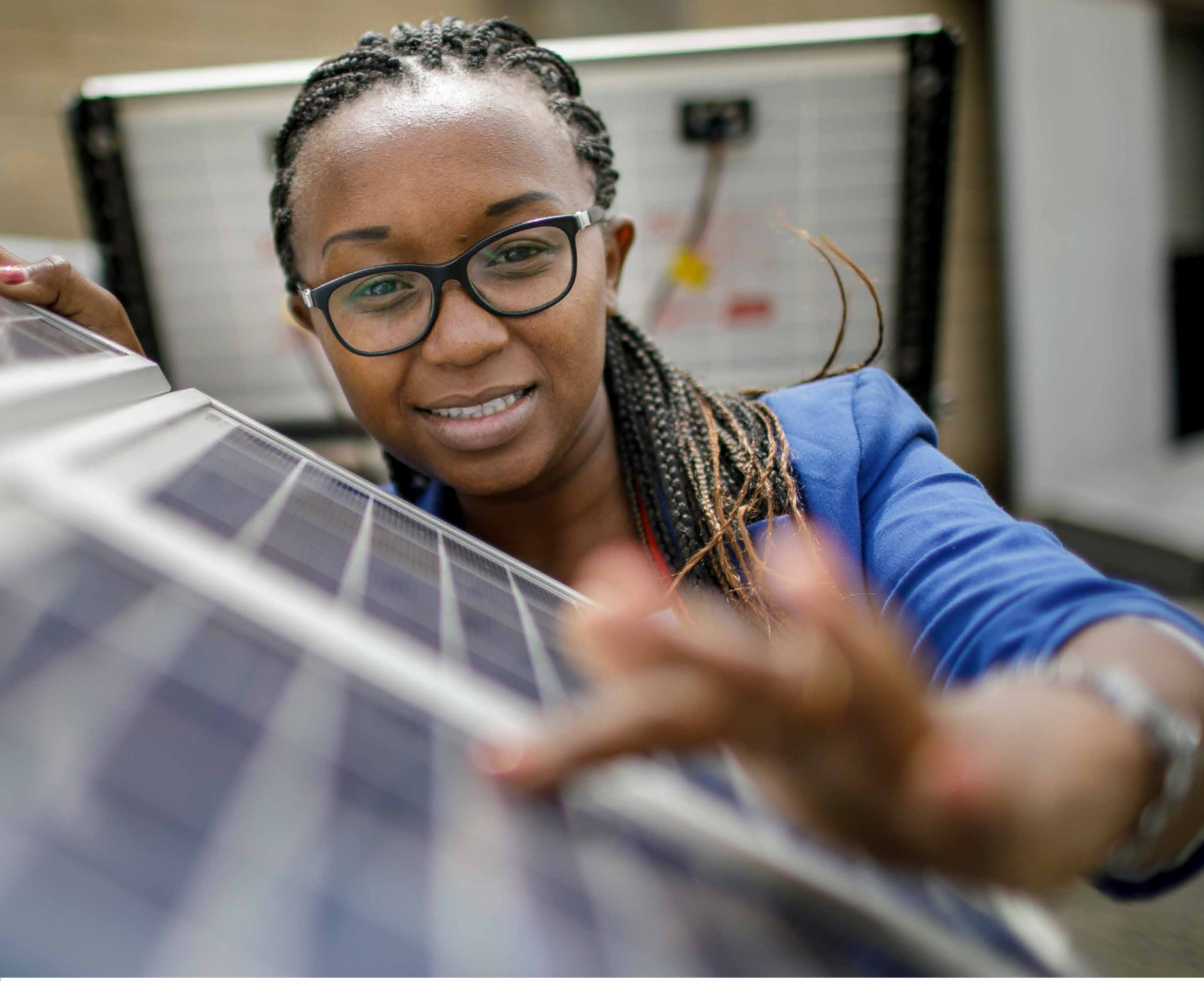

The Renewable Energy Transition in Africa

Country Studies for Côte d'Ivoire, Ghana, South Africa, Morocco and Rwanda

Implemented by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

IRENA International Renewable Energy Agency

On behalf of the

Federal Ministry for Economic Cooperation and Development

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ACEC	–	Africa Clean Energy Corridor
AfDB	–	African Development Bank
AU	–	African Union
AUDA-NEPAD	–	African Union´s Development Agency
CAGR	–	Compound Annual Growth Rate
CSP	–	Concentrated Solar Power
CO_2	–	Carbon Dioxide
CwA	–	Compact with Africa
EAPP	–	Eastern Africa Power Pool
ECOWAS	–	Economic Community of West African States
EU	–	European Union
GDP	–	Gross Domestic Product
GIZ	–	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	–	Gigawatt
IEA	–	International Energy Agency
IFC	–	International Finance Corporation
IPP	–	Independent Power Producer
IRENA	–	International Renewable Energy Agency
kg	–	Kilogram
kWh	–	Kilowatt-Hour
LCOE	–	Levelized Cost of Electricity
MW	–	Megawatt
MWh	–	Megawatt-Hour
NDC	–	Nationally Determined Contributions
OECD	–	Organisation for Economic Co-operation and Development
PPA	–	Power Purchase Agreement
PSP	–	Private Sector Participation
PV	–	Photovoltaic
RE	–	Renewable Energy
REFiT	–	Renewable Energy Feed-In Tariff
SAPP	–	Southern Africa Power Pool
SDG	–	Sustainable Development Goals
SEforAll	–	Sustainable Energy for All
T&D	–	Transmission and Distribution
TWh	–	Terawatt-Hour
UN	–	United Nations
USD	–	United Stated Dollar
WAPP	–	West African Power Pool

1 Preamble to the five country studies

1.1 Context of the study

The global transition toward sustainable energy systems is gaining speed, driven both by the continuing drop in renewable energy costs and improvements in performance, and expedited by globally-agreed goals such as Sustainable Development Goal 7 and the Paris Agreement. This transition presents enormous opportunities to transform and modernise energy systems across the globe. African countries – many of them rich in renewable resources – have much to gain from this transition, particularly in terms of a resilient and affordable low-carbon energy system development and universal access to electricity. It is also vital for all nations to accelerate their pace of decarbonisation in order to meet the Paris Agreement goals of achieving carbon neutrality by 2050 and limiting the warming of the planet to well below 2°C (and if possible, 1.5°C) compared to pre-industrial levels.

