 2050. World steam coal prices rise by 10-15% to around USD 120 per tonne and natural gas import prices rise by about USD 4/ GJ to between USD 9 to USD 14/GJ.

Prices in Africa today are often decoupled from world market prices for a variety of reasons, but it is assumed that fuel prices will increasingly be linked to world market prices over time. However, natural gas is much cheaper in markets close to the producing fields, where no extensive transportation is needed, and export options are currently limited or non-existent. A price of USD 7/GJ in North Africa and West Africa by 2030 is therefore assumed. Domestic South African coal is projected to double to USD 3/GJ by 2030. The same fossil fuel prices have been used for the Renewable Scenario, based on the assumption that changes in African consumption will not affect global prices for fossil fuels.

4. Electricity scenarios for Africa

Electricity planning can be done on many levels – from the level of the individual power plant up to the national electricity grid, through to several interconnected countries or even the continent as a whole. Different models and analysis are needed for these different scales. Moreover, different timescales must be considered, as the aggregation of time segments cannot be carried too far if the analysis is to ensure that electricity supply mixes with high shares of variable renewables can always meet demand. The analysis presented here for Africa focuses on two scenarios:

- The **Reference Scenario:** This is a continuation of existing economic, demographic and energy sector trends and only takes into account existing policies. Universal electricity access is not achieved and peaks at 43% in 2030.
- The **Renewable Scenario:** This scenario examines the impact of policies in Africa to actively promote the transition to a renewable-based electricity system to meet the growing needs of its citizens for electricity, to boost economic development, and improve electricity access. Importantly, this scenario achieves electricity access for all by 2030 and includes a CO_2 price of USD 25/t CO_2.

As a first step, country scenarios from the literature were analysed (IRENA, 2011a) in order to inform the scenario development and identify the key existing trends. These country scenarios suggest that Africa will need to undertake massive investment in new power generation capacity in the coming two decades, with capacity additions of around 250 GW to meet demand growth (Table 13). This is equivalent to a tripling of current installed capacity in just 20 years. These figures are supported by the IRENA Reference Scenario demand analysis that suggests a tripling of demand between 2008 and 2030. Such an expansion of electricity capacity will help to reduce outages, increase access to electricity, improve the lives of the people of Africa, and promote economic growth.

It should be noted that the demand projections are significantly higher than those of the IEA's *World Energy Outlook* and scenarios from EREC/Greenpeace (IEA, 2011 and EREC/Greenpeace, 2010). The projections in the scenario analysis presented here are more in line with the aggregated projections of individual country studies.

Table 13: Electricity generation capacity needs in the Reference scenario, 2010 to 2030

(GW)	2010	2030
South Africa	42	85
Egypt	22	65
Algeria	50	150
Nigeria	10	30
Ethiopia	2	16
Others	14	60
Total	140	409

Source: based on IRENA, 2011a.

Model structure and development

The analysis presented here necessitated the development of two new power pool models, one for southern Africa and one for ECOWAS. The International Atomic Energy Agency originally developed these models, but IRENA has substantially updated and refined the representation of renewables in them, as well as making other improvements. These models are ideally suited to study the issues of national grid extension and operation, electricity generation mix, and the benefits of interconnection. To complement them IRENA has developed a new model for Africa as a whole, where the electricity supply from these two power pool models is incorporated into a five-region model for Africa to model electricity supply and demand in each region. This integrated, regional model is then used to develop electricity scenarios on a continental level.

These two model sets unfortunately do not have the required level of detail to assess the viability of grid expansion versus mini-grids or off-grid systems. Spreadsheet models that can evaluate the costs and benefits of these options have been developed for this analysis and are used as inputs to the five regional electricity supply models.

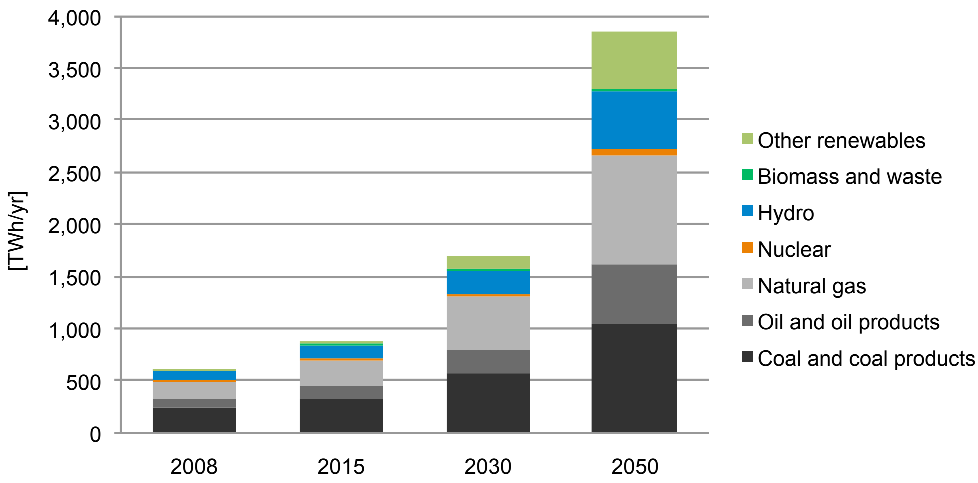
The Reference Scenario, in addition to the demographic and economic drivers already discussed, includes all energy, economic and rural development, as well as climate policies in place to date. No new policies are assumed in the Reference Scenario, so existing policies with a foreseen end date are not assumed to be extended. The Reference Scenario also only includes those policies currently enacted. Policies under discussion, or those without legislative or regulatory backing, have not been included.

The Reference Scenario

In this scenario total electricity production is projected to nearly triple between 2008 and 2030, and then more than double between 2030 and 2050. However, despite this rapid increase, electricity access in 2030 is still only 43%. The results for the Reference Scenario (Figure 7) also indicate that a notable shift from coal to gas will occur. This is explained by the fact that electricity demand in southern Africa grows at a much slower rate than in other African regions, and coal-based power generation is concentrated in South Africa. Significant quantities of hydropower, and in later decades wind, are added in the Reference Scenario. However, fossil fuel-based electricity generation continues to grow strongly in this scenario and is more than five times higher in 2050 than in 2008 and still accounts for around 70% of generation in 2050.

In the Reference Scenario, the use of renewable energy for power generation therefore does not increase rapidly enough to become the most important source of electricity generation. Fossil fuel-based power generation will still account for most capacity added between now and 2050 in the absence of new policies. The barriers to the uptake of renewable electricity generation are not sufficiently overcome in the Reference Scenario to achieve a transition to renewable energy technologies in Africa, which will require the introduction of transformational new policies.

Figure 7: Business as usual electricity supply projections for Africa 2008-2050



The Renewable Scenario

The Renewable Scenario assumes more policy emphasis on renewable energy driven by economic, development and environmental factors. In the Renewable Scenario, new and ambitious deployment policies for renewable power generation technologies are complemented by significant new energy efficiency policies to form a single policy package. The other key difference to the Reference Scenario is that the Renewable Scenario achieves universal access to electricity in Africa by 2030. This combination of policies, along with the rapid growth in capacity required, means that Africa's power generation sector could leapfrog the inefficient and fossil-fuel dominated development path taken by industrialised countries and could transition to a system dominated by renewables. However, this assumes concerted government action in the area of efficiency standards and programmes, as well as renewable deployment policies and regulation.

