IRENA

International Renewable Energy Agency

AFRICA POWER SECTOR: Planning and Prospects for Renewable Energy

SYNTHESIS REPORT

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org

Acknowledgement

The main body of this report is based on six previously prepared studies on the prospects for renewables in Africa. One addresses potential for renewables in the continent as a whole, and that information was used in the other five, which address regional prospects for deploying renewables (West, Southern, Central, East, and North, in the order of publication date). IRENA prepared these six reports in close collaboration with several partners.

For *Planning and Prospects for Renewable* Energy reports for West Africa and for Southern Africa (IRENA, 2013a, 2013b), Bruno Merven (University of Cape Town) conducted the major development work on the system planning model for West and Southern Africa (SPLAT-W and SPLAT-S), provided modelling support in the development of future scenarios and contributed in interpreting the results. The International Atomic Energy Agency (IAEA) made earlier models available to IRENA for the West and Southern African power sectors. IRENA is also grateful to Mario Tot of the IAEA for providing inputs for model enhancement. For *Planning and Prospects for Renewable Energy* reports for Central, East and North Africa (IRENA, 2015a, 2015b, 2015c), Sweden's Royal Institute of Technology (KTH) executed the development work for SPLAT-C, SPLAT-E, and SPLAT-N. The main contributors from KTH on these reports are Mark Howells (overall coordination), Oliver Broad (SPLAT-N), Nawfal Saadi (SPLAT-E), and Constantinos Taliotis (SPLAT-C).

A resource-assessment paper, *Estimating the Renewable Energy Potential in Africa* (2014), was also prepared by IRENA in cooperation with KTH. Sebastian Hermann (KTH) prepared GIS data based on IRENA's Global Atlas database and analysed it. The results of this study were used as inputs to the five regional reports.

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Disclaimer

Africa Power Sector:
Planning and Prospects for Renewable Energy

Synthesis Report

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Abbreviations

ACEC	Africa Clean Energy Corridor
AVRIL	Addressing Variable Renewables in Long-term Energy Planning
CCGT	Combined Cycle Gas Turbine
CO_2	Carbon Dioxide
COMELEC	Comité Maghrébin de L'Electricité (Maghreb Electricity Committee)
CSP	Concentrated Solar Power
DIVE	Diversification and Environmental Investment
DRC	Democratic Republic of Congo
EAC	East African Community
EAPP	Eastern Africa Power Pool
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
GIS	Geographic Information System
GW	Gigawatt
HFO	Heavy Fuel Oil
IRENA	International Renewable Energy Agency
IAEA	International Atomic Energy Agency
KTH	Royal Institute of Technology (Sweden)
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impacts
MoU	Memorandum of Understanding
Mton	Megatons
MW	Megawatt
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
OCGT	Open Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and Maintenance
PEAC	Pool Energétique de l'Afrique Centrale (Central African Power Tool)
PIDA	Programme for Infrastructure Development in Africa
PIK	Potsdam Institute for Climate Impact Research
PJ	Petajoules
PV	Photovoltaic
SADC	Southern African Development Community
SANEDI	South African National Energy Development Institute
SAPP	Southern African Power Pool
SPLAT	System Planning Test Model
T&D	Transmission and Distribution
TWh	Terawatt-hour
UNECA SRO-EA	United Nations Economic Commission for Africa Sub-Regional Office for Eastern Africa
USD	United States Dollars
VRE	Variable Renewable Energy
WAPP	West African Power Pool

1. Introduction

Renewable energy resources are plentiful in Africa, including solar, wind, biomass, geothermal and hydro. These resources are spread across the continent and could provide affordable and secure supplies of energy where they are in high demand. Renewables could help diversify energy supply and contribute to universal and sustainable energy access. Markets for renewable energy are growing fast in some countries in Africa and that trend is spreading. A long-term vision to support effective investment in renewables is crucial to ensure the best use of available regional resources by countries and regional groups.

The International Renewable Energy Agency (IRENA) Regional Action Agenda calls for countries and regional organisations to consider cost-effective renewable power options for optimising investment in electricity generation and transmission infrastructure. Renewables should be considered when planning for the future and in establishing long-term master plans in light of their declining costs, energy security, and environmental and socio-economic benefits. Planning is critical to ensure effective energy infrastructure and development and to achieve sustainable development goals. It creates a predictable environment that will help countries attract outside investment in energy infrastructure. There are currently several obstacles to producing such plans, including limited access to data on renewable resources and technologies to harness them, and a shortage of expertise, tools and methodologies. Institutional and human capacity should be enhanced to overcome these challenges.

This report presents a summary of IRENA's first attempt to systematically assess the prospects for renewable energy deployment in the African power sector by 2030. Sub-regional least-cost energy-supply options are explored under different policy assumptions using IRENA's System Planning Test (SPLAT) model. The report was prepared using the work of six previously prepared IRENA studies – one surveying renewables potential across continent (IRENA, 2014) and five separate assessments of how they could be deployed in specific regions (IRENA, 2013a, 2013b, 2015a, 2015b, 2015c). These areas were loosely defined according to Africa's five existing power-pool institutions: Comité Maghrébin de L'Electricité (COMELEC) in North Africa, the West African Power Pool (WAPP), Pool Energétique de l'Afrique Centrale (PEAC) in Central Africa, the Eastern Africa Power Pool (EAPP), and the Southern African Power Pool (SAPP). In this paper, these five assessments are synthesised into a single discussion of renewable energy's future in Africa.

The results discussed in this paper aim to show how SPLAT models can be used in policy making. They can be used for national, regional and continental scenario analysis to help design power systems. The modelling framework provides a starting point for Africa's national and regional planning officers that allows them a structured analysis of various assumptions and results, and provides for investigation of the benefits and challenges associated with the accelerated deployment of renewables in the region.

The approach used for these analyses, the SPLAT model, is explained in Chapter 2. Chapters three through seven present summaries of each of the five regional power sector analyses and Chapter 8 synthesises them in a discussion of investment need for the continent. Chapter 9 addresses how IRENA member states can use SPLAT modelling and tools for themselves, particularly in the context of capacity building. For country planning purposes, the benefits of SPLAT include:

- country-specific power capacity expansion modelling, pre-calibrated to replicate each country's baseline data
- best available data for renewable energy potential, cost, technology performance
- consistency with the latest regional master plans
- urban and rural access considered separately
- decentralised options explicitly modelled
- regional interconnection and trade accounted for

- compatibility with other tools to identify projects
- free access and use
- support services available from IRENA and the International Atomic Energy Agency (IAEA)

In addition, the model supports the Africa Clean Energy Corridor project and REmap 2030, an IRENA-led effort to double renewables' share of the global energy mix by 2030.

Chapter 10 closes the report with a discussion of what steps can be taken next, including further development of the five SPLAT models at the country level and using national data. This could provide further validation of the results by country experts and ensure the SPLAT results are consistent with national planning goals.

2. Regional power sector: analytical approaches

Regional electricity networks are an attractive option for Africa because its energy resources are dispersed and because 84% of its borders are land borders. These factors make it suited to cross-border grid connections. IRENA conducted five concrete assessments for five groups of countries, loosely defined by the existing power pools they have formed along regional lines. Some countries are members of more than one, so figures for the whole continent cannot be derived from adding up those of the five regions.

Three of the five regional power pools have created power sector-development master plans (WAPP, EAPP and SAPP), and IRENA's assessments of renewable deployment prospects are based on those documents. IRENA has replicated their methodologies and updated them with newer assessments of potential and costs for building new renewable-energy capacity. For the regions based on the COMELEC and PEAC power pools, which have not produced master plans, publicly available information was collected and simplified assumptions were made. Potential and costs data from IRENA were also used to complete the analysis.

IRENA developed customised databases and modelling frameworks to study renewables in each region. The five assessments addresses renewable resource, deployment, investment needs, and in each case consider factors specific to those regions. The results are a policy-relevant set of scenarios for each.

Unless otherwise noted electricity production in this report refers to net production: gross production minus efficiency losses within the power plants. Demand refers to final electricity demand, defined as gross demand minus transmission and distribution losses.

The SPLAT modelling tools

IRENA'S SPLAT methodology – the set of tools used to form the regional assessments – uses a comprehensive database of existing power-infrastructure and least-cost capacity expansion models, which are a framework to calculate technically feasible and economically optimal investment paths for power generation and transmission lines. These paths are based on differing policy options available to countries and regions. A separate SPLAT model was developed for each region, and within them each country was represented separately. Interconnections within regions were also explicitly modelled.

This system-based approach of SPLAT modelling leads to better understanding of how renewable technologies would fit in a region or country's overall power sector in the future. This context is important because different electricity technologies, both renewable and others, have characteristics that impact performance depending on the time of day, week or year. Using modelling to see how they would work together under various scenarios helps to ensure that renewable-energy options are properly understood and represented in long-term energy-sector planning.

The SPLAT tools were developed using the modelling platform called Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE), which was developed at the International Institute of Applied Analysis (IIASA) and later improved by the International Atomic Energy Agency (IAEA). MESSAGE is ideal for SPLAT model development because it is already widely used in Africa and because of its flexibility. It can be used to extend the power sector analysis to cover the whole energy sector in the future, including heat and transport use of energy.

The SPLAT models define electricity demand by three types: industrial, urban and rural. This allows for analysis of different transmission and distribution requirements as well for decentralised generation options. Each demand segment is characterised by its specific daily, weekly and seasonal profile. The table below lists the technologies that could meet future demand in Africa. Their availability varies by region, and some of the decentralised options can meet only some types of demand. Differences in the capability of the various options to meet fluctuating demand are accounted for, as are their contributions to reserve margins (generation capacity that is not normally used but exists for times when extra is needed, such as when a plant has failed and needs repair).

The total technical wind potential is above 7,000 GW, but is more unevenly distributed. High quality resources (defined as having a capacity factor of 40%, meaning that annual output is at least 40% of full potential) were found in only half of African countries. All but a few African countries are endowed with lower quality wind potential (capacity factors between 20-40%), adding additional wind generation potential of more than 250,000 GW. Further assessment is needed to determine how much of this technical potential is economically viable, which would consider factors including proximity to demand centres and to existing transmission network infrastructure[3].

Table 1. Generation technologies considered in the study

	Fossil	Renewable
Centralised generation	Diesel	Geothermal
	HFO*	Bagasse Boiler
	Natural gas: OCGT, CCGT*	Hydro
	Supercritical coal	Wind
	Nuclear	Solar PV
		CSP* with storage
		CSP* without storage
		CSP combined with gas
Decentralised generation	Diesel 1kW (urban and rural demand)	Small Hydro (rural demand)
	Diesel 100 kW (heavy industry)	Solar PV without battery
		Solar PV with battery

** HFO = Heavy Fuel Oil; OCGT and CCGT = Open Cycle and Combined Cycle Gas Turbine; CSP = Concentrating Solar Power*

Renewable-based power generation potential[1]

IRENA's Global Atlas (IRENA, 2014a) is an online tool for renewable energy opportunities. IRENA and Sweden's Royal Institute of Technology (KTH) collaborated to quantify technical power-generation potential for solar and wind energy resources for each country in Africa. Technical power-generation potential calculates all possible resources and then subtracts from the final figure areas that cannot be developed for various reasons, and are considered exclusion zones. Exclusion zones are defined here as urban structures, protected land, bodies of water, forests and sloped areas[2].

The results found significant potential. Technical solar PV generation capacity for the continent is 300,000 gigawatts (GW). For most countries the range is between a few thousand and tens of thousands of GW. Current installed capacity for Africa, counting all types of generation, is 150 GW. The total technical generation potential for concentrating solar power (CSP) is about half of that of solar PV. Some West African countries have no CSP potential.

Woody biomass and sugarcane are the two main biomass sources IRENA considered for power generation in Africa. The REmap biomass assessment shows that there is almost no surplus forest available for power generation in Africa. Woody biomass potential was assessed within the REmap biomass programme (IRENA, 2014b). The potential for processing and logging residue for Africa was assessed at between 400 petajoules (PJ) to 800 PJ and 400 PJ to 500 PJ respectively. That would provide about 12GW to 20GW of power generation potential if all of the existing resources were available for power generation.

Africa's hydro potential is also vast. As of 2011 installed capacity was 26 GW, with another 20 GW

[1] This subsection is based on a 2014 working paper titled Estimating the Renewable Energy Potential in Africa, prepared under the IRENA-KTH (Royal Institute of Technology, Sweden) Project agreement (IRENA and KTH, 2014). The outcome of the analysis will be further disseminated via the Global Atlas

[2] In addition to the physical exclusion zones that were applied in this study, normal practice is to apply an arbitrary factor of about 3%-25% to further take into account legislative constraints (Black and Veatch Corp, and NREL, 2009). The study has not applied such a factor linked to legislative constraints, as we have chosen to leave these decisions up to future policy makers..

under construction. Regional master plans as well as the *Platts World Electric Power Plants Database* (Platts, 2012) list hydro projects under consideration that could add 80 GW. This is comparable to the latest estimate from Hydro Power and Dams World Atlas (Norwegian Renewable Energy Partners, 2013) that shows about 50 GW to 125 GW of additional capacity is planned to be built.

Renewable generation cost prospects

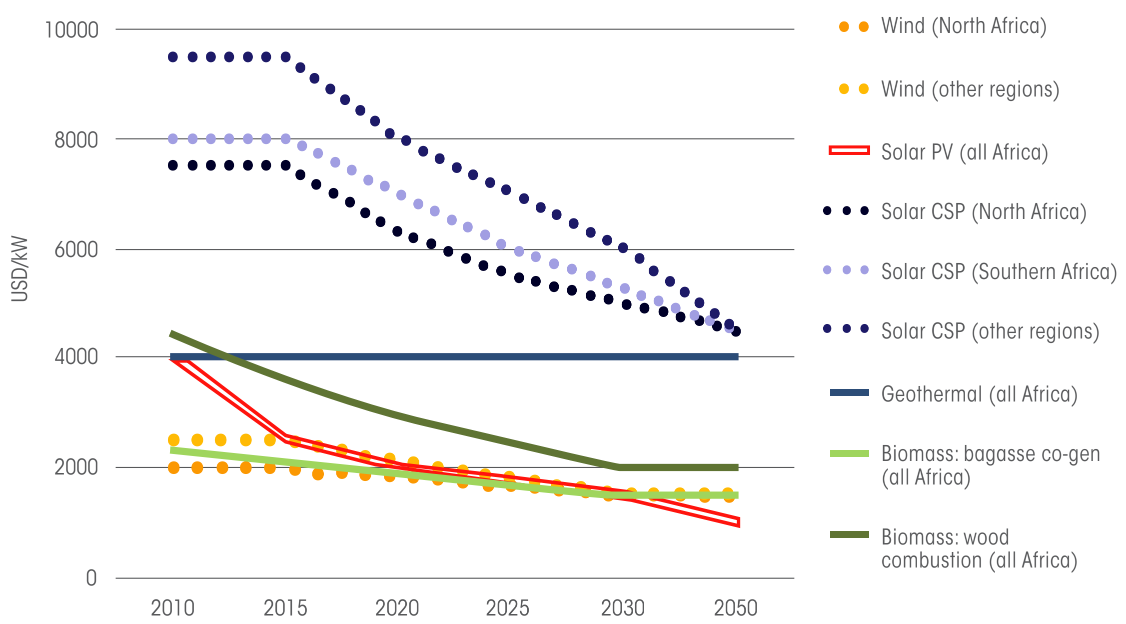
IRENA's renewable-energy costing database contains data from more than 9,000 utility-scale renewable-energy projects and partial data for another 5,000. It is continuously being expanded through the agency's Renewable Costing Alliance, a group of companies, industry associations, governments and researchers sharing data within the group on real-world renewable-energy projects. The Renewable Costing Alliance's own database is updated regularly and as of 2014 information has been logged for about 150 non-hydro projects in Africa. IRENA has observed significant cost reductions for renewable infrastructure in recent years, and these trends underscore the benefits of renewable energy and the important of active policy support to governments. African governments can lower costs for building renewable-energy facilities by benchmarking local methods to global best practices, by developing indigenous manufacturing capacity for the necessary equipment and by achieving economies of scale. Transportation and logistics costs could be lowered by streamlining regulations and tax regimes and addressing logistical bottlenecks such as roadblocks. IRENA's assessment shows that such regional efforts could considerably bring down renewable energy investment costs as shown in Figure 1.

Regional definitions and duplications

Six African countries participate in more than one power pool, and these duplications were preserved in defining the five SPLAT models. Tanzania is a member of both EAPP and SAPP, for example, and factors in both regional analyses here. Table 2 shows the list of countries that are included in more than one SPLAT models.

Demand projections and policy assumptions for all countries in a given region are derived from regional sources to ensure the consistency of policy assumptions across countries within a region. Using Tanzania as an example, assumptions for the country for the East Africa analysis were taken from the ECA/EAPP Master Plan (SNC Lavalin and Parsons Brinckerhoff, 2011). For the Southern Africa analysis Tanzania assumptions

Figure 1. Africa renewable-energy cost development assumptions (overnight investment costs)



[3] *A methodology to assess the economic viability of geographical clusters of resources is being developed by IRENA under the Africa Clean Energy Corridor Initiative and in collaboration with Lawrence Berkeley National Laboratory (LBNL and IRENA, 2014).*

came from the SAPP Master Plan. Two main differences are that in the EAPP Master Plan Tanzania's electricity demand projection is more conservative and its fossil-fuel price assumptions are lower.

Interpretation of results

Different assumptions and projections, such as those for Tanzania, are not an obstacle for SPLAT modelling or a challenge to offering quality analysis. IRENA's aim is not to precisely forecast the future, or pick from sets of assumptions the ones it believes are most realistic. Furthermore, external market factors are also important that are by definition uncertain. Another example can be found in Rwanda: under different scenarios the country may end up a net importer or net exporter by 2030. Rather than take a position on which is more realistic, this study explores the potential impacts of both. The goal is to consider different assumptions and projections and their implications, to provide a robust range of options and scenarios for policy makers and to contemplate scenarios for policy makers that will best inform policy decisions.

The results discussed in this paper show how SPLAT models can be used in policy making. The modelling framework provides a starting point for Africa's national and regional planning officers that allows them a structured analysis of various assumptions and results, and provides for investigation of the benefits and challenges associated with the accelerated deployment of renewables in the region. For energy planners in the region, IRENA recommends reviewing the modelling assumptions, adjusting them according to their own data and expectations, and assessing how the conclusions change as a result.

Table 2. SPLAT model duplications

SPLAT	N	E	C	W	S
Angola			x		x
Burundi		x	x		
DRC		x*	x		x
Egypt	x	x			
Rwanda		x	x		
Tanzania		x			x

*DRC is not included in SPLAT-E because the EAPP master plan includes only Eastern DRC

3. Five-Region Synthesis: Continental Prospects

This report's analyses provide valuable insight on the potential role of renewables in the African power sector if conditions for their deployment were optimal. Showcased in these regional studies are system-wide assessments of future investment needs for electricity generation and for national and international transmission networks. This chapter is a discussion of the five regional assessments presented in Chapters 4 to 8, and a summation of their figures to provide a continental perspective.

Two main scenarios were developed for each region, along with alternative ones as dictated by the policy questions relevant for each. In all regions one of the two main scenarios envisions fast renewable-energy cost reductions as a result of renewable-promotion policies, in order to depict a renewable-oriented transformation of the power systems. In the other main scenario a contrast is presented, with marginal deployment of renewable energy and power systems are imagined with increased reliance on fossil fuels as sources. Table 3 summarises investment needs under renewable-promotion scenarios, and Table 4 shows them assuming renewables will be a more limited part of the future mix. Six countries are analysed in more than one regional study (see Table 2), therefore a simple sum of all five regional results does not provide a total for the continent. The numbers in these tables for the continent as a whole have been adjusted to avoid double counting.

By 2030, Africa total net electricity generation is expected to be between 1,800 TWh and 2,200 TWh, approximately a threefold increase from 650 TWh in 2010. This range would require installed capacity between 390 GW and 620 GW. In 2010 capacity was 140 GW, implying that an additional 250 GW to 480 GW of new capacity is needed by 2030. The wide range reflects the fact that renewable generation typically has a lower capacity factor. More use of renewable energy in the mix means more total capacity is needed. Therefore the range for capacity needs under the renewable-promotion scenarios is substantially wider, at 430 GW to 620 GW, than in the renewable-limited scenarios, at 390 GW to 440 GW.

In financial terms, investment needs for new generation capacity between 2015 and 2030 are in the range of USD 420 billion to USD 800 billion (not discounted), which on an annual basis is USD 26 billion to USD 50bn for the 15-year period. To put this number into perspective, the Africa Energy Outlook (Sofreco, 2011) projects GDP for Africa in 2030 at about USD 13 trillion, a sevenfold increase from less than USD 2 trillion in 2010. Investment needs for transmission and distribution (T&D) range from USD 270 billion to USD 400 billion. The bulk of this investment would be for domestic transmission as opposed to international connections. T&D investment needs will be lower under the renewable-promotion scenarios in countries and regions where decentralised options play a larger role.

Whilst the deployment of hydro capacity is projected in a relatively narrow range of 72 GW to 94 GW, implying 260 TWh to 370 TWh of generation, deployment of other renewable energy would be more sensitive to the assumptions in the scenarios considered, resulting in a larger range of projected installed capacity, between 40 GW and 280 GW. Under the renewable-limited scenarios the range would be 40-50 GW, whilst in the renewable-promotion scenarios it expands to 90 GW to 280 GW. The assumptions for renewable energy cost development, which are the main drivers to account for the differences between two sets of scenarios, have strong impacts on the renewable energy deployment potential. Under the renewable-limited scenarios the share of renewables in the total generation would be in the range of 20-30% in 2030, which is an increase from 17% in 2010. Under the renewable-promotion scenarios the share would reach to 30-60% depending on the assumptions.

TABLE 3. INVESTMENT NEEDS IN RENEWABLE ENERGY-ORIENTED SCENARIOS: SUMMARY

		N	W	C	E	S	Africa
Power Gen. in 2030 (TWh)	All Sources	1,050 - 1,052	215 - 247	110 -124	577	623 - 626	**1,813 - 2,165**
	Large Hydro	10	70 - 71	55 - 57	129	92 - 139	**257 - 367**
	Other R.E.	167-469	44 - 69	30 - 44	254	120 -175	**276 - 857**
Installed capacity in 2030 (GW)	All Sources	230 - 318	63 - 72	31 - 36	187	148 -160	**431 - 620**
	Large Hydro	3	19	14 - 15	32	25 - 34	**72 - 94**
	Other R.E.	51-146	13 - 22	10 - 15	74	50 - 73	**91 - 283**
Investment, 2015-2030 (USD bn.)	All Sources	236-403	89 - 108	38 - 46	197	174 - 203	**424 - 793**
	Large Hydro	2	36 - 37	17 - 18	36	26 - 44	**84 - 128**
	Other R.E.	92-275	31 - 49	17 - 25	116	116 - 129	**165 - 505**
	T&D	184-189	48 - 52	24 - 25	147	87 - 90	**340 - 391**

TABLE 4. INVESTMENT NEEDS IN RENEWABLE ENERGY-LIMITED SCENARIOS: SUMMARY

		N	W	C	E	S	Africa
Power Gen. in 2030 (TWh)	All Sources	1052	246	110	559	634	**1,842 - 2,117**
	Large Hydro	10	70	52	85	140	**258 - 307**
	Other R.E.	80	25	3	76	44	**147 - 174**
Installed capacity in 2030 (GW)	All Sources	207	64	24	128	125	**391 - 444**
	Large Hydro	3	19	13	25	35	**74 - 83**
	Other R.E.	24	6	1	19	14	**41 - 50**
Investment, 2015-2030 (USD bn.)	All Sources	211	87	28	125	194	**458 - 538**
	Large Hydro	2	36	16	28	45	**94 - 113**
	Other R.E.	56	21	2	39	33	**87 - 120**
	T&D	188	46	24	145	111	**269 - 397**

4. West Africa Power Sector[4]

The West Africa power sector analysis includes the following 14 countries: Benin, Burkina Faso, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. The SPLAT model used for analysis was primarily built on the Economic Community of West African States (ECOWAS) Revised Master Plan for the Generation and Transmission of Electrical Energy (WAPP, 2011), in which different power generation and transmission projects are analysed and evaluated from technical and economic perspectives within the time horizon of 2011-2025.

Current situation

In 2010 total installed capacity was 10 GW, producing about 50 terawatt hours (TWh) of electricity. More than 90% of capacity comes from Nigeria, Ghana and Cote d'Ivoire. Half of this grid-connected capacity uses natural gas in thermal power plants, a fifth comes from hydropower and the remainder from mostly oil. Current grid-connected capacity lags demand, and consumers use diesel generators to bridge the gap. Generator-based capacity is estimated at more than 1 GW. The current contribution of renewables – excluding hydro – is insignificant in the region for both centralised and decentralised generation. Electricity trading in the region accounts for just 5% of gross demand, but countries including Togo, Benin, and Niger rely almost entirely on imports to meet demand.

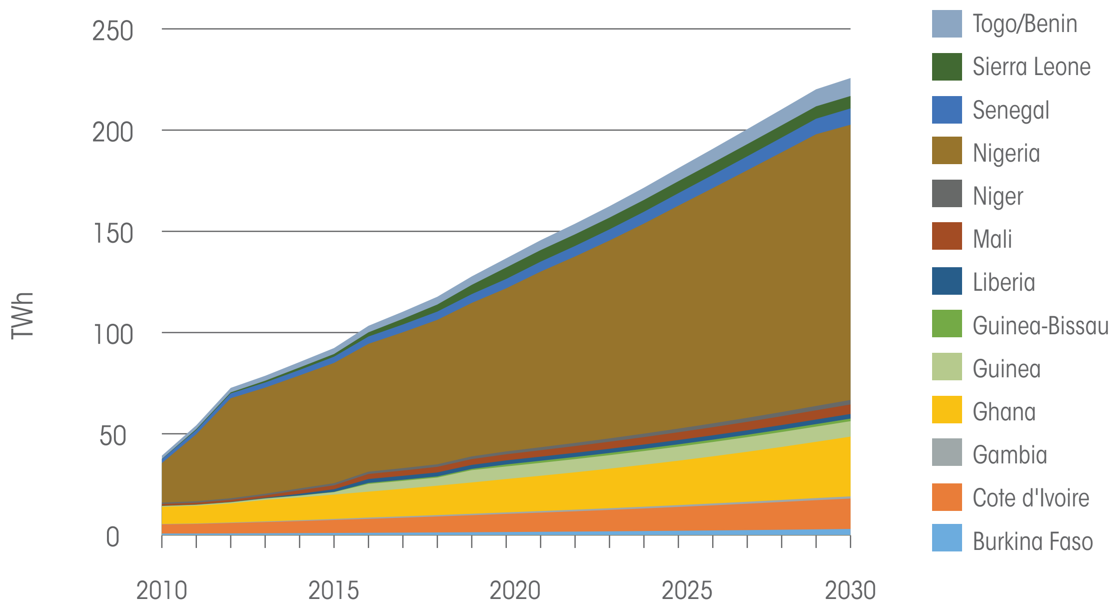
Demand projection

Electricity demand is projected to increase fivefold by 2030, to 250 TWh (Figure 2). This estimate was adapted from the ECOWAS Master Plan and includes demand from mines, which are accounted for separately in the Master Plan and in some countries are a significant driver of electricity demand. Currently, 87% of demand comes from urban users, with almost all of the rest from industry. Rural demand is insignificant. That mix is projected to change by 2030, with urban demand dropping to 48% of the whole, industrial demand rising to 45% and rural demand climbing to 7%.

Regional energy sources

Natural gas deposits are located offshore in the Gulf of Guinea in the territorial waters of Nigeria, Cote d'Ivoire, and Ghana. The West African Gas Pipeline, which traces the coastline from Nigeria through Benin and Togo to Ghana, can also be used to send Nigerian gas to those countries.

FIGURE 2. WEST AFRICA: FINAL ELECTRICITY DEMAND BY COUNTRY



[4] *This subsection is based on the executive summary of: West Africa Power Pool: Planning and Prospects for Renewable Energy (IRENA, 2013a) and Pool Énergétique d'Afrique de l'Ouest: Planification et perspectives pour les énergies renouvelables (IRENA, 2014)*

Most West African countries with existing hydro capacity still have vast untapped hydro potential. The ECOWAS Master Plan identified hydro projects equivalent to about 12 GW, including 3 GW each in Nigeria and Guinea, and 1 GW in Cote d'Ivoire. Additional hydro projects of about 7 GW for Nigeria were included in this analysis.

On a per-square-metre-basis all countries have very large solar PV potential except for Liberia and Mali. Gambia and Guinea-Bissau have the highest potential for solar CSP. In absolute terms Nigeria and Niger have the biggest potential both for solar PV and CSP. High-quality wind resources were identified only in Niger and Senegal. Burkina Faso, Gambia, Nigeria have large potential for middle-quality wind.