By presenting the Renewable Scenario and comparing it to the Reference Scenario this paper aims to show that the Renewable Scenario is both a feasible development pathway and has important benefits compared to a business as usual pathway.

In the Renewable Scenario, a gas distribution infrastructure is not developed because demand is so low that investment costs per unit of energy would be too high, given the lack of space heating demand, even with the predicted rate of urbanisation. The use of coal-fired power generation is an option in outhern Africa, but in the Renewable Scenario it comes under increasing pressure because of greenhouse gas concerns. Nuclear expansion is minimal due to the high investment costs and lack of indigenous manufacturing and installation capacity. This leaves local natural gas, which remains an attractive option where abundant local resources mean that gas is cheap.

The additional deployment of renewables in Africa is enough to accelerate technology learning, leading to reduced costs for renewable power generation technologies. However, the lower demand for fossil fuels could also make some fossil fuels relatively cheaper than in the Reference Scenario in some regions.

Electricity demand and production by region and technology

The Renewable Scenario assumes electricity access for all Africans by 2030. The demand projections result in average per capita electricity consumption growing by 120% between 2008 and 2050 to between 3 to 4 kWh/day on average. There is a wide range of growth by region, from an increase of 35% in the South to a more than ten-fold increase in Central Africa that is dependent on current levels and income growth.

In the Renewable Scenario, more ambitious energy efficiency policies are implemented that improve energy efficiency by 20% to 30% compared to the Reference Scenario in 2050. These are additional efficiency gains on top of what already occurs in the Reference Scenario. These energy efficiency policies complement the efforts to promote renewable electricity generation by allowing a given amount of investment in renewable energy to provide electricity access to a larger number of Africans than the same investment in the Reference Scenario. However, despite the Renewable Scenario achieving universal electricity access, electricity demand is still about 15% lower in 2050 than in the Reference Scenario as not all of the energy-efficiency savings are offset by the increased consumption of those additional people given access to electricity. However, even though electricity demand is lower, the underlying energy services delivered are higher in the Renewable Scenario due to the increase in efficiency.

Table 14: Electricity generation by region in the Renewable Scenario, 2008 to 2050

(TWh)	2008	2015	2030	2050
East Africa	24	40	96	253
North Africa	237	331	610	1 158
West Africa	42	76	180	425
South Africa	302	393	537	844
Central Africa	16	31	116	467
Total	620	870	1 537	3 146

Source: Howells et al., 2011; IRENA, 2011c; and IRENA, 2011d

The share of PV in total electricity generation grows from virtually nothing in 2008 to 8% in 2030 (Figure 8) and 14% in 2050. CSP grows to 6% of total generation in 2030 and 10% by 2050, wind reaches 14% in 2030 and 17% in 2050, while biomass technologies reach 4% in 2030 and 10% in 2050. The share of hydro is relatively stable at 17% in 2030 and 21% in 2050 , but this masks a very significant growth in absolute terms (2.8-fold by 2030 and neary 7-fold by 2050). The share of electricity generation from fossil fuels falls to 50% in 2030, but demand growth is so rapid that this is still a 47% increase in generation between 2008 and 2030. However, between 2030 and 2050 renewables become the most competitive option and virtually all of the growth in electricity generation over this period is from renewables.

The trade in renewable electricity increases significantly in the Renewable Scenario as low-cost resources are brought to market. One-quarter of the electricity from the Grand Inga hydroelectric project is exported South Africa and at a later stage another quarter is developed for export to West Africa. In North Africa, if the DESERTEC project is completed, 100 GW of renewable capacity in North Africa will export 400 TWh of electricity per year to Europe by 2050, bringing in important revenue streams.

Installed capacity and system costs

Figure 9 shows the installed capacities for both the Reference and the Renewable Scenarios. The total installed capacity is higher in the Renewable Scenario despite lower demand, because the average capacity factor is lower. By 2030 there is already a significant difference in the capacity mix and hence installed capacity required. In the Reference Scenario around 410 GW of total capacity is in operation in 2030, while in the Renewable Scenario it rises to 442 GW. This gap widens as the share of renewables increases and by 2050 around 80 GW more capacity is installed in the Renewables Scenario than in the Reference Scenario.

The Renewable Scenario in 2030 has around 95 GW wind capacity. However, it is between 2030 and 2050 that the dramatic transformation of the African electricity sector occurs. During this period, virtually all the growth in capacity in the Renewable Scenario is based on renewable power generation technologies. This is driven by cost reductions in renewables and their increasing competitiveness in this scenario.