Bagasse-based power generation potential was estimated to be about 20 GW in the region, with about half of the total from Nigeria. Burkina Faso, Cote D'Ivoire, Ghana, Niger, and Mali also have high potential.

Scenario description

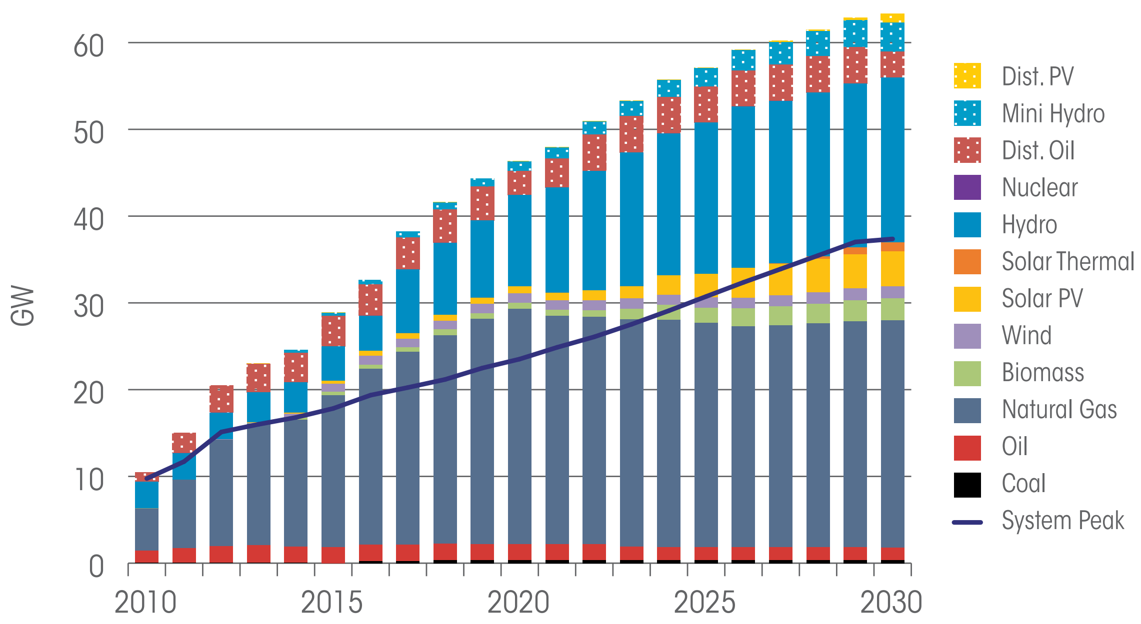
A reference scenario in which renewables are not promoted, another in which they are, and two variations of that renewables-promotion scenario have been assessed. The reference scenario was designed to replicate the ECOWAS Master Plan. The renewable-promotion scenario and its two variations increase the role of renewable energy through policy-driven renewable-energy cost reductions and increased fossil fuel prices. Imported electricity from Central Africa was included as an option after 2025, based on the availability of hydro power from the Grand Inga project in the Democratic Republic of Congo (DRC). The energy-security scenario, a variation of the renewable-promotion scenario, assumes a ceiling on imports at 25% of electricity demand for each country. Another variation excludes imports from Central Africa as an option. In all scenarios the progressive availability of carbon finance is assumed, starting from USD 0 per ton of CO_2 and reaching USD 25 by 2030.

Results

More than half of the 10 GW of existing capacity as of 2010 is expected to be retired before 2030. To meet demand, more than 60 GW of additional capacity would be needed by 2030, almost half of which would be met by renewable technologies under the renewable-promotion scenario. That includes more than 13 GW of non-hydro renewables, of which 4 GW would be decentralised options. The mix of installed generation capacity between 2010 and 2030 is shown in Figure 3.

Under the renewable-promotion scenario renewables including hydro would account for more than 50% of generation share by 2030, rising from the current level of 22%. Whilst the region's potential in hydropower would remain important, non-hydro renewables would increasingly contribute to the generation mix, climbing to approximately 20% of

Figure 3. West Africa: Installed capacity by source under the Renewable-Promotion scenario



the total by 2030. Solar PV, small-scale hydropower and biomass would be the largest contributors, followed by solar CSP and wind power. The reference scenario envisions renewables accounting for less than 40% of capacity, comprised of mostly hydro power and supplemented by biomass. Natural gas would remain the most important source for power generation.

The regional picture is to a large extent determined by Nigeria and Ghana, which account for about 60% and 10% of regional electricity demand. Figure 4 shows the electricity supply mix (generation and net import) for each country under the renewable-promotion scenario. Across the region renewable technologies are a path to diversification of energy sources. Hydropower is a significant source in Cote d'Ivoire, Guinea-Bissau, Liberia, Nigeria and Sierra Leone and Ghana. Solar PV, wind, and biomass-based electricity generation remain a small part of the overall regional electricity generation mix in some countries. The three technologies together account for more than 90% of domestically produced, grid-connected electricity in Burkina Faso, Togo and Benin and more than 60% in Gambia, Guinea-Bissau and Senegal.

By 2030 West Africa could benefit from importing more than 30 TWh of hydroelectricity via DRC and Cameroon, but Guinea also has the potential to become an electricity exporter, by sending more than 4 TWh of electricity to neighbours such as Guinea-Bissau, Mali, Senegal and Sierra Leone, as well as to Cote d'Ivoire through Liberia (Figure 5). Cote d'Ivoire would then export to Mali, Burkina Faso and Ghana. Some countries are currently net exporters but would become net importers by 2030, including Nigeria and Senegal. Analysis of the scenarios considered indicates that the DRC's Grand Inga project is a key variable for the future power prospects of West Africa. Without it, solar and biomass technologies would be further deployed to make up the gap. In the scenario in which no country imports more than 25% of its needs, these regional results are roughly the same, although in some countries additional local solar capacity would replace those imports.

Economic implications

Figure 6 shows required total system costs under the renewable-promotion scenario between 2010 and 2030, including investment cost, fuel costs, net-import cost, and operation and maintenance (O&M) cost. The numbers are annualised and undiscounted. Overall investment needs in the region during this period amount to USD 170 billion, with domestic transmission and distribution (T&D) costs and cross-border transmission lines comprising about 37% of the total. Under the renewable-promotion scenario the average cost of electricity generation would drop from USD 139 per megawatt hour (MWh) to USD 128 per MWh by 2030, because of a reduced reliance on liquid fuels for power generation. Without imports from Central Africa there would be a smaller savings, however. The average cost of USD 132 under that scenario implies that inter-regional electricity trade could reduce West Africa's average generation costs in 2030 by 3%.

Figure 4. West Africa Electricity supply mix (generation and net imports) under the Renewable-Promotion scenario

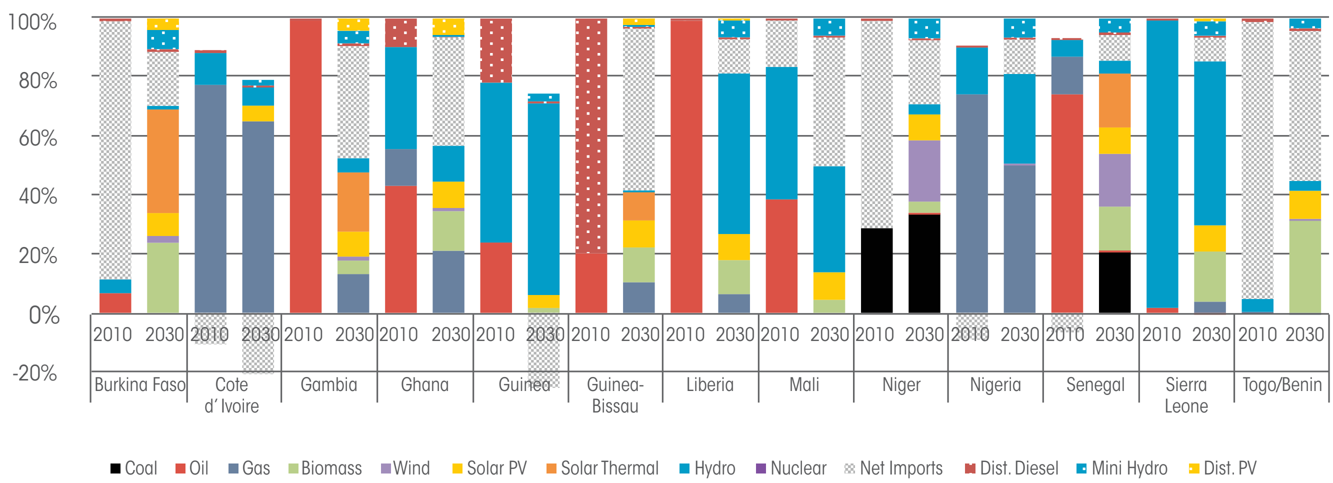


Figure 5. West Africa: Regional Trade in 2030 in the renewable-promotion scenario

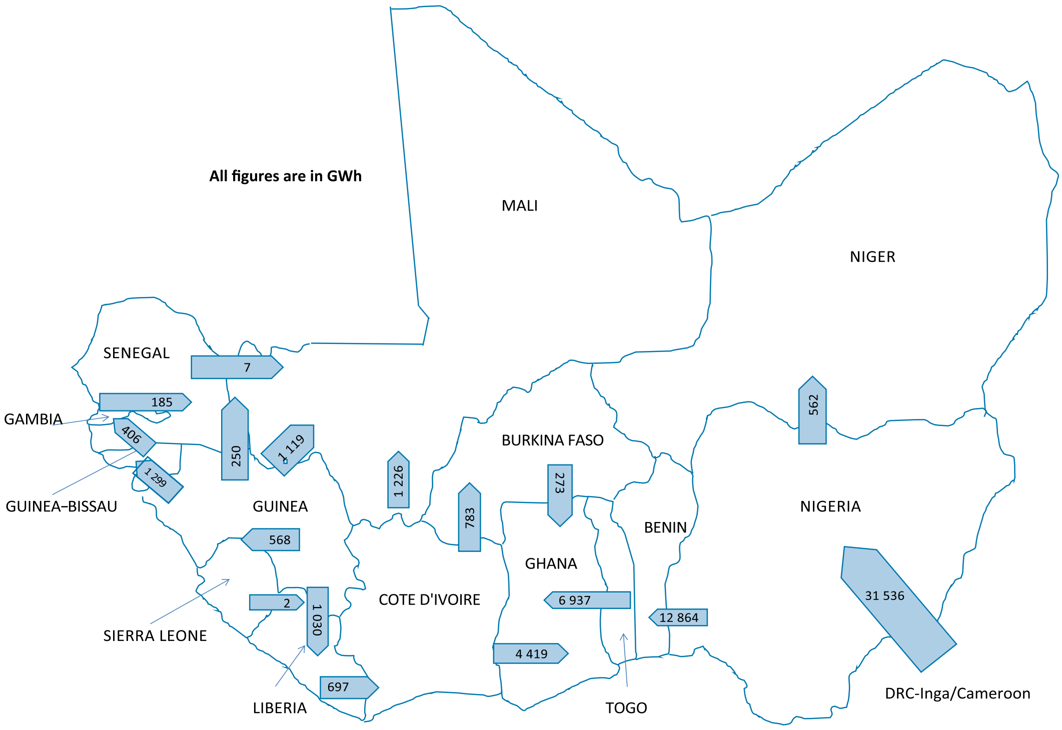
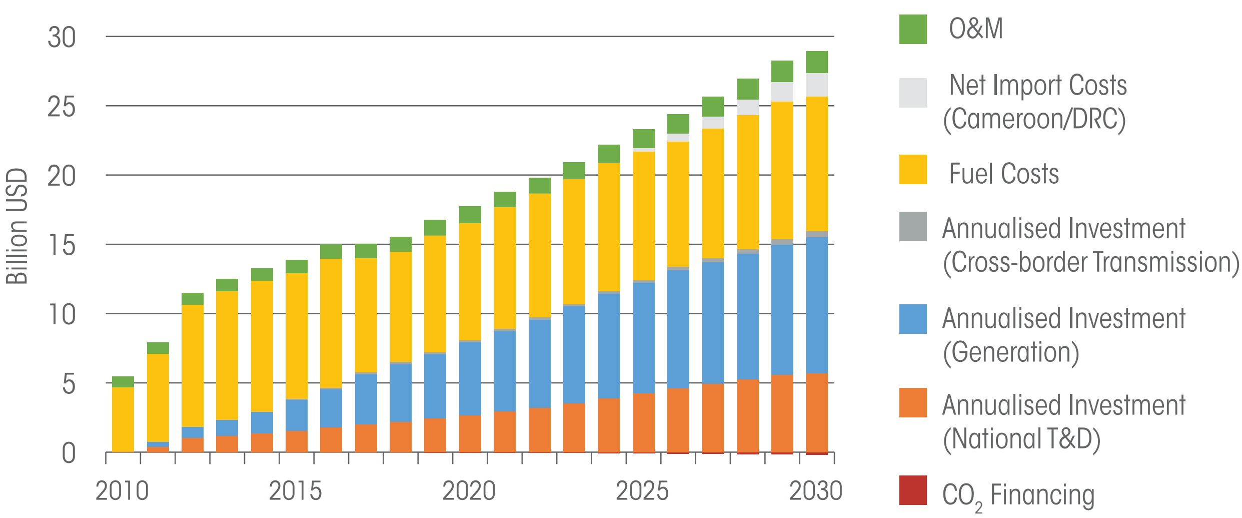


Figure 6. West Africa: Annualised system costs (undiscounted) under the Renewable-Promotion scenario



Box 1: West Africa analysis updates

West African Power Pool: Planning and Prospects for Renewable Energy was published in 2013. In December 2012, IRENA and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) organised a three-day training workshop to discuss the use of energy-planning tools in the ECOWAS region in general and SPLAT model assumptions and results for the region in particular. The development and availability of the SPLAT model was considered timely because the ECOWAS heads of states adopted the ECOWAS Renewable Energy Policy (EREP) soon after in 2013. The EREP action plan foresees that all 14 ECOWAS countries should develop and adopt national renewables action plans, for which analytical tools such as SPLAT would be needed to develop quantitative baselines. ECREEE invited IRENA to develop a regional renewable-energy policy scenario to be used as a benchmark for national target setting in ECOWAS countries.

For that purpose, several additional model updates have been implemented after the publication of the report. They include:

- The splitting of Togo and Benin, which up until then were combined into one region.
- The inclusion of Cape Verde
- Updates for solar PV, wind and mini-hydro data.

Updated results were to become available in 2015.