Figure 8: Electricity production by fuel in the Renewable scenario, 2008 to 2050

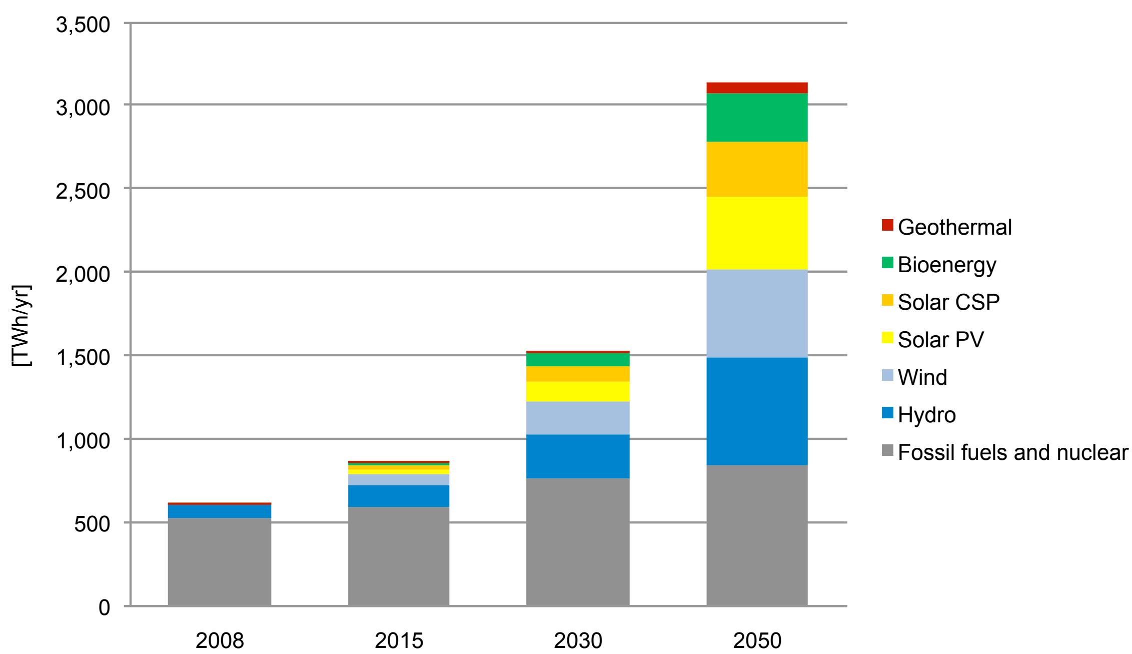
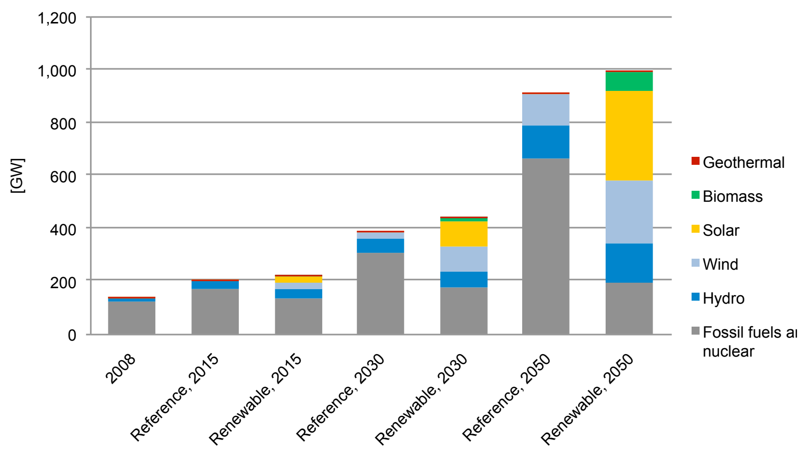
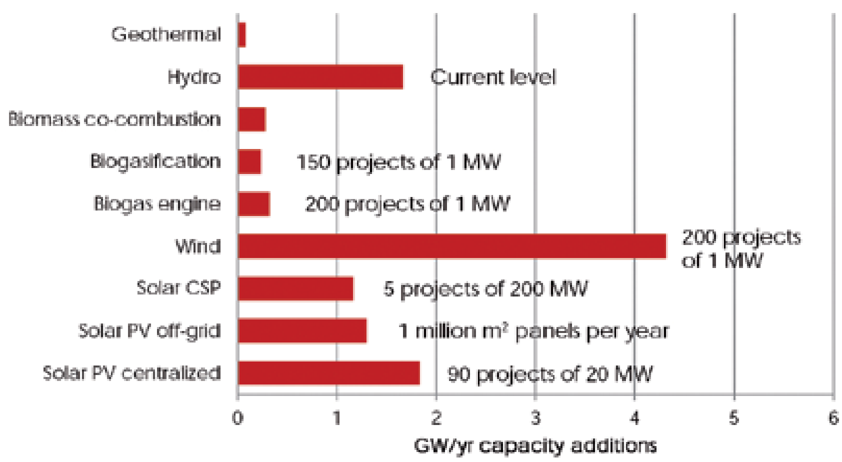


Figure 9: Installed electricity generation capacity by fuel in the Reference and Renewable Scenarios, 2008 to 2050



The difficulty of achieving the results envisaged in the Renewable Scenario should not be underestimated. The magnitude of the challenge that the Renewable Scenario faces can be shown by the annual capacity additions needed between now and 2030 (Figure 10). Today's annual capacity additions are, with the exception of hydro, nowhere near close to the numbers required. The Renewable Scenario will therefore require a very significant acceleration in renewable power generation deployment in Africa. Achieving these levels of annual deployment will be particularly challenging for wind and solar. However, these levels of capacity additions are not without precedent, as they are of a similar order of magnitude to the investments taking place in Spain or Germany, despite the much poorer renewable resources in these countries. The real challenge therefore lies in finding the funding needed and in developing the industrial manufacturing base, as well as the installation and service industries required to support these investments. Building this base and raising the local content should be a priority as it will also create jobs and help create economic growth.

Figure 10: Average annual renewable capacity additions required in the Renewable Scenario, 2008 to 2030



The capital-intensive nature of renewable power generation technologies, combined with the absence of (or low) fuel costs, implies a shift in the cost structure of the electricity system. Larger initial investments will be offset by lower fuel costs for generation. Table 15 illustrates this for the scenario analysis by providing a breakdown of the electricity system cost for the Reference and the Renewable Scenarios.

The Renewable Scenario is more expensive in the period to 2030, as total costs are USD 2.95 trillion (tr) compared to USD 2.24 tr for the Reference Scenario. The additional cost for the Renewable Scenario to 2030 is therefore USD 710 bn, or about USD 32 bn per year, or 32% more than the Reference Scenario. However, when looking longer-term at the total costs between 2008 and 2050, the undiscounted systems cost of the Renewable Scenario is about 14% (USD 1 tr) lower than the Reference Scenario. This includes the additional cost of energy access for all, without which the overall systems cost of the Renewable Scenario would be even lower.

The average annual investment between 2010 and 2030 in the Renewable Scenario is USD 133 bn per year. Recent estimates of the cost of global energy access have been put at between USD 34 bn and USD 100 bn per year (Bazilian, 2010 and IEA, 2011). Given that half of the people without access to electricity live in Africa, the cost for universal electricity access in Africa could be in the range of USD 20 bn to USD 50 bn per year. The Renewable Scenario costs, despite being based on different analysis, are broadly in line with these earlier estimates. One study estimates that, investment and operational costs of the African power sector are around USD 50 bn per year today (UNECA, 2011). Our estimate for the coming two decades is nearly three times as high, which can be explained by the much higher service level achieved as a result of universal electricity access.

Regional results

As can be expected given the different renewable resource distribution, significant differences in the power generation mix occur between the regions. In addition, intra- and inter-regional trade also grows significantly in the Renewable Scenario.

Table 15: Electricity System cost for the Reference and Renewable Scenarios

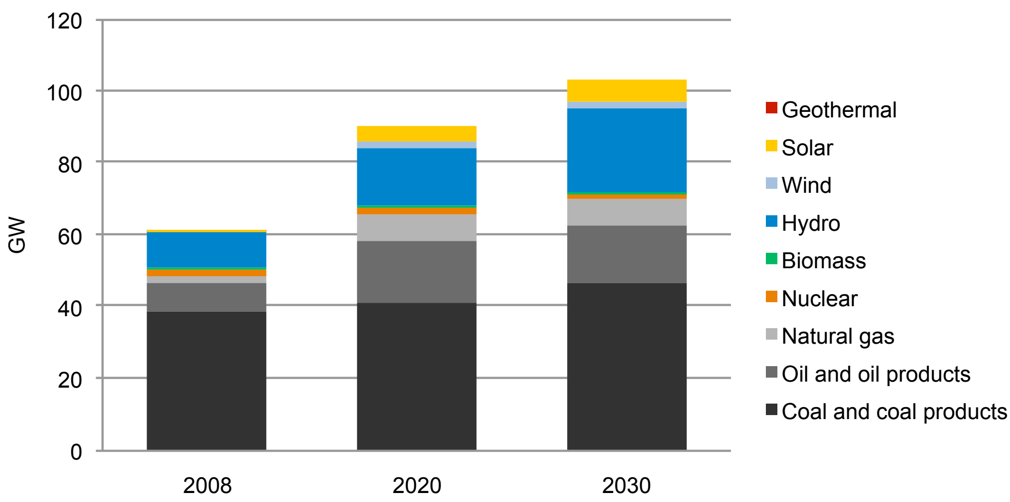
Bn USD	Reference 2008-2030	Renewable 2008-2030	Reference 2008-2050	Renewables 2008-2050
Investments	646	1,203	1,965	2,928
Fuel cost	883	693	4,475	2,180
Transmission and distribution	700	1,000	1,300	1,400
Grid investments for renewables	10	50	25	200
Total	2,239	2,946	7,765	6,708

The bulk of the lower costs in the Renewable Scenario can be attributed to the reduced electricity demand, which translates into lower fuel and investment costs.

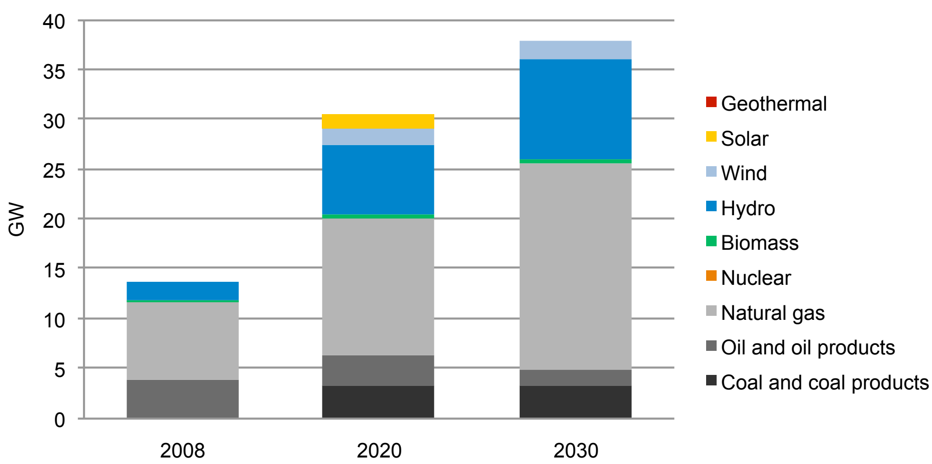
However, on a per kWh produced basis the costs of the Renewable Scenario are roughly equal to those of the Reference Scenario. It should also be noted however, that these cost calculations do not take into account the future value of the investments in renewables and infrastructure that stems from their use beyond the time horizon of the model analysis. Critically, all of this is achieved while putting in place a supply infrastructure to ensure lower-cost domestic equipment supply and O&M capacities, with their associated economic and social benefits, as well as achieving full electricity access for all Africans.

In East Africa, 34GW of new wind capacity is added. This is well below the favorable resource potential at over 30% capacity factor. In addition, 11 GW of hydro is added. The excellent wind resource allows very high average load factors (37% on average) to be achieved. Although the wind potential in North Africa is large, wind expansion is constrained to a maximum of 1 GW per year. However, even with this conservative constraint, wind still accounts for 20% of capacity in this region by 2030.

Figure 11: Renewable Scenario power capacity development for the five Africa regions, 2008-2030 (excludes DESERTEC)

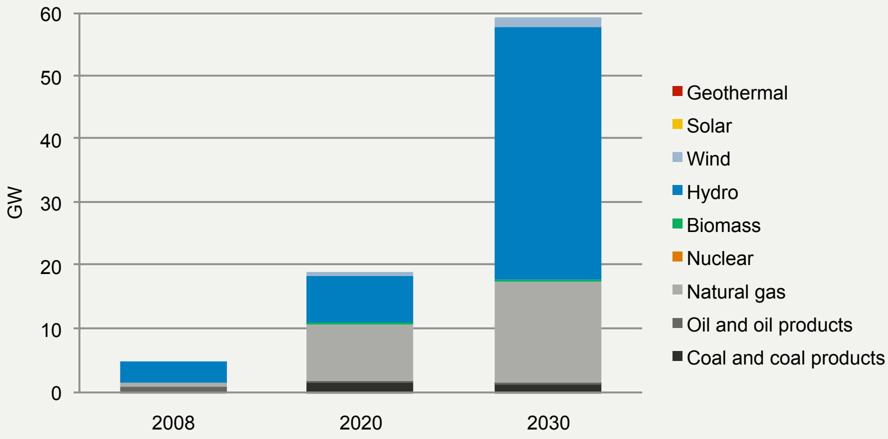


South

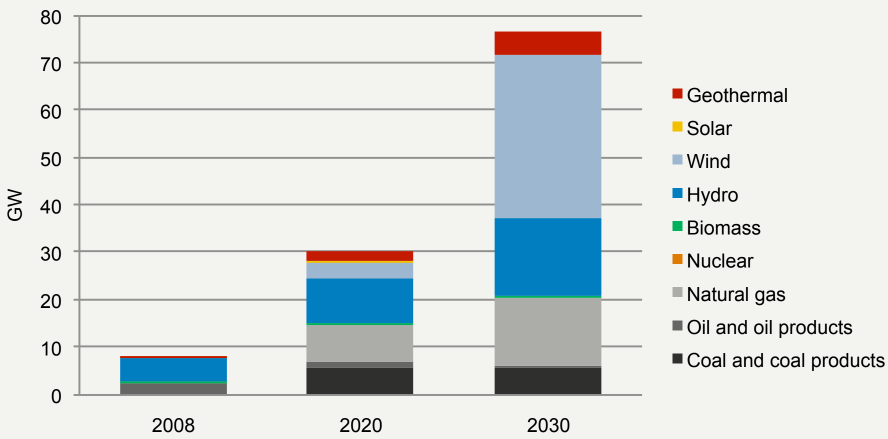


West

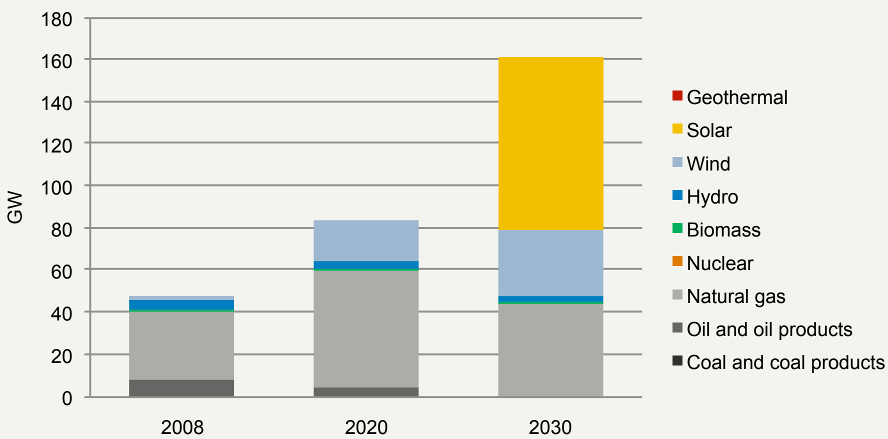
Source: Herman, et al., 2011; Howells et al., 2011; IRENA, 2011c; and IRENA, 2011d.