5. Southern Africa Power Sector[5]

The Southern Africa power sector analysis includes the following 12 countries: Angola, Botswana, the DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. The model database is primarily built on the SAPP Master Plan (SAPP, 2007), with elements of South Africa's Integrated Resource Plan for Electricity (South Africa Department of Energy, 2011), a memorandum of understanding (MoU) on SAPP priority projects adopted on September 17, 2012, by the Summit of the Southern African Development Community (SADC) Heads of State, and several country-level documents.

Current situation

Total installed capacity was 54 GW as of 2010, generating about 320 TWh of electricity. South Africa accounted for nearly 80% of installed capacity in the region. Coal is the main energy source in South Africa, Botswana and Zimbabwe. Natural gas is the primary feedstock in Tanzania and Angola. The rest of the region relies predominantly on hydropower, supplemented by oil-fired power plants. About 12% of the electricity generated in the region is traded within the region, with smaller countries reliant on imports.

Demand projections

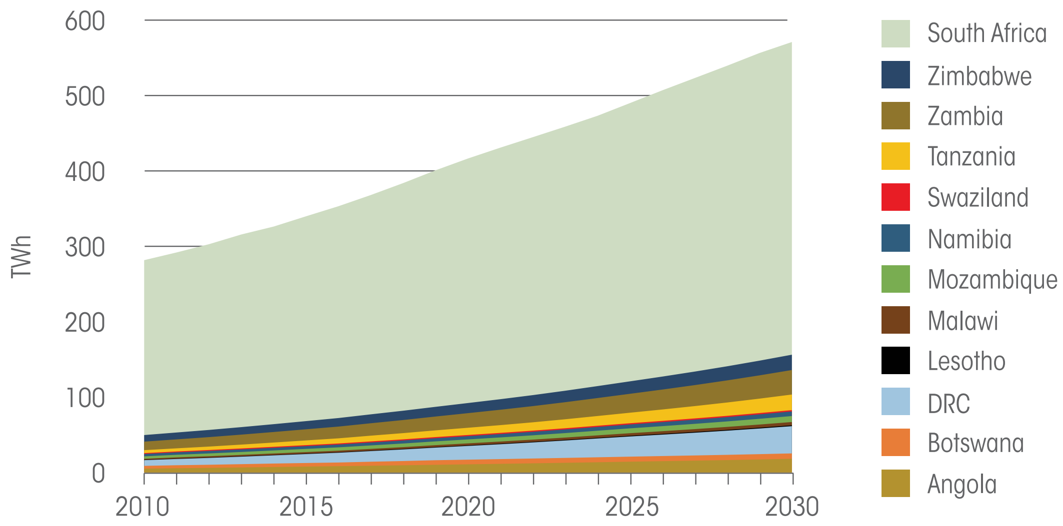
Regional demand is projected to almost double by 2030, from a current level of 280 TWh to 570 TWh (Figure 7). South Africa's share of demand is seen dropping from 82% to 72% by 2030 because of its mature economy and therefore faster growth rates in the rest of the region. Industrial demand is projected to decrease from the current level of 66% to 57%, whereas urban demand is seen rising from 32% to 38%. Rural demand is projected to move from 2% to 4%.

Regional energy sources

The region is endowed with a rich mix of fossil and renewable resources, notably solar and wind. Eight countries have domestic coal resources, providing a basis for inexpensive power: Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. Five have domestic gas reserves (Angola, DRC, Mozambique, Namibia and Tanzania), however there is no major oil production in the region. For biomass, Mozambique, Swaziland, Tanzania and Zambia have sizeable sugar cane production from which bagasse could be made available for power production. DRC and South Africa have some biomass potential in the form of residual woody material from industrial processing and logging.

The SAPP master plan identifies nearly 40 GW in future hydropower projects that could be potentially deployed within this time horizon, with the Grand Inga site in DRC accounting for half of this total[6]. Potential hydro capacity in Angola, Mozambique, Zambia, and Zimbabwe ranges between 1 GW and 7 GW. All SAPP countries have

Figure 7. Southern Africa: Final Electricity Demand by country



[5] *This subsection is based on the executive summary of: Southern African Power Pool: Planning and Prospects for Renewable Energy (IRENA, 2013b).*

high solar PV and CSP potential in comparison with the rest of the continent. On a per-square-metre basis Malawi has the highest potential. South Africa has the most high-quality wind potential, followed by Malawi and Zimbabwe.

Scenario description

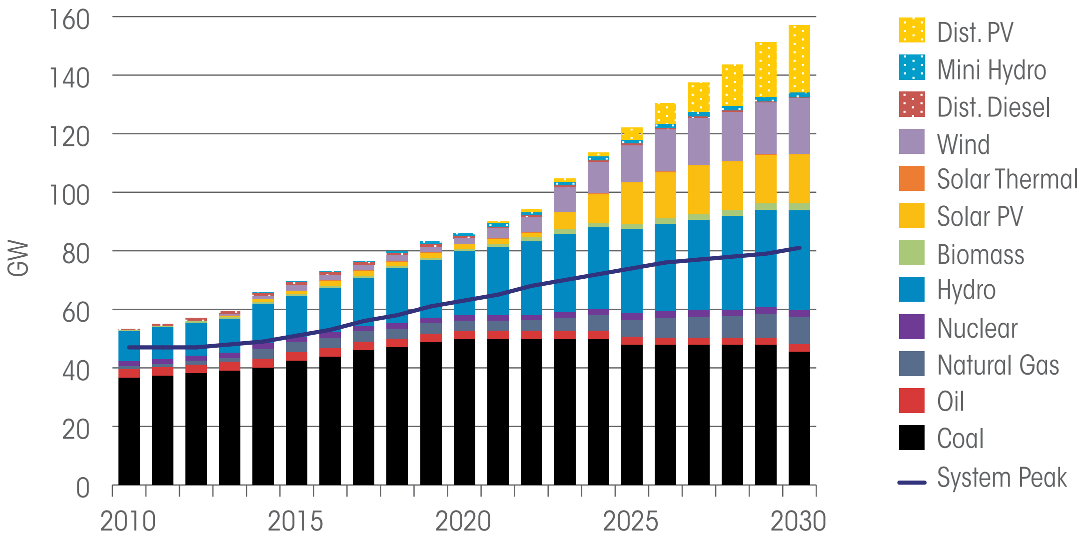
Four scenarios were developed to determine the roles for renewable technologies in Southern African power systems in the next 20 years. A renewable high-cost scenario was designed to replicate the SAPP Master Plan and does not take into account the recent trend of significant cost reductions for renewable energy projects. A renewable-promotion scenario was created to reflect that trend, and also assumes that supportive government policies toward renewables would bring down the investment costs further. Two variations of the renewable-promotion scenario were developed further, to assess the impacts of the Grand Inga project and to consider the role of carbon finance. In all scenarios South Africa's carbon emission target of 275 megatons (Mton) of CO_2 from the power sector after 2024 was used.

Results

A quarter of the existing 54 GW of generation capacity is expected to be retired before 2030, requiring an additional 110 GW in capacity needed to meet demand by 2030 under the renewable-promotion scenario. Almost 80% of additional investment would be met with renewable technologies in this scenario, including 22% from decentralised renewable technologies. Of the 41 hydro projects currently under consideration, 32 would be built, and by 2030 new hydropower capacity would amount to 24 GW. Approximately half of this would be accounted for by the Grand Inga project. During the 2021-2030 period nearly 40 GW solar would be deployed, with more than 60% of it coming from decentralised solar PV options. Wind deployment would be about 20 GW under this scenario. Coal would still be deployed (more than 10 GW in new capacity), but mostly from already-committed projects. Massive investment in distributed generation starting from 2025 would mostly corresponds to the deployment of solar roof-top PV systems with one-hour batteries for urban applications in South Africa. The installed capacity mix between 2010 and 2030 is shown in Figure 8.

Under the renewable-promotion scenario a general trend of replacing coal with renewables begins in around 2020, and the share of renewables used in electricity generation would rise from 12% currently to 46% in 2030. The region's rich potential in hydropower would be a key catalyst, accounting for 22% of total generation in 2030, roughly double the current total. Other renewables would account for 23% of generation in 2030, rising from currently insignificant levels: 13% from solar PV (more than half of it decentralised), 8% from wind and 2% from biomass. Approximately 17% of the generated electricity would be traded within the region in 2030, an increase from 12% in 2010.

FIGURE 8. SOUTHERN AFRICA: INSTALLED CAPACITY BY SOURCE UNDER THE RENEWABLE-PROMOTION SCENARIO



[6] *The latest deployment plan for the Grand Inga Project was published in March 2014. At the time of the execution of this study (2011-2012), only a generic deployment schedule was available, based on which we assessed up to 900 MW per year would be deployed for Grand Inga as of 2018.*

The overall picture is to a large extent dominated by developments in South Africa, which accounts for 85% of the total regional electricity generation. Figure 9 shows the electricity supply mix (generation and net imports) for each country under the renewable-promotion scenario. In general, renewable technologies would contribute significantly to the diversification of energy supply, and in some countries decentralised renewable energy options would account for a sizable share of electricity supply.

In 2010 only Mozambique and South Africa were net exporters, while six countries in the region relied extensively on imported electricity, comprising between 40% and 80% of supply. Import dependency would drop by 2030 and some countries would become net exporters as they develop their own resource, including Botswana, DRC and Malawi.

In the high-cost scenario, deployment of non-hydro renewable energy would be about 50 GW lower. The deployment of solar technologies would be significantly limited by high costs, and nuclear and natural gas plants would become more important.

In the scenario in which the Grand Inga's several phases of projects do not reach production, more aggressive deployment of all other types of renewable technologies would be necessary to compensate. In addition to renewables nuclear power would also be required. Electricity trade volume in 2030 would be 67 TWh in this scenario, 36% lower than if Grand Inga's potential were fully realised.

In the scenario without carbon finance, the reduction in coal usage would be smaller. Countries surrounding South Africa, such as Swaziland, Botswana, Zimbabwe, would increase fossil-based generation and export to South Africa under this scenario. The differences would mainly come in the 2020s, however, as in the first decade already-committed projects would be implemented.

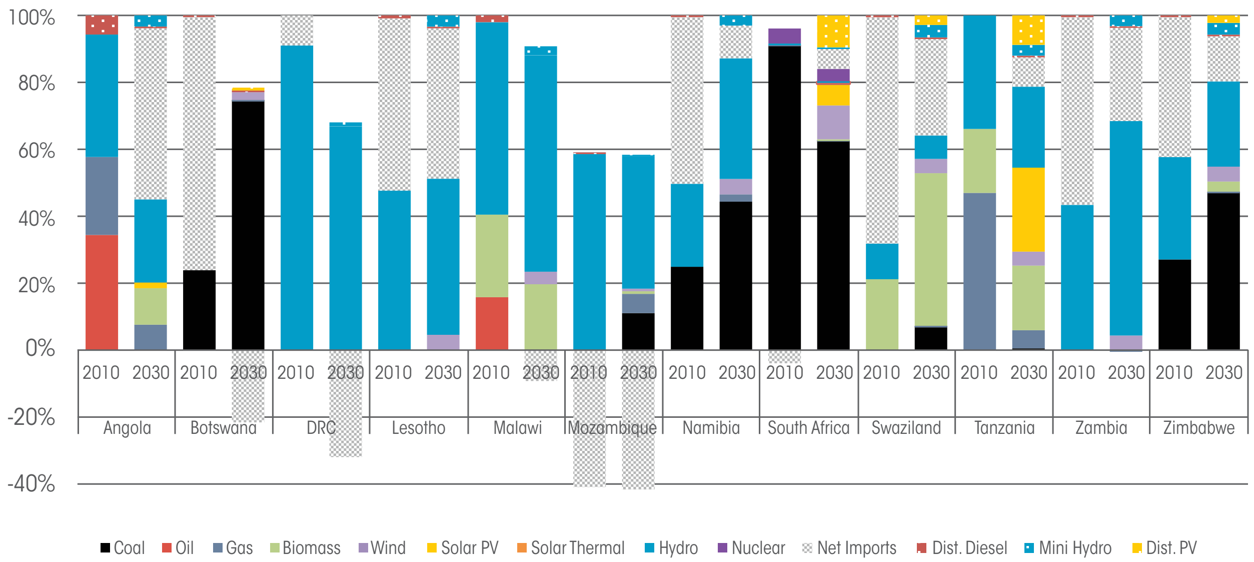
Economic implications

Figure 10 shows required total system costs under the renewable-promotion scenario between 2010 and 2030, including investment cost, fuel costs, net-import cost, and O&M costs. The numbers are annualised and undiscounted.

Overall investment needs in the region during this period amount to more than USD 270 billion. This includes domestic T&D costs and cross-border transmission lines, which would account for nearly half of total investment costs. The use of decentralised options under the renewable-promotion scenario would save about USD 20 billion in T&D during 2010-2030 compared with the high-cost scenario.

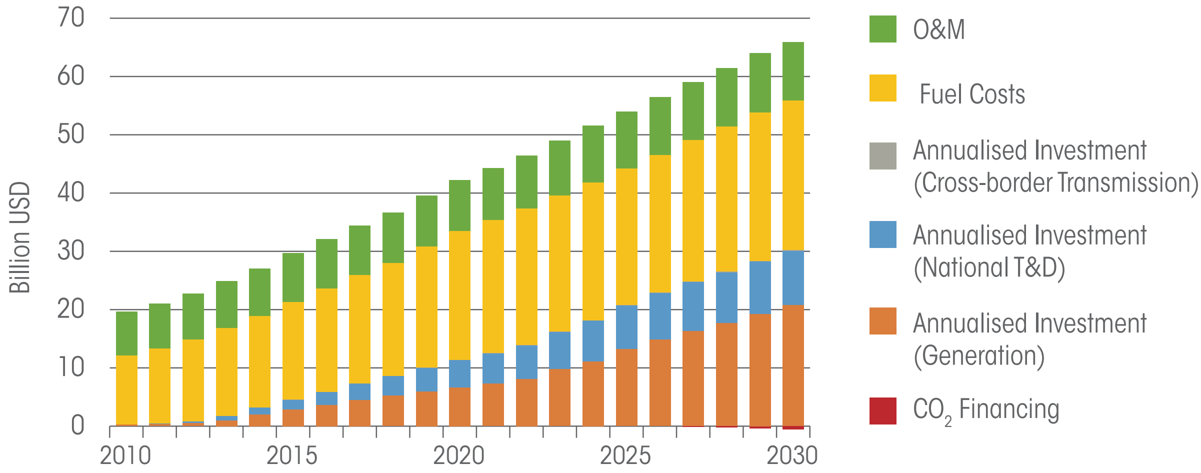
The average cost of electricity generation would increase significantly in all scenarios, from USD

Figure 9. Southern Africa: Electricity supply mix (generation and net imports) under the Renewable-Promotion scenario



70 per MWh to a range between USD 110 and USD 125 per MWh by 2030. The difference between the renewable-promotion scenario and the scenario without Grand Inga power highlights the cost-reduction potential of this one project for the entire Southern African region– it would lower average generation costs by 9% by 2030.

Figure 10: Southern Africa: Annualised system costs under the renewable-promotion scenario



Southern Africa Power Pool: Planning and Prospects for Renewable Energy was published in 2013. The SPLAT model for the region has been updated since then in a number of areas. The most significant is the update of the Grand Inga schedule according to with the World Bank (2014). The other major updates include costs and seasonal supply profiles for renewable energies and biomass availability.

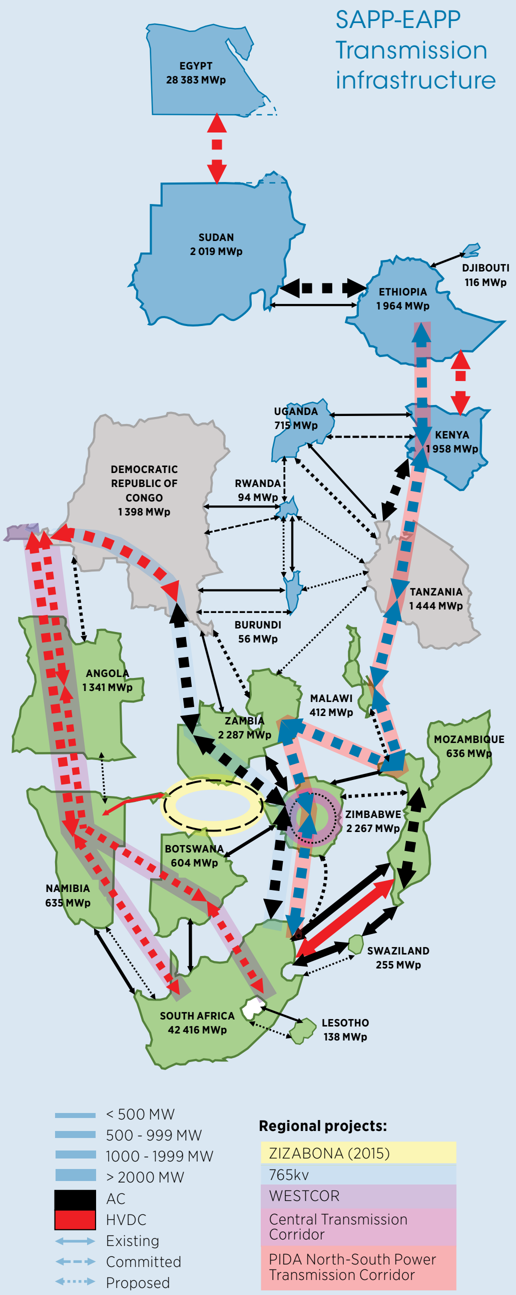
The updated SPLAT model was linked with the one for East Africa and used to conduct the Africa Clean Energy Corridor (ACEC) impact assessments, which counted as one of IRENA's contributions to United Nations Climate Summit organised in September 2014 in New York. The ACEC initiative aims to facilitate regional cooperation in promoting regional electricity trading and renewable deployment, facilitating the harnessing of tremendous renewable-energy potential existing in the East and Southern African sub-regions. This would be done through a clean-energy corridor from Egypt to South Africa. Figure 11 shows the cross-border transmission projects studied in this analysis.

IRENA's assessment shows that regional cooperation to promote trade and renewable-energy deployment would significantly reduce the CO_2 emissions and total energy system costs in comparison with deploying more fossil fuel-based power. In an environment in which trade is limited, hydro resources would be mainly used for meeting domestic demand.

Annual CO_2 emissions from the power system would nearly double from the current level of 360 Mton CO_2 to more than 700 Mton CO_2. The ACEC initiative, aiming to further promote renewable energy deployment through regional cooperation, found that the CO_2 emission level in 2030 could be reduced by 310 Mton if the use of renewable technologies were accelerated. From 2010 to 2030 the total savings would amount to 2,500 Mton of CO_2 emissions, creating a significant decarbonisation of the power sector whilst increasing electricity supply by a factor of 2.5. The ACEC initiative found that nearly half of the power needed in the region can be met by renewable sources. It would bring the economic benefits of reducing average generation costs (taking into account investment into transmission lines as well) by about 4%, mainly through a reduced reliance on the fossil based fuels. It would also increase economic opportunities associated with major renewable energy investment.

The complete ACEC impact assessment report will be made available during 2015.

Figure 11: Cross-border projects analysed in the ACEC impacts assessment



*Peak capacities for SAPP include a 15% target reserve margin

6. East Africa Power Sector[7]

The East Africa power sector analysis includes the following 11 countries: Burundi, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. For most of these, the model database is primarily built on the Regional Power System Master Plan and Grid Code Study of the EAPP and the East African Community (EAC), with additional information from Platts' database.

Current situation

In 2010, total installed capacity was more than 38 GW, generating about 160 TWh of electricity largely from gas-fired power plants. Egypt accounts for more than 70% of the installed capacity in the region. In Ethiopia, Burundi, Uganda and Sudan, hydropower is the main source. After gas and hydro, remaining capacity is mainly based on oil-fired power plants, with small contributions from wind and solar. Electricity trade within the region is low but imports from DRC are important for dependent countries such as Burundi and Rwanda.

Demand projections

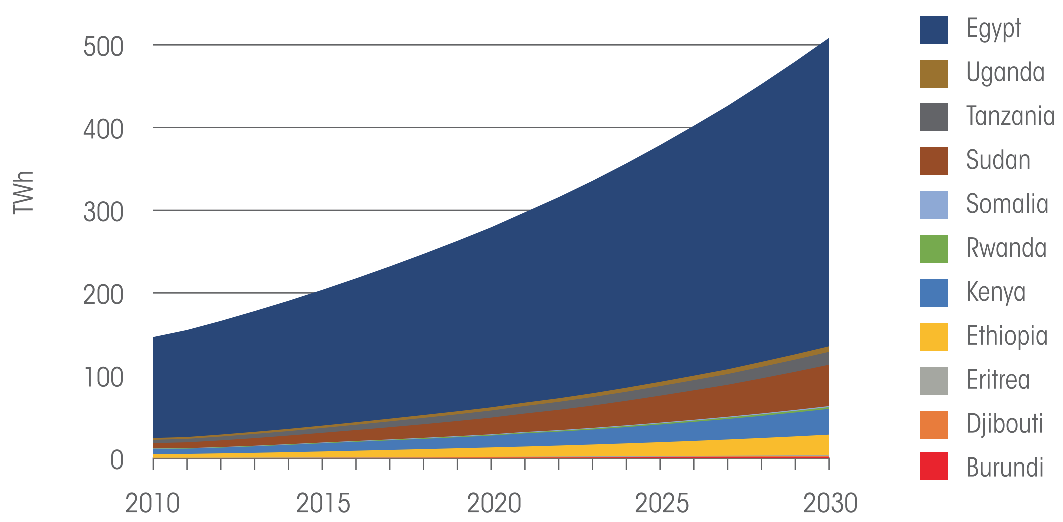
Demand is projected to increase by a factor of 3.5 by 2030, based on the EAPP/EAC master plan and other sources and projections. That would boost the figure from about 150 TWh in 2010 to 500 TWh in 2030 (Figure 12). Egypt, the second-most populous country in Africa, is seen accounting for almost 75% of the total, at more than 370 TWh. In contrast, five smaller countries (Burundi, Djibouti, Eritrea, Rwanda and Somalia) would together provide less than 2% of the total. Demand from industrial users would account for the largest share by 2030, at 44%, with urban and rural demand at 39% and 17% respectively.

Regional energy resources

The region is endowed with a rich mix of fossil and renewable resources. A majority of the countries in the region have domestic gas reserves, including Egypt, Ethiopia, Rwanda, Somalia, Sudan, Tanzania and Uganda. Four have domestic oil production, and Tanzania produces coal. The region has the highest geothermal potential in Africa, and Kenya in particular is an experienced producer. Nearly 3 GW of additional geothermal projects are identified for Kenya with an additional 1.4 GW identified across the region. Ethiopia has vast hydro resources, with almost nearly 15 GW of potential projects identified. Sudan, Tanzania, and Uganda have also identified 2 GW to 3 GW of potential projects each. Egypt has the biggest installed hydro capacity as of 2010 (2.8 GW), but less potential, with only 0.7 GW of additional projects identified.

All countries in the region have vast solar and wind potential. Somalia has the most high-quality wind potential of any African country, both in absolute terms and on a per-square-meter basis. Djibouti and Kenya also have significant potential on a per-

FIGURE 12: EAST AFRICA: FINAL ELECTRICITY DEMAND BY COUNTRY



[7] This subsection is based on the executive summary of: Eastern Africa: Planning and Prospects for Renewable Energy (IRENA, 2015b).

[8] Demand projections for Burundi and Eritrea are not in the EAPP/EAC Master Plan, so the Nile Equatorial Lakes Subsidiary Action Programme (NELSAP) report was used. For Eritrea and Somalia projections were made according to the average growth of the rest of the region excluding Egypt.

square-metre basis, whilst Sudan, Ethiopia, Kenya, and Tanzania have large resources in high-quality wind on an absolute basis. All countries in the region offer notable potential for both solar PV and solar CSP. The region has the highest PV and CSP potential in Africa on a per-square-metre basis.

Scenario description

Trade is important to harness the rich mix of resources in the region. Two scenarios were developed with different trade assumptions. The renewable-promotion scenario is the primary one, in which renewable-energy policy is assumed to be most effective. In this scenario there are six international transmission projects expected to be developed, and nine proposed ones that will be considered if found optimal. In the other scenario, renewable-energy policy is assumed to be ineffective and only international transmission projects in the pipeline would be considered.

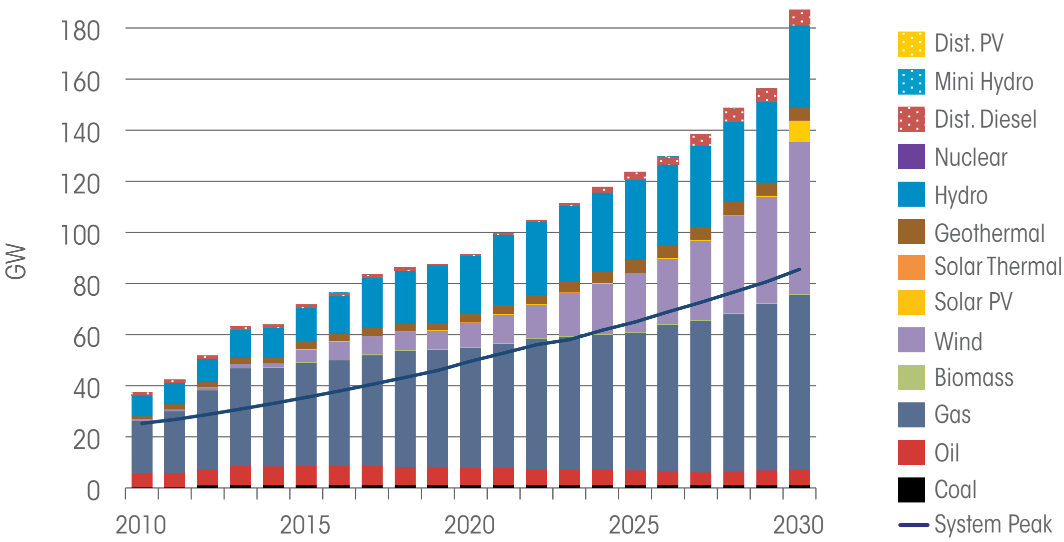
Results

Of the 38 GW of installed generation capacity as of 2010, approximately half is expected to be retired before 2030. To meet growing demand an additional investment of about 170 GW in capacity would be needed between 2010 and 2030 under the renewable-promotion scenario, and in it renewables would add to the diversity of supply. The scenario envisions a total installed capacity of about 190 GW by 2030, with renewable technologies accounting for more than 100 GW. Wind is seen as the most prominent, at more than 60 GW, followed by hydro (30 GW), solar PV (8 GW) and geothermal (5 GW). The installed generation capacity mix between 2010 and 2030 is shown in Figure 13. The regional supply structure will be dominated by trends in Egypt because it accounts for 70% of regional generation as of 2010, and would still account for roughly two thirds of it by 2030.

In most countries, the changes would transform the structure of supply. The share of hydropower in the regional generation mix would rise from 19% in 2010 to 22% in 2030, whilst wind's share would be 34%, with significant supply in Egypt, Eritrea, Somalia and Tanzania. Hydro would be important for Ethiopia, Burundi and Uganda. Utility-scale solar PV would play an important role in many of them, in particular in Burundi, Djibouti, and Rwanda. Biomass is important in Rwanda, with its 13% share of generation, and in Kenya geothermal would account for 60% of the generation mix. Figure 14 shows the electricity supply mix (generation and net import) for each country under the renewable-promotion scenario.

Increased regional integration would encourage countries with inexpensive hydro resources, such as Ethiopia, Burundi and Uganda, to export to those more dependent on fossil fuels. Each country could have a surplus above 20% of domestic demand. Under the renewables-promotion scenario,

Figure 13. East Africa: Installed capacity by source under the Full-Integration scenario



approximately 10% of generated electricity would be traded within the region, with considerable benefits for both importers and exporters. Uganda and Ethiopia would be the major exporters and Egypt, Kenya and Sudan the primary importers. Smaller economies such as Djibouti and Rwanda would also benefit from importing from neighbours to meet considerable shares of their demand. In the alternative scenario, in which cross-border transmission options are limited, Ethiopia and to a lesser extent Uganda would have fewer export opportunities, and hydropower in those two countries would mainly serve domestic needs. Wind in Egypt and geothermal in Kenya would still play significant roles in the generation mix. But without policy-driven cost reductions for renewables, some investment in those two areas would be diverted to gas-fired projects.

Economic implications

Figure 15 shows the development of a power-system cost structure under the renewable-promotion scenario, including investment cost (for generation, country-level T&D and international transmission), fuel costs and O&M. Total investment needs between 2010 and 2030 would amount to almost USD 400 billion (undiscounted), of which more than 40% would go to country-level T&D. Cross-border transmission investment needs would be insignificant.