Central



East



North

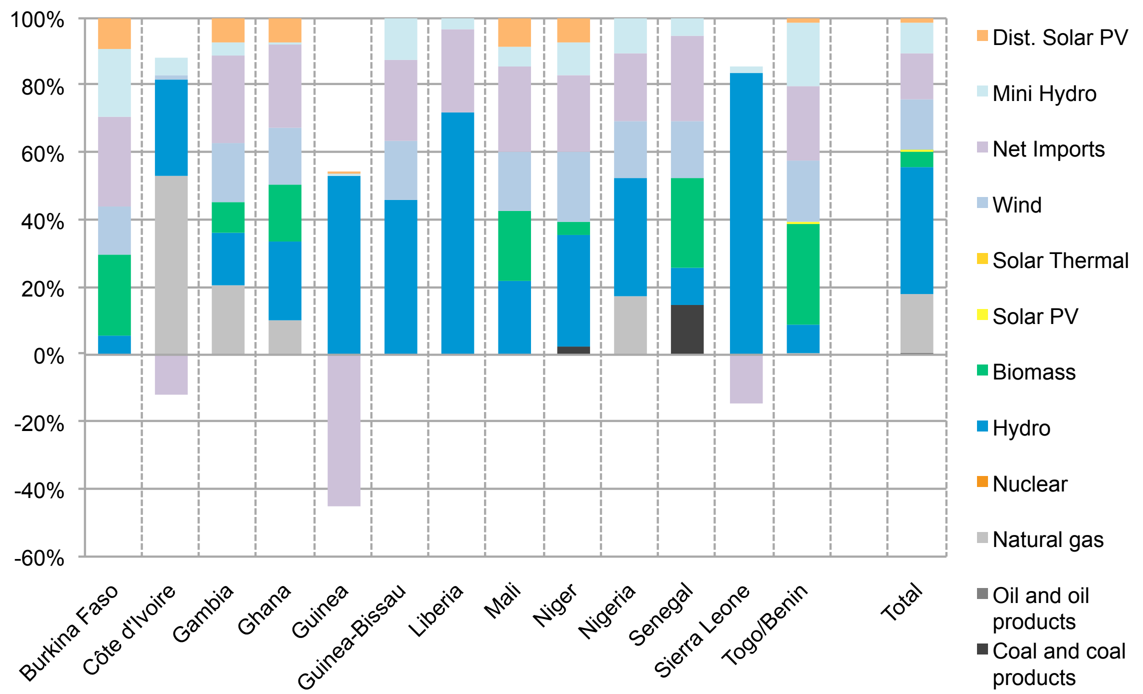
The high level of wind penetration in North and East Africa means that careful attention will need to be paid to ensuring that system reliability is maintained as the level of variable renewables grows. In East Africa, the high share of large-scale hydro in the energy mix will mean that it can act as an effective balancing tool, as long as there is better grid integration. Where hydropower is not available to provide storage, it should be possible use wind to meet the future demand for desalinated water, given that water is relatively inexpensive to store and most of the best wind resources are in coastal areas.

The rate of renewable deployment is constrained in each of the five regions to ensure realistic deployment paths. As a result, with the exception of the South, none of the regions reach their full economic investment potential in renewable power generation by 2050. In every region, apart from southern Africa, increasing the penetration of renewable electricity generation technologies would therefore be cost optimal.[18]

Electricity trade between regions is allowed in the Renewable Scenario, but growth is limited to what is economic taking into account new transmission line costs. The model assumes that HVDC transmission links between regions will increase the installed costs of any project with significant exports by USD 100/kW. The other key factor that determines the cost of exported electricity is the level of electricity losses between regions. Average losses of 7% are modelled for regional interconnection, except for interconnections between the North and other regions. Losses of around 20% are assumed for interconnections with North Africa due to the distances involved and the impact of the climate.

In the ECOWAS region, electricity supply growth between now and 2030 is dominated by large hydro and to a lesser extent wind (37% and 16% of electricity supply in 2030, respectively). Moreover in this scenario Nigeria imports significant amounts of hydropower from Cameroon and at a later stage from the Grand Inga project in the DRC. Solar capacity in 2020 is at a later stage replaced with imported hydro. The dynamics of this result need to be assessed in more detail at a later stage. In the ECOWAS power pool for Western Africa, significant differences occur in terms of the power mix for each country – ranging from purely large hydro with significant exports (Guinea) to a mixed biomass, wind and mini-hydro supply (Togo/Benin) – and in the importance of trade (Figure 12).

Figure 12: Electricity production mix in the Renewable Scenario by country and fuel in the ECOWAS power pool, 2030. Source: IRENA, 2011d



Note: Cape Verde is not shown.

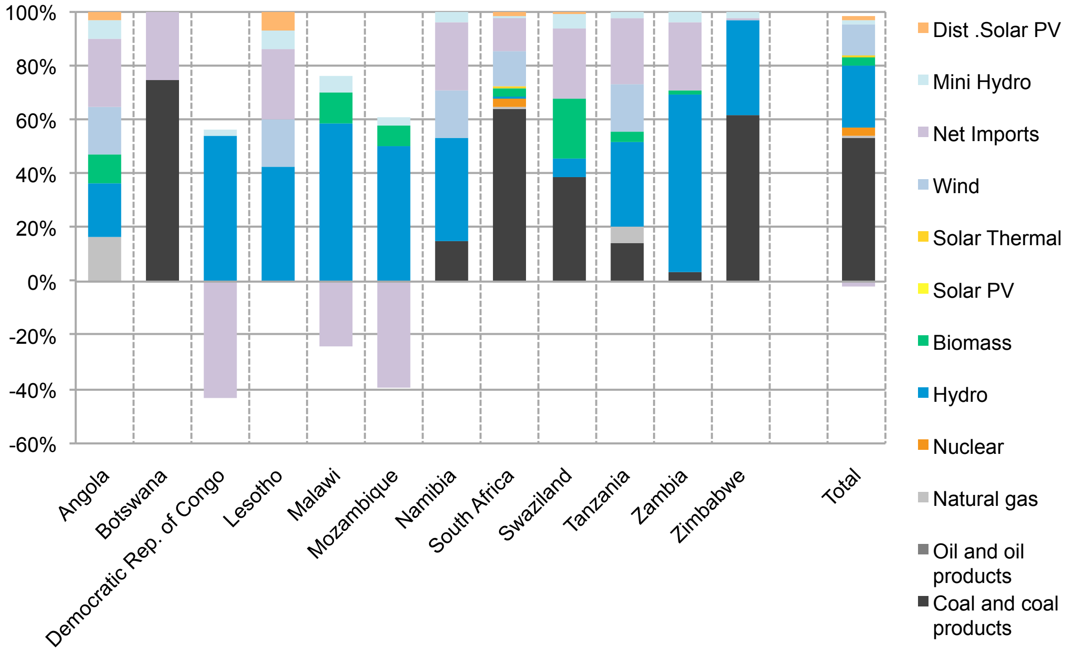
[18] *Higher rates of renewable deployment, and the necessary conditions to make this feasible, will be examined in future scenarios.*

In West Africa Burkina, Guinea, Guinea-Bissau, Liberia, Mali and Sierra Leone all have a 100% renewable electricity generation mix by 2030. Niger and Togo/Benin have very low levels of fossil fuel production. Only Cote d'Ivoire, Gambia, Ghana and Nigeria have significant fossil fuel-fired power generation. Total renewable electricity generation reaches 153 TWh in 2030 and fossil fuel-fired electricity generation is 40 TWh (virtually all gas). There is significant electricity trade, with only Niger and Togo/Benin not exporting, and only Sierra Leone not importing, some quantity of electricity.