FIGURE 14: EAST AFRICA: ELECTRICITY SUPPLY MIX (GENERATION AND NET IMPORTS) UNDER THE RENEWABLE-PROMOTION SCENARIO

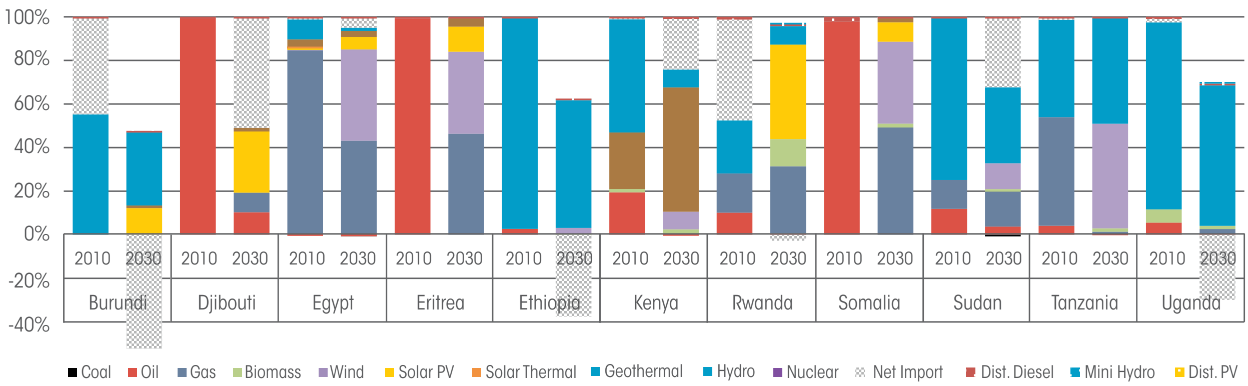
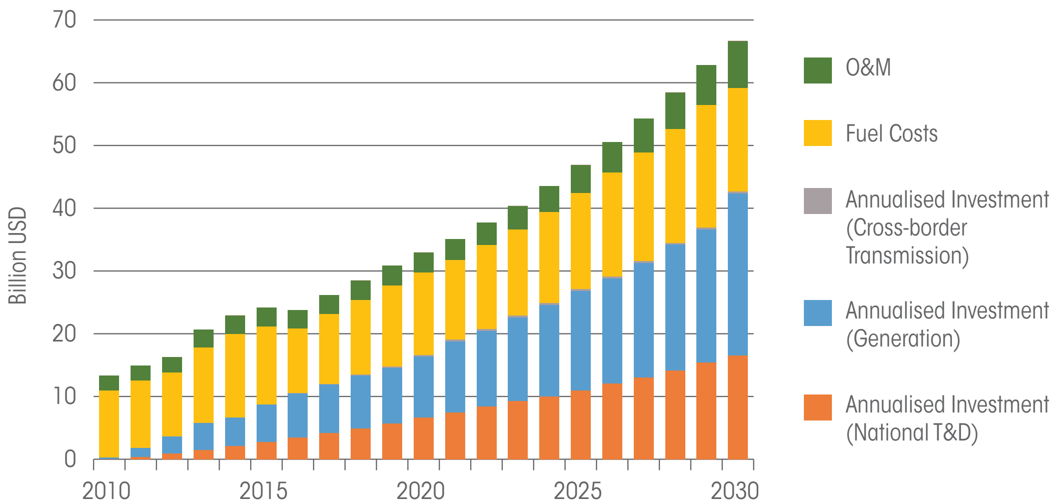


FIGURE 15: EAST AFRICA: ANNUALISED SYSTEM COSTS UNDER THE RENEWABLE-PROMOTION SCENARIO



Corrected on page 27 (January 2016)

7. Central Africa Power Sector[9]

The Central African power sector analysis includes the following ten countries: Angola, Burundi, Cameroon, Central African Republic, Chad, Republic of the Congo (Congo), DRC, Equatorial Guinea, Gabon, and Rwanda. Angola and DRC are also members of the SAPP, and utilities from Burundi, DRC and Rwanda are also members of the EAPP. As there is no regional master plan, IRENA's model instead draws on other documents as well as simplified assumptions inferred from the other African regions.

Current situation

Central Africa currently has the lowest electrification rate on the continent, at 20% (Sofreco, 2011). In 2010 total installed capacity was 5.6 GW, with a net electricity production of about 20 TWh. Three countries, DRC, Angola and Cameroon, are responsible for more than 80% of production. Approximately 75% of total installed capacity comes from hydropower, with most of the rest from thermal plants. Chad, Equatorial Guinea, Gabon, and Rwanda use mostly oil, whereas Congo complements its hydropower with gas-fired thermal plants. Imports meet just 4% of demand in the region, but are concentrated: import dependency is particularly high in some smaller countries, including Burundi and Rwanda.

Demand projection

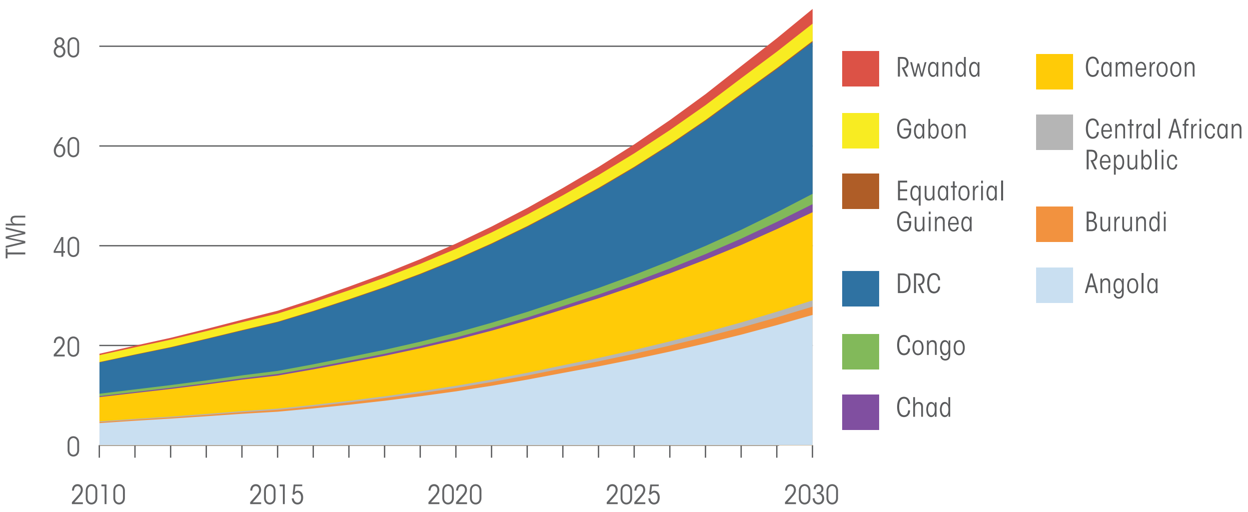
The analysis of future demand in the region is based on the African Energy Outlook (Sofreco, 2011). Electricity demand is expected to increase from about 20 TWh in 2010 to 90 TWh in 2030 (Figure 16). Urban, industrial and rural demand are projected to account for 57%, 39% and 4% respectively of final electricity demand in 2030. The current share of rural electricity demand is negligible.

Regional energy resources

Six countries in the region have domestic gas reserves: Angola, Cameroon, Congo, Equatorial Guinea, Gabon, and Rwanda. DRC produces coal. The region is known for its vast hydro resources, which account for 60% of Africa's total potential in this area. DRC's Grand Inga project alone is estimated at more than 40 GW of technical potential. All countries in the region except Equatorial Guinea have significant levels of hydro potential. Various sector studies, including the EAPP and SAPP master plans and Platts' database (Platts, 2012) identified hydro projects that amount to more than 30 GW.

Solar and wind resources are less promising compared to those in other parts of Africa,

Figure 16: Central African: Final electricity demand by country



[9] *This subsection is based on the executive summary of: Central African Power Pool: Planning and Prospects for Renewable Energy (IRENA, 2015)*

although at an absolute level, potential is still high for solar PV. On a per-square-metre basis, Equatorial Guinea, Congo, Cameroon and Gabon have the highest potential. Chad has the most potential for wind, and is the only country in the region that could deploy wind turbines in areas where average capacity factors exceed 40%. Burundi, Congo, Equatorial Guinea, Gabon and Rwanda have no large-scale wind potential.

Scenario description

Five scenarios were developed, which differ primarily in assumptions about the extent of regional integration in the future. A fossil-fuels scenario assumes that deployment of renewable energy and regional trade in 2030 are limited to the current levels.

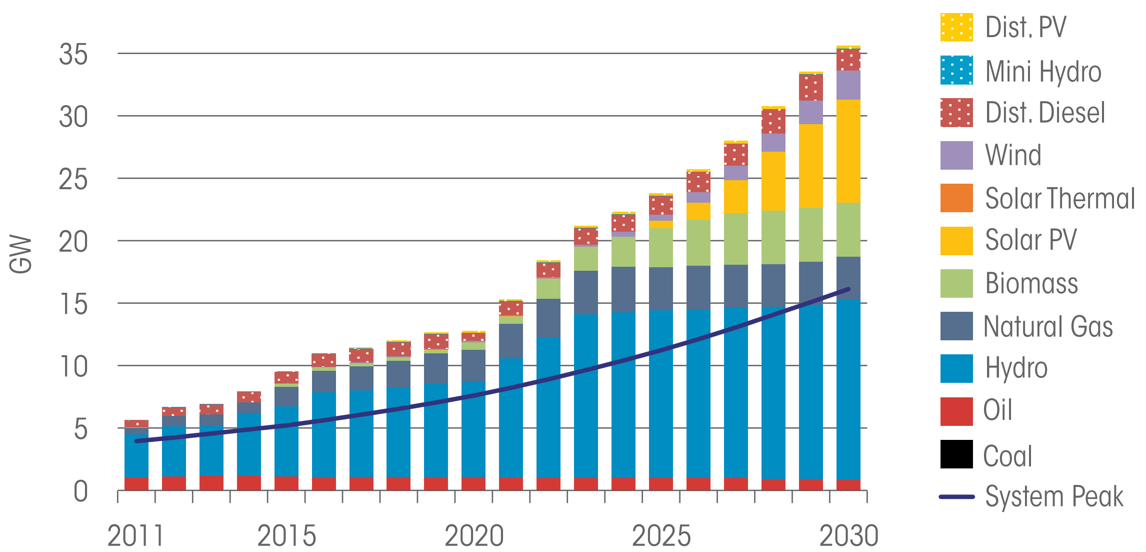
The other four scenarios assume that non-hydro renewable costs will fall as a result of supportive policies and that various degrees of cross-border interconnection would encourage the optimal deployment of the energy-supply technologies. They include scenarios assuming no growth in trade, assuming trade only within the region, with exports to SAPP and WAPP countries, and with trade within the region as well as exports to the two others.

Results

Because hydropower facilities have a longer lifespan than other power plants only 700 MW of existing generation capacity (5.6 GW) is expected to be retired by 2030. Under the scenario assuming full regional integration, an additional 33 GW in capacity would be needed to meet growing demand between 2011 and 2030. This would imply a total installed capacity of 36 GW by 2030. Renewable sources would account for 29 GW of that total, with hydro being the most prominent (14 GW). The expected full commissioning of the next phase of Grand Inga (Grand Inga 3 Phase 1) would add 4.8 GW in 2023. In addition, more than 8 GW of centralised solar PV and 2 GW of wind power would be added. Another 4 GW of biomass-fired facilities are envisioned by 2030 under this scenario. Between 2010 and 2020, most investments would occur in hydro and fossil-fired power plants, with wind, grid-connected solar PV and biomass playing more prominent roles in the latter decade as their investment costs decrease. The installed generation capacity mix between 2010 and 2030 under this scenario is shown in Figure 17.

Hydropower will still be the most common energy source by 2030, but the scenario envisions its share of total generation dropping from a current level

Figure 17: Central Africa: Installed capacity by source under the full-integration scenario



of 70% to 45% as potential from other sources is developed. The shares of non-hydro renewables would increase significantly from current levels of negligible deployment, together reaching 36% of total generation. Solar PV, biomass and wind would account for 15%, 15%, and 6% respectively. Non-renewable generation would make up the remaining 19%, which is the lowest usage rate for fossil-fuel based energy among the five regions. After Grand Inga becomes operational in 2021, between 20% and 30% of generated electricity would be exported to SAPP and WAPP countries.

Regional trends in Central Africa are shaped by its three largest countries, DRC, Angola, and Cameroon. Figure 18 shows the electricity supply mix (generation and net import) for each country under the full-integration scenario, with Cameroon, Chad, Congo, DRC, Equatorial Guinea and Rwanda projected as net exporters by 2030. In part because of the underdeveloped state of the power sector at present there could be fundamental changes in the common sources of electricity for most countries in this region, because many of them have very small electricity systems currently and any new capacity addition has the potential to overhaul the generation mix. Wind would be deployed in Chad and Cameroon, whilst grid-connected solar PV would rise in importance in Angola, Burundi, and Central African Republic. Use of biomass would climb in all countries, but in particular in Rwanda and Central African Republic. Distributed solar PV with batteries would be deployed in rural Burundi, Central African Republic, the Republic of Congo, Gabon and Rwanda.

Cross-border links would be used to export electricity beyond the region to WAPP and SAPP via Cameroon and DRC. Exports to neighbouring countries would exceed 26 TWh by 2030, compared with the domestic demand of countries in the region of 90 TWh. The future of non-hydro renewables in Central Africa are directly linked to trade options, because even though hydro potential is vast, the pace of hydro development would not be sufficient to meet export demand in 2030. That would boost the need for non-hydro renewables to fulfil export potential, including solar PV and biomass. Trade to other regions would require extra capacity, but trade within the region would not. The level of trade within Central Africa would influence only the generation mix. More trade would mean less demand for building gas- or coal-fired capacity in Rwanda and Angola. Trade-friendly policies are therefore crucial to support renewable energy.

Economic implications

Figure 19 shows the development of a total power system cost under the full-integration scenario. Total investment between 2011 and 2030 would amount to more than USD 60 billion (undiscounted), of which one third would go to T&D. Annualised system costs for 2030 would surpass USD 12 billion, whilst more than USD 3 billion in revenues would come from exports to WAPP and SAPP from 2023, assuming the Grand Inga project proceeds as planned.

Figure 18 Central Africa: Electricity supply mix (generation and net imports) under the full-integration scenario

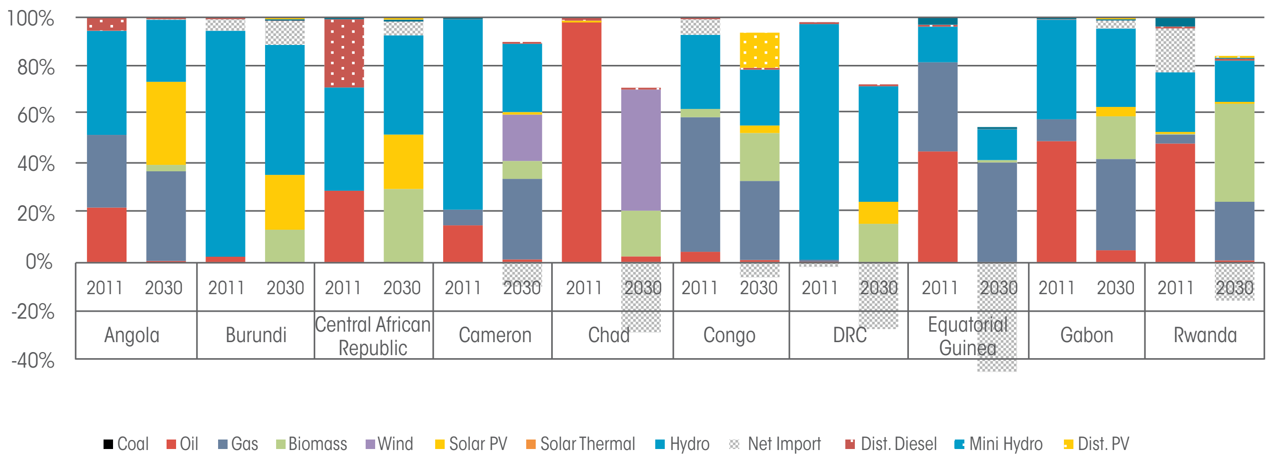
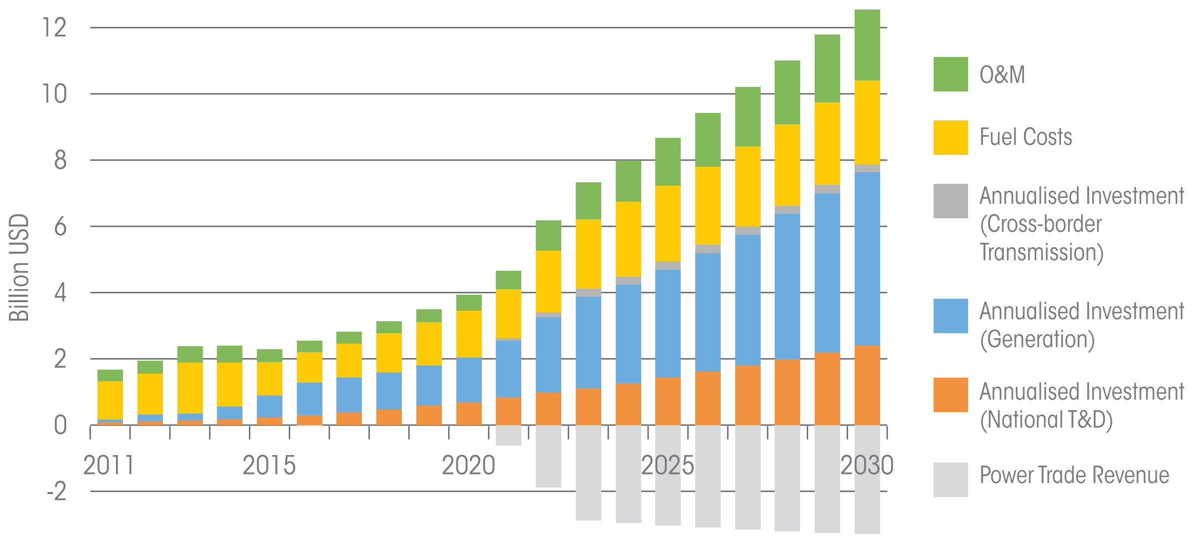


Figure 19: Central Africa: Annualised system costs under the full-integration scenario



8. North Africa Power Sector[10]

The North African power sector analysis includes the following six countries: Egypt, Algeria, Libya, Mauritania, Morocco, and Tunisia. The latter five are known as the Maghreb countries.

Current situation

In 2010, total installed capacity in the region was 60 GW, generating about 260 TWh of electricity. More than half of the generation is accounted for by Egypt. The region relies on fossil fuel sources for electricity generation. In Algeria and Egypt the bulk of the installed capacity is natural-gas-based, and Libya and Mauritania are highly dependent on oil-fuelled power plants. Morocco uses oil, hydropower and coal. Hydro accounts for 10% of total regional capacity, and non-hydro renewables more than 2%, from grid-connected wind farms in Egypt, Morocco and Tunisia. Imports correspond to 2% of gross demand in the region, with Morocco and Mauritania notable for being more reliant on foreign power than the others in the region. Both import about 15% of their gross demand. North African countries actively register Clean Development Mechanism projects, and Egypt and Morocco alone accounted for 7% of all mitigation-related investment assistance from 2007 to 2012 (OECD, 2014).

Demand projection

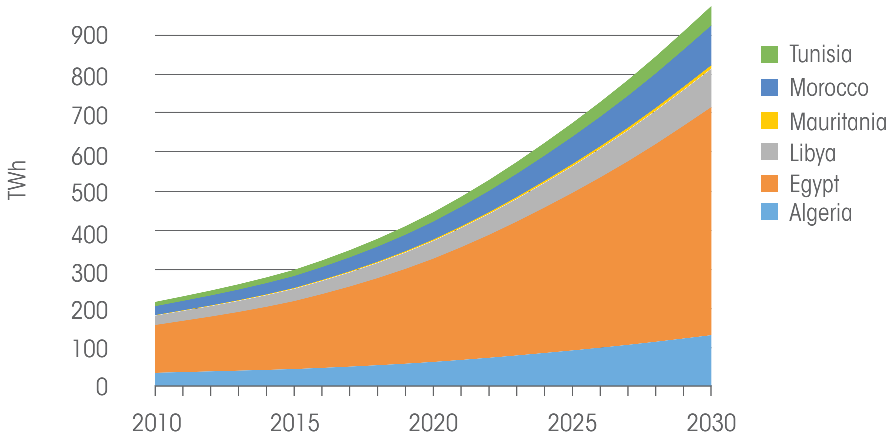
There are no regional electricity demand projections for North Africa from COMELEC, so the analysis of future demand in the region is based on the African Energy Outlook[11] (Sofreco, 2011). Electricity demand is expected to increase by a factor of five, from 220 TWh in 2010 to 980 TWh in 2030. As shown in Figure 20, Egypt will remain the largest source of demand in the region, while Libya, Morocco, and Tunisia also will experience a significant increase. Urban, industrial and rural demand currently account for 42%, 47% and 11% respectively of final electricity demand in 2010, and this split is not expected to change dramatically. The only difference anticipated is urban demand rising by a few percentage points because of urbanisation.

Regional energy resources

The region is rich in fossil fuel resources as well as solar and wind resources. Algeria, Egypt, and Libya are the major gas and oil producers, with others producing smaller amounts or none. Large quantities of domestically produced gas and oil are exported. Egypt also has some coal reserves which could be exploited in the future.

All countries in the region are endowed with high solar and wind potential. On a per-square-metre basis, Morocco and Egypt have the highest solar PV and solar CSP potential in the region, and Tunisia also has high solar CSP potential. Also on a per-square-metre basis Morocco and Tunisia have the most potential for high-quality wind, followed by Mauritania.

Figure 20: North Africa: Final electricity demand by country



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[10] *This subsection is based on the executive summary of: North African Electricity: Planning and Prospects for Renewable Energy (IRENA, 2015a).*

[11] *In comparison to other studies, the projections from this source tend to fall on the high side. For example, demand projections for Egypt in 2030 are 30% higher than the one used in EAC/EAPP Master Plan discussed in Chapter 5.*

The region is not expected to see large-scale deployment of hydro in the coming two decades. Only a few GW of potential have been identified, mainly in Egypt and to a lesser extent in Algeria. According to Platts' database, Morocco has 600 MW of hydro projects are identified[12], and Egypt also has a smaller-scale hydro project.

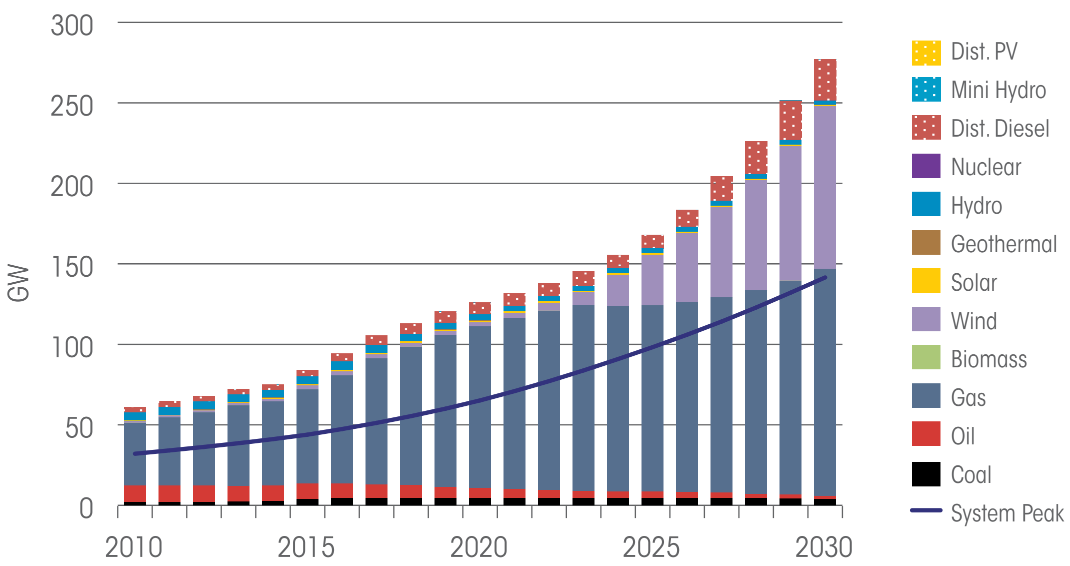
Scenario description

Despite the present dominance of fossil fuel-based power generation, countries in the region aim to diversify their power systems. Fossil-fuel subsidies, supportive renewable-energy policies and the use of carbon-mitigation investment assistance are among the key policy instruments used by North African governments. Three scenarios were analysed to address these policy issues. The frozen future scenario (FF) assumes ineffective renewable-energy policy support and renewable-energy technologies receiving financial incentives for mitigating CO_2 at USD 25 per Mt. The progressive-technology scenario (PT) envisions successful renewable-energy policies resulting in cost reductions for building renewable generation capacity as well as identical CO_2 finance incentives. A diversification-and-environmental investment scenario (DIVE) builds on the PT scenario by assuming that natural gas for power production will cost power plans the same as what governments could get by selling it at international market rates instead of at lower values. All scenarios assume no new trade links within the region, because of a lack of data regarding potential expansion. Finally, a sensitivity analysis was performed with respect to the value of the CO_2 mitigation incentives, ranging from USD 0 to USD 50 per ton of CO_2.

Results

More than half of the installed capacity of 60 GW in 2010 is expected to be retired before 2030. Since electricity demand is expected to increase by a factor of five in that period, extensive investments will be required to expand power infrastructure. Under the DIVE scenario an additional investment of 260 GW in capacity would be needed during this period, which amounts to a total installed capacity of about 280 GW by 2030. Renewable technologies would account for 105 GW, with wind being the most prominent (100 GW), followed by hydro (3 GW), and lastly, solar PV (1 GW). The implied surge in wind capacity is partly because of the lower capacity factors of this technology in comparison to fossil-fired power plants – comparatively more capacity is required to deliver the same amount of electricity as other methods. Under this scenario balancing and reserve capacity would be provided by large quantities of electricity from gas-fired plants. It should be noted that a greater use of solar technologies would have been expected were the model period extended, because costs are expected to

Figure 21: North Africa: Installed capacity by source under the DIVE scenario



[12] *Identified projects within the Platts data base are those projects in the phase of construction with an expected date of commissioning.*

fall over time. The installed generation-capacity mix between 2010 and 2030 is shown in Figure 21. Under the DIVE scenario the share of renewables in power generation would rise from the current level of 0.1% to 32% by 2030, led by wind, with natural gas remaining the largest single feedstock. Using wind power at this rate would allow generation capacity to rise with demand whilst also stabilising annual CO_2 emissions at the current level of 300 Mt of CO_2 per year by. Trade in the region would account for less than 1% of generated electricity.

The overall picture is to a large extent dominated by developments in Egypt, which would account for more than 60% of total regional generation in 2030. Figure 22 shows the electricity supply mix (generation and net import) for each country under the DIVE scenario. Oil is displaced with cheaper sources, and in most countries there is a significant shift to wind.

Natural gas will be the main fuel for the bulk of electricity generated in the DIVE scenario as well as in the two alternatives, with wind in an increasingly important role. Comparing the DIVE and PT scenarios helps to understand the impacts of gas pricing and usage policies. In the DIVE scenario, in which power generators pay market rates for gas instead of getting a discount, wind would generate 330 TWh by 2030. In the PT scenario wind would account for 170 TWh. For the gas-producing countries of the region, this means more gas available for export, increasing state revenue.