Hydro and wind dominate the total renewable electricity generation. Large-scale hydro generates 84.1 TWh in 2030, small hydro 19.8 TWh, wind 34.5 TWh, biomass 11.6 TWh and solar PV 3.5 TWh. Wind's share of electricity (including net imports) reaches 21% in Niger. The electricity systems of Guinea, Liberia and Sierra Leone are 100% hydro by 2030, although Nigeria has the largest output (51.7 TWh).

In the SAPP region, coal remains an important source of electricity in the Renewable Scenario despite policy efforts. However, the addition of capacity is dominated by renewables, notably hydro and wind, so that the share of electricity generation from fossil fuels drops below 60% by 2030. In the SAPP power pool, significant differences occur in terms of the power mix. Large-scale hydro dominated systems evolve in the DRC, Mozambique and Malawi, while coal still dominates in Botswana, South Africa and Zimbabwe.

Figure 13: Electricity production mix in the Renewable Scenario by country and fuel in the SAPP, 2030.
Source: IRENA, 2011c



In southern Africa, South Africa is the main power market today. Its relevance will decrease as other economies in the region grow at a faster rate, but even so, it will still account for two-thirds of power generation in the Southern region in 2030 and its dominance will not be eroded until well after 2030.

In South Africa coal-based power generation dominates. South Africa has benefitted from low electricity prices based on power generation from low-cost, local coal. However, electricity prices are rising rapidly. Eskom's (the South African utility) nominal tariffs rose 24.8% in 2010/2011 and are scheduled to increase by 25.8% in 2011/2012 and a further 25.9% in 2012/2013. The average electricity price will rise to USD 0.082/kWh (R 0.65/kWh) in 2012/2013 in nominal terms as a result. This excludes the distribution cost. If these are added, the average domestic tariff will be USD 0.10/kWh in 2013 and be as high as USD 0.17/kWh for large domestic consumers.

These cost increases suggest that coal's competitiveness and dominance may be being undermined. The latest trends in wind costs[19] suggest that in areas of South Africa with good wind resources, independent power producers using wind could compete with Eskom without subsidies in the near future. Similarly, although solar is not currently a priority for South Africa, the rapid decline in PV costs means PV could soon achieve an LCOE of USD 0.10 to USD 0.15/kWh in South Africa. As a result, solar PV could rapidly become competitive if even a modest a CO_2 reduction incentive were to be introduced.[20]

Renewable energy forms a key part of the country's Integrated Resource Plan, or IRP, which envisages that renewable energy technologies will contribute 42% (17.8 GW) of South Africa's new generation capacity by 2030. If this is achieved, hydropower would account for 7% of generation capacity and wind for 14% (GSA, 2011).

In addition to indigenous renewable production, South Africa will import significant amounts of renewable electricity. The Lesotho Highlands Power Project (LHPP) will generate 6 GW of wind power and 4 GW of hydropower, mainly for export to South Africa. This is equivalent to nearly one-quarter of South Africa's total current energy supply. The Grand Inga and other large projects will also find a large export market in South Africa in the coming decades.

Sensitivity of South Africa's electricity system to different CO_2 price assumptions

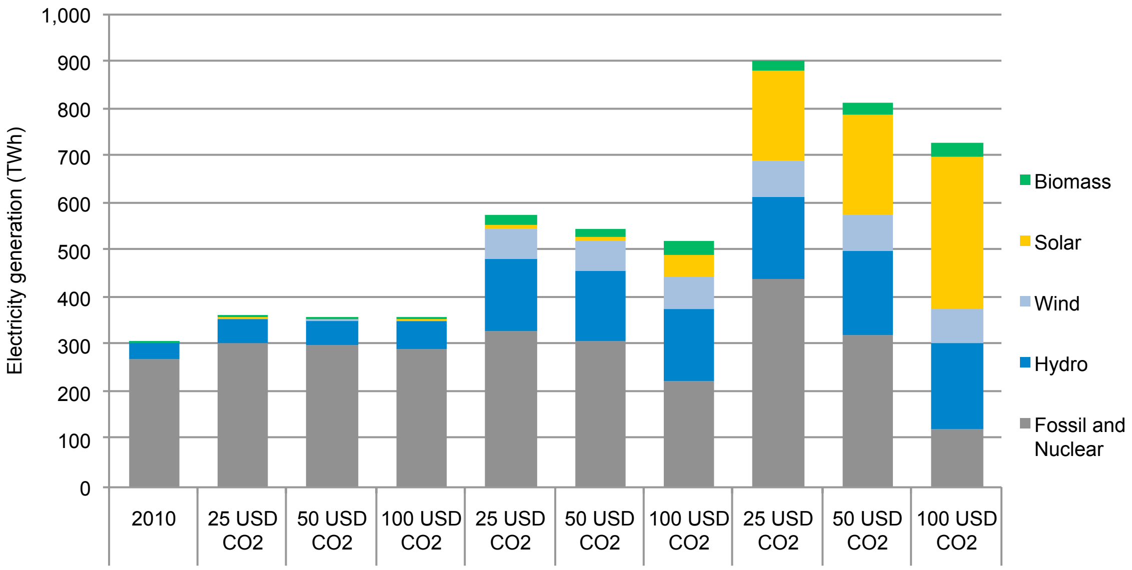
Given the dominance of coal in power generation in South Africa, the sensitivity of the results for South Africa to CO_2 prices was analysed. In addition to the Renewable Scenario's assumed CO2 price of USD 25/t CO2, scenarios examining a CO_2 price of USD 50/t CO_2 and USD 100/t CO_2 were also examined.

In the USD 50/t CO_2 and USD 100/t CO_2 scenarios electricity demand is 10% and 20% respectively lower than in the Renewable Scenario, due to price increases. The impact of raising the CO_2 price to USD 50/t is slight in 2030. However, by 2050 the impact is more significant. The impact of raising the price to USD 100 /t CO_2 has a more dramatic effect in 2030, as the share of renewables rises to 57% and to 83% in 2050. Most of the additional renewable capacity to 2030 in this scenario is wind, solar and biomass given that hydro development cannot be accelerated much more in this timeframe than is the case in the Renewable Scenario. By 2050, solar dominates in the USD 100/ t CO_2 scenario, as hydro and wind reach their constraints and CSP with 15 hours of thermal storage is relied on to provide quasi-baseload capacity in the place of coal.