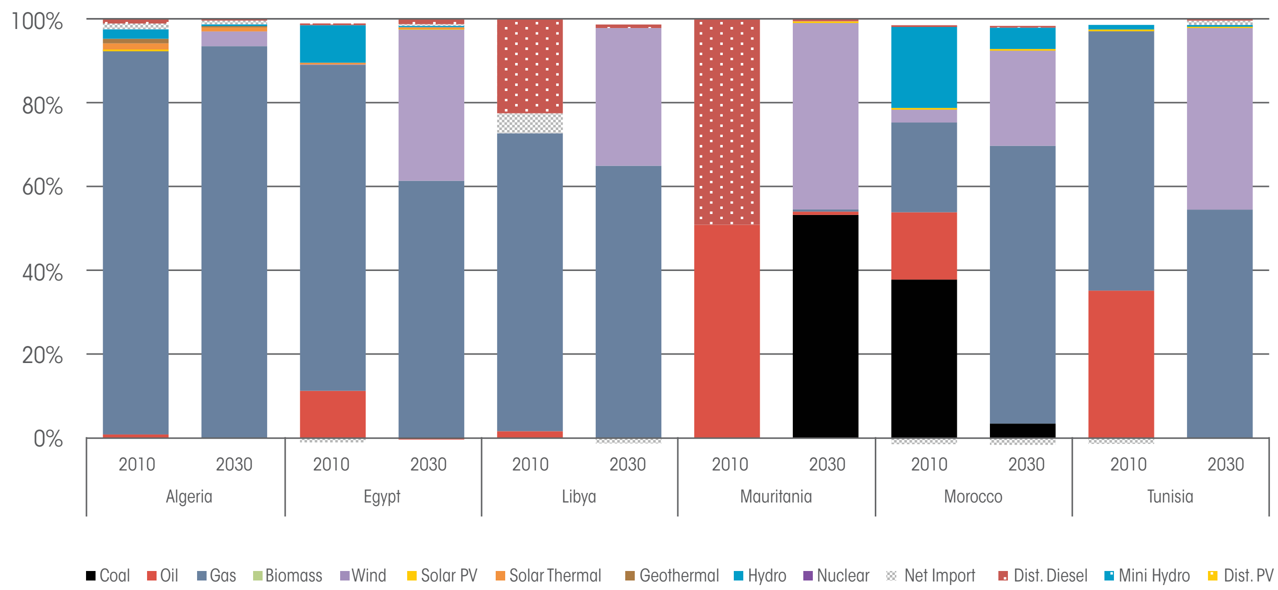
Comparing the FF and PT scenarios highlights the impact of successful renewable-energy policies. Wind generation in the FF scenario would be limited to 80 TWh by 2030, whereas according to PT's assumptions it would be 190 TWh. Additional wind capacity would come as a result of effective policy support in Tunisia, Morocco, and Mauritania, where natural gas reserves are much smaller or non-existent. For solar technology, however, further policy measures would be needed to make it competitive.

Annual CO_2 emissions in 2030 would be at 300 Mt under the DIVE scenario, the same as in 2010, and 600 Mt in the FF one.

Economic implications

Figure 23 shows required total system costs under the DIVE scenario between 2010 and 2030, including investment cost, fuel costs, net-import cost, and O&M costs. Total investment needs between 2010 and 2030 would amount to USD 450 billion (undiscounted), of which about 40% would be for national transmission and distribution. Preliminary assessment suggests that additional gas exports according to the DIVE scenario would increase state revenue in the region by about USD 15 billion per year by 2030.

Figure 22 North Africa: Electricity supply mix (generation and net imports) under the DIVE scenario

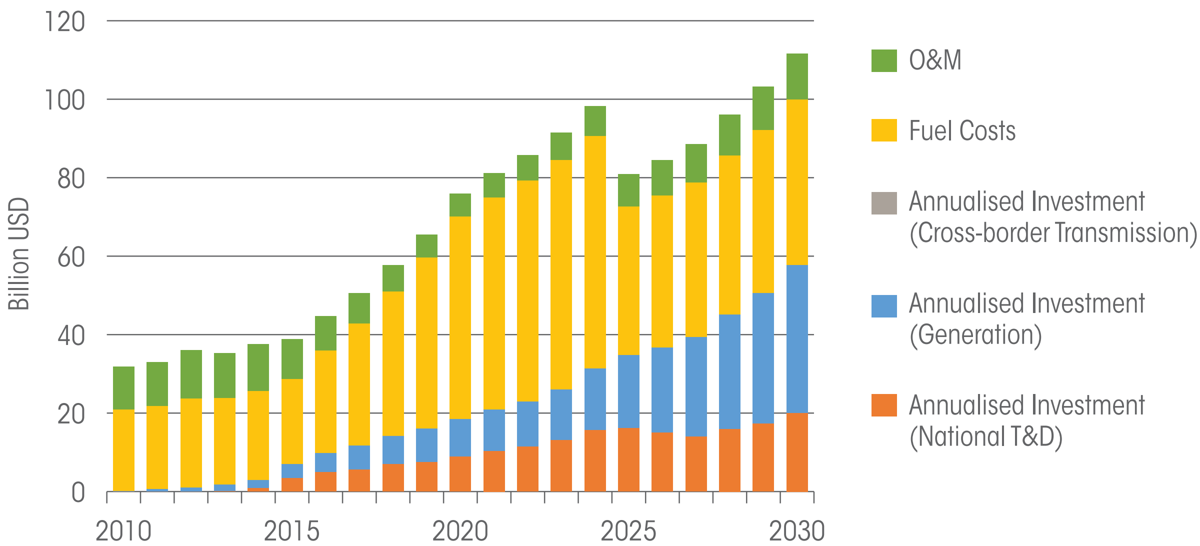


Caveats

Although most of the North African countries have sophisticated electricity master plans, and the data availability is expected to be the best on the continent, it was beyond the scope of this phase of the study to do country-level data collection. Because of the lack of publicly available regional data-gathering efforts, the level of the analytical detail for North Africa is weak compared with the other regional models.

Solar PV cost data for North Africa in IRENA's costing database is limited. The available data shows that solar PV installation costs may be substantially lower than in the rest of Africa. The results will be updated as more data becomes available and could in the future indicate a stronger economic case for solar PV deployment.

Figure 23 North Africa: Annualised system costs under the DIVE scenario



9. Defining national pathways: country-level planning

IRENA's Regional Action Agenda calls for country- and regional-level planning to consider renewable power options, on account of their declining costs, energy security, and environmental and socio-economic benefits. However there are obstacles to doing so in Africa, including limited access to data on renewable resources and the technologies to harness them, and a lack of tools and methodologies. Institutional and human capacity should be increased in order to establish reliable, transparent and updated long-term energy plans.

IRENA has developed its SPLAT tools, five collections of individual country models corresponding to the five African regions analysed, to close this gap and provide a good starting point for developing power-sector master plans. SPLAT tools are capacity-expansion models, available at no charge to users, to compute least-cost investment pathways in order to achieve a given set of policy goals. The SPLAT models are based on the MESSAGE planning software that many African countries already use, which makes them suitable for building capacity.

The SPLAT tools include both centralised and decentralised renewable options with the ability to consider urban and rural demand separately. On a regional level, they can account for interconnection and trade. One significant benefit of the SPLAT tools is their link to IRENA's renewable technology databases, such as the Global Atlas for Renewable Resources, the Renewable Project Cost database, Technology Briefs, and Renewable Roadmaps in various sectors. SPLAT thus offers access to the best and latest data available for renewable energy potential, cost, and technology performance. This data is also consistent with the latest regional master plans.

SPLAT tools are 'model cases' built within the MESSAGE modelling software for each African country. SPLAT allows countries a head start in developing a country model that is pre-calibrated by IRENA with base-year energy balances, regional master plans, and IRENA's renewable generation potential, costs and performance data.

Energy planners in the region can adjust country case studies developed within IRENA's five regional studies presented above according to their own data and expectations if they wish, to assess how those changes impact the findings. Country studies with the SPLAT model would help identify and prioritise investment projects for network and generation plans. The main reports from the five regional studies include annexes with lists of priority projects. The model also allows the analysis of electricity-access issues in three demand categories, in order to discover the right balance of centralised, small scale and off-grid solutions to achieving universal access to electricity. This analysis is also included in the main reports.

Whilst good data and transparent methodologies are the foundation of good planning, country-level expertise in energy planning is important for overall energy-sector coordination among various energy-sector stakeholders, and also for timely updates of master plans. Further capacity building is needed.

IRENA supports the use of SPLAT models by organising training courses on an ad hoc basis. Training for MESSAGE software and its applications for country planning is provided through the technical cooperation programmes of the International Atomic Energy Agency, with whom IRENA collaborates.

10. The Way forward

Given the long lifespan of energy infrastructure, investment decisions made today can shape an energy system for decades. Long-term planning is crucial to support cost-effective development of renewable infrastructure within integrated energy systems. This synthesis report is aimed at helping that process. It presented IRENA's SPLAT tools for methodologies as well as underlying data, five summaries of power sector analysis for five African regions, and an explanation of how SPLAT can aid in country-level planning. The IRENA databases and tools used are available to others and frequently updated, as the agency believes reliable statistics and data are the foundation of good planning. This report is a part of IRENA's efforts to supply them, and 2015 will feature a continuation of them, for Africa as well as for other regions.

Enhancements of planning tools and methodologies

Planning also requires transparent methodologies, in order for the analysis to be traceable, credible, and easy to update. IRENA's SPLAT models are a step in that direction for African planners, as they are based on the MESSAGE software that many are already familiar with and link to IRENA databases for data access. The SPLAT tools use relatively simplified assumptions to compensate for the limited amount of reliable data in many African countries.

An additional challenge is the intermittency of some renewable technologies, such as wind and solar, which must be considered in such models and planning. The Addressing Variable Renewables in Long-Term Energy Planning (AVRIL) project, initiated in 2014 by IRENA, aims to improve planning methodologies involving model-based analysis. A specific objective is to assess whether current planning methodologies are failing to account for important impacts of variable renewable-energy technologies, especially in the context of developing countries and, if so, how these factors can be incorporated into analysis. The second objective is to identify the key pillars of a robust energy-planning methodology.

AVRIL's findings will be published as a comprehensive report during 2015, followed by pilot studies with interested countries to implement selected methodologies in SPLAT models in order to address variability in long-term energy policy planning. Examples of policy questions include how changing demand structure affects load curves and the implications for renewable energy integration. The case studies will show how a power system should be designed in an African context to overcome the challenges presented by variable renewable energy.

For the Africa Clean Energy Corridor iniative, IRENA collaborated with Lawrence Berkeley National Laboratory in the United States, to develop a methodology to assess the economic viability of geographical clusters of renewable energy resources, which is called a zoning methodology. This could help to improve planning by improving how the technical and economic characteristics of possible future projects are accounted for in SPLAT models. Geographic Information System (GIS) mapping will be used to help find the right balance between centralised, mini-grid and off-grid solutions.

REmap 2030 regional analysis

In 2012, the United Nations General Assembly declared the years between 2014 and 2024 as the Decade of Sustainable Energy for All (SE4ALL). IRENA is designated as the renewable energy hub for SE4ALL. Within that context IRENA developed REmap 2030 – a global renewable energy roadmap – in order to assess how the SE4ALL target for renewable energy can be achieved (IRENA, 2014). The basis of REmap 2030 is formed by 26 individual country studies developed in collaboration with national REmap experts and IRENA. By the end of 2015, REmap 2030 is to be extended to add 11 new countries. In order to complement the country studies and complete the global picture, several regional REmap reports, for Latin America, South Asia, and Southeast Asia, are in preparation.

The five regional studies presented in this report will be used as a basis for IRENA's REmap Africa regional analysis, scheduled to be completed during 2015. The presented analysis builds on publicly available databases and information on power systems and policies for the respective African regions as of the time of execution of the analysis. Updating the analysis with newer data from national sources and having them validate policy assumptions will be important to make this coming regional renewable roadmap relevant to the region as well as to validate the SPLAT-based five regional power sector analyses.

Within the SE4ALL context, African countries currently participating are developing SE4ALL Country Action Agenda (AA) with support from the African Development Bank. The AA is structured in three parts: vision and targets to 2030; priority action areas; and coordination and follow up. The first part is where quantitative assessment is directly needed, in particular for setting baselines for power sector visions and targets.

Capacity building within regional initiatives

Several major regional initiatives seek to mobilise investment into power and infrastructure in Africa, such as the Programme for Infrastructure Development in Africa (PIDA) and the United States' Power Africa initiative. IRENA encourages regional infrastructure building to focus on renewable resources and avoid negative environmental impacts through initiatives such as ACEC, which promotes the accelerated deployment of energy resources and cross-border trade of renewables-generated power in EAPP and SAPP regions. The four pillars of the ACEC Action Agenda are zoning and resource assessment; enabling a framework for investment; national and regional planning; and capacity building. The pillar for national and regional planning supports countries and power pools using energy-planning tools to develop and update master plans that integrate cost-effective renewable power options whilst also maintaining system reliability.

In addition to efforts that are part of specific initiatives, IRENA organises regional workshops and training sessions to promote and improve energy planning in Africa. Two three-day regional workshops were held in 2012 in Johannesburg in collaboration with the South African National Energy Development Institute (SANEDI) for SADC countries, and in Abidjan in collaboration with ECREEE for ECOWAS countries. The SPLAT models were presented and all models and data were made accessible through the IRENA website[13]. Further consultations with utility representatives were conducted at the annual Assembly of Association of Power Utilities (APUA) in 2013. Three energy training sessions were organised during 2014, along with a joint workshop with the United Nations Economic Commission for Africa's Sub-Regional Office for Eastern Africa (UNECA SRO-EA) for Eastern African countries[14]; two joint workshops in collaboration with the IAEA and the governments of Tunisia for North African countries; and one with the IAEA and the government of Cameroon for Central African countries. In addition a half-day expert meeting on generation expansion was conducted in 2013 during the Windaba conference in Cape Town.

Consultations at these sessions revealed a variety of approaches to energy planning among African countries. Some did so solely through ad hoc contracts with foreign consultancy firms. Within SAPP, only four member utilities had access to proper planning tools as of the time of consultation. In West Africa only three ECOWAS member countries use planning tools.

At these workshops and training sessions IRENA explicitly targeted three groups: government planning offices, utility planning offices, and academia. IRENA's main counterpart is governmental institutions but aims to work with the other two stakeholders as well to enhance overall planning capabilities. Coordination between these parties is lacking in many countries, and planning expertise is not always well distributed among them. Feedback from regional meetings and training workshops identified further capacity building needs, but also those with expertise in planning who could share with their peers across the continent.

Based on these consultations, regional training programmes are being developed with ECREEE for West Africa and with UNECA SRO-EA for East Africa. Another capacity-building programme is in development for selected other African countries in cooperation with interested partners.

The future for SPLAT tools should include national-level participation and data entry, as well as use by regional planners. Regional applications can help elaborate country targets based on regional targets, such as for ECOWAS countries (see Box 1). There are also several regional initiatives ongoing

[13] *The web site for the Southern African Workshop is found at www.irena.org/SAPP and for the Western African Workshop at www.irena.org/WAPP*

[14] *The web site for the UNECA-IRENA training session is found at www.irena.org/EAPP..*

that partially or fully aim to improve energy-planning capacity in Africa. IAEA's technical co-operation programmes support member states in conducting studies, planning and policymaking. For the past 30 years, these options have included training on the MESSAGE modelling software, on which the SPLAT models are based.

EAPP has an ongoing capacity-enhancement project supported by Sweden and Norway and executed by Denmark's Energienet and Ea Energianalyse. One component of it includes long-term energy planning and the application of the Balmorel modelling tool, originally developed by the Danish Energy Research Programme, to update the EAPP Master Plan from 2012. IRENA cooperates with these institutions to provide effective and sustainable capacity building support.

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