[19] *In the last Brazilian auction earlier this year wind was offered for USD 0.065/kWh. Although these values are perhaps not easily replicable, it suggests that with good resources competitiveness may not be far off for wind in South Africa.*

[20] *With an average electricity price of USD 0.82/kWh in 2012/2013, a CO_2 price of USD 25/t would increase the cost of coal-based power generation by USD 0.025 / kWh and make solar PV cost-competitive in some situations.*

Figure 14: Impact of different CO_2 price assumptions on electricity generation by fuel in South Africa, 2008 to 2050



5. Conclusions and recommendations

Conclusions

The Reference Scenario indicates that Africa will need to make large investments in new power generation capacity (more than 250 GW) in the coming two decades to meet demand growth. Africa faces a unique opportunity as nearly two-thirds of the additional capacity needed in 2030 has yet to be built. The continent can benefit from the recent global progress in renewable power generation technologies and their cost reductions to leapfrog the development path taken by industrialised countries and move directly to a renewable-based system. This working paper suggests that hydropower, onshore wind, solar PV and CSP can play a key role in increasing electricity supply in Africa. Beyond 2030, the Renewable Scenario outlines a pathway where virtually all the growth in supply could come from renewables.

Africa is endowed with vast untapped renewable energy resources that can provide electricity for all across the continent at an affordable cost. Many African countries have ambitious plans to increase the share of renewables in their electricity mix. The Renewable Scenario highlights that in many cases, this could be a least-cost development pathway in the future if the right policies are in place, particularly for bringing electricity access through renewable off-grid systems to millions of Africans currently lacking access to the grid.

Large hydropower is the least-cost renewable energy solution today. This is followed by onshore wind, biomass and geothermal. Solar is still more expensive, but has a huge potential and costs are rapidly falling.

In the long term, the development of manufacturing clusters and the promotion of an increasing share of locally-manufactured content will help reduce costs even further and allow a transition away from imported equipment. However, the high cost of inland freight transport and basic materials (e.g. cement and steel) will still raise plant costs in many parts of Africa.

Renewable power generation technologies alone will not meet Africa's energy challenges. Nevertheless, the Renewable Scenario shows that it is possible to rapidly expand the supply of renewables-based electricity and achieve universal electricity access in Africa by 2030. Renewables can thus play a vital role in overcoming the two key energy challenges Africa faces in the future.

In the Renewable Scenario, half of Africa's electricity production in 2030 would come from renewable sources. Hydro would provide 17%, wind 14%, solar 14%, and bioenergy 5%. By 2050 Africa's power generation would be dominated by renewables and fossil fuels would provide just 23% of total generation, down from 84% today. However, because renewable resources are not evenly distributed geographically, the outlook by country and by region looks different from the average for Africa. To simplify, in North Africa solar and wind are the preferred renewable solutions, while in East Africa and, to a lesser extent southern Africa, it is a combination of wind and hydro. In Central Africa and West Africa hydro is the dominant solution.

The Renewable Scenario implies higher investment costs than in the Reference Scenario up to 2030, but it significantly reduces the undiscounted energy system costs over the long run to 2050 by reducing fuel costs (and as a consequence fuel import costs). In the Renewable Scenario, the total energy sector costs (investment and fuel) between 2008 and 2030 are USD 2.7 trillion, USD 710 bn higher than in the Reference Scenario. However, over the period 2008 to 2050 the undiscounted total system costs (including fuel cost savings) are USD 1 trillion lower than in the Reference Scenario.

These investment figures mask significant additional macro-economic benefits. If the local content of renewables projects can be raised, it will result in lower absolute costs per kW and improved balance of payments positions, as well as higher economic activity and sizeable job creation.

Africa's renewable energy potential is not evenly distributed and not always located close to demand centres. Very large investments will therefore be needed in electricity transmission lines. This includes special interconnectors between countries and power pools. These investments will require a long-term vision and need government support. They will only take place if investors believe in the stability of the policy framework and are confident of making a fair return on their investment. These interconnections are necessary for the development of large-scale renewable projects, will help improve security of supply, and facilitate the integration of an ever-increasing share of variable renewables into the generation mix.

To achieve the results foreseen in the Renewable Scenario, it is essential that policies supporting the deployment of renewable power generation options are complemented by increased efforts in the efficient use of electricity. This will allow a given investment in renewable power generation to meet the electricity needs of a larger number of African citizens than would otherwise be the case.

In the Renewables Scenario, which achieves universal electricity access by 2030, additional investment needs are colossal in the period to 2050 and beyond the scope of government budgets. The level of carbon funding that is being discussed today is small compared to the levels of investment that will be needed in Africa. Even if public funding is forthcoming, it is uncertain just how much and how stable the flows might be. The required level of investments will only be achieved if supported by public-private partnerships. Therefore the policy framework needs to provide equal opportunities for large- and small-scale projects to compete on merit. The alternative is that a high-risk environment will restrict investments to a few limited projects with exceptionally high returns. This would condemn Africa to ongoing energy shortages, reduce GDP growth and mean that millions of Africans would still be without access to electricity.

Recommendations and future work

The following section seeks to highlight some of the key recommendations and areas for future work that have emerged from the scenarios and strategy analysis for Africa to date. Areas of future work could include policy development or regional co-operation identified as critical to the scenario pathways. They could also point to areas of future research that would greatly improve the accuracy and value of the scenario analysis.

Better publically-available data on resource potentials is required. While the potentials are in many cases understood, verifiable data is often not available, and better resource measurements are needed to support bankable project proposals. Therefore, an important requirement is that resource potential data is developed on a sufficiently detailed level to remove this barrier.

Off-grid solutions are of special importance in Africa and should be the focus of increased policy efforts. The cost of PV panels is falling rapidly and off-grid solar PV systems are already cost-effective today compared to diesel generators. However, a massive roll-out would require new electricity storage solutions. Mini-grids involving small hydropower, solar PV and/or biomass plants can serve as a stepping stone towards electrification, followed by integration with the grid at a later stage. Mini-grids and off-grid solutions should be seen as complementary to grid extensions even in the long term. While they may only represent a small part of total demand they are vital to reach universal access by 2030. Adequate policy attention should be provided to accelerate their deployment at scale. Strategies for community power and distributed generation based on renewables can help to accelerate electricity access.

The cost of equipment is a key hurdle for most renewables. Currently Africa must import most of this equipment. Therefore, it is essential to reduce this cost through import tax exemptions, and by developing and strengthening the national equipment supply chains. The expertise necessary to develop local equipment manufacturing industries already exists in many countries but should be further developed. IRENA has started a targeted analysis of the competitive advantages of this approach and hopes to report in early 2012.

Land use planning, water resource management, food production and agricultural productivity enhancements must be integrated with energy planning, especially in the case of large hydropower and bioenergy projects. This nexus approach requires further research and analysis to understand the real impacts and interactions of different policies.

Improved energy sector planning: Energy planning tools and scenarios should be more systematically applied to the development of policy strategies. Governments might consider developing improved, publicly-available datasets including energy balances and technology-related information. Integrated resource planning is critical to leverage the resource potential in a sustainable manner, Integrated planning also entails balancing of supply- and demand side opportunities to make energy more reliable and affordable.

Expanding regional power trade. Power trade holds the key to transformative impact; it is critical to unlock the continent's large renewable potential, raise efficiency and put Africa on a lower GHG-emissions path. Large hydropower projects that may not be economically viable for one country alone become highly valuable when they accommodate demand from multiple countries. Security and reliability of supply can be greatly improved at regional. Building interconnections is the first step towards integration. However, regional planning; harmonization of standards, practices, grid codes and regulatory arrangements; coordinated energy system planning and operation at power pool level; and equitable commercial framework for energy trading represent the soft infrastructure of power pools and are as much important as building the wires. Countries need to commit to regional priorities and develop integrated resource planning at national level consistent with them.

Recommitting to the reform of the power sector. Creditworthy national utilities are a key element to create an enabling environment for PPPs. Adequate utility capacity for project management is also essential for sustainable implementation of investments. In many countries grid access could be improved for independent producers.

Further sensitivity analysis is required to refine the scenarios and strategies analysis for Africa. It is essential to undertake sensitivity analysis in order to identify key parameters. With high levels of trade and variable generation, the coordinated development of a strong transmission system is important. The effects of varying transmission costs and losses should be further investigated. In this analysis, the cost of fossil fuels should be varied in order to determine the relationship between international gas prices, local coal, as well as oil and renewable energy deployment by region. Similarly, the cost of key renewables technologies should be further investigated in order to determine at what price range they become cost-optimal. This is particularly important as various costs are expected to fall in line with the learning process.

There are significant gaps in our knowledge on a wide range of topics in Africa and more studies are required. Future studies – beyond the scope of this project – should include, among others, the potential for system balancing, transmission development and the role of smart grids (in the context of variable loads, such as desalination).

More analysis of the potential for local content in equipment manufacturing is warranted. The next step in the Africa Scenarios and Strategies Project is a study on the current situation of the equipment supply. This will help to develop strategies to increase local content and reduce equipment costs. It will show how a transition to renewables can be combined with accelerated growth and the creation of new economic activity.

This upcoming study will include: an analysis of the current renewable energy equipment supply situation in Africa for wind, solar PV, solar CSP, hydro, biomass combustion, biomass gasification, first and second generation biofuels, industrial biofuels, and solar water heaters; an assessment of the main barriers to building a manufacturing base and/or for using renewable energy equipment (patents, technical expertise, capital, economies of scale etc.); and an outline of potential solutions to address these barriers.

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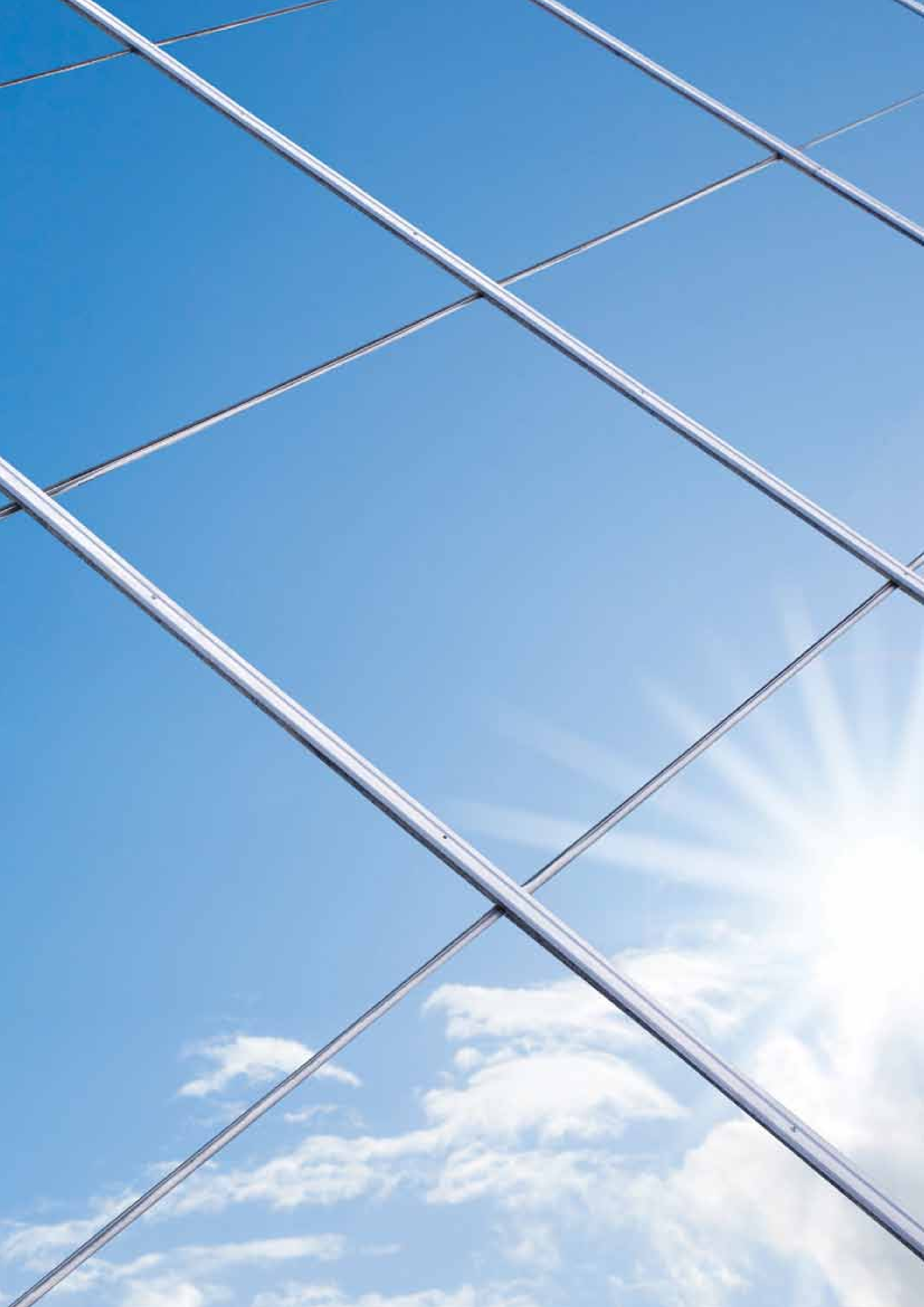
Acronyms and abbreviations

AUC	African Union Commission
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
EAPP	East African Power Pool
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
EUR	Euro
GDP	Gross Domestic Product
GEAI	Geothermal East Africa Initiative
GHG	Greenhouse Gas
GW	GigaWatt
HVDC	High Voltage Direct Current
IRP	Integrated Resource Plan
kWel	kiloWatt electric
LCOE	Levelized Cost of Electricity
Mtoe	Millions of tons of oil equivalent
MW	MegaWatt
NAS	Sodium-Sulphur batteries
O&M	Operation and maintenance
OECD	Operation for Economic Co-operation and Development
PV	PhotoVoltaics
SAPP	Southern Africa Power Pool
T&D	Transmission & Distribution
TWh	TeraWatt hour
USD	United States Dollar



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