Energy is the foundation of economic development, and energy poverty is the greatest obstacle to that development. Therefore, the goals of German development cooperation in the energy sector are to reduce energy poverty and to promote economic and social development, while also decarbonising the power sector and supporting partner countries in the transformation to a low-carbon economy. The solutions to achieving those goals, however, will usually vary between countries, as well as among different sectors within countries, from the household level to the industrial level. To ensure that energy meets the specific needs of a country or sector, it has to be available in the right amount, at the right time, in the right place, in the right quality and at the right price. Special attention should be given to ensuring energy is used productively to foster and kick-start local economic activity, thus stimulating economic development and creating local employment. When that is done successfully, the energy sector acts as a driving force for a comprehensive, sustainable transformation and contributes to the development of national economies.

The potential for an African energy transition is explored in the report, The Renewable Energy Transition in Africa, jointly prepared by Germany's KfW Development Bank, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and the International Renewable Energy Agency (IRENA) on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

The following analysis was prepared by IRENA to provide a basis for German development cooperation in Africa. The analysis supplements the joint report's insights by providing the country-specific power sector contexts of the African Energy Transition in five priority countries identified by BMZ. The selected countries are the members of the Compact with Africa Initiative: Ghana, Ivory Coast (Côte d'Ivoire), Morocco, Rwanda and the G20 member South Africa.

1.2 Structure of the five country studies

All country studies follow a unified structure, as presented below.

Section 1, the "Status quo of the power sector", starts with a brief overview of the supply and demand structure of energy commodities in the country (x.1.1), followed by a discussion of key power sector characteristics (x.1.2) and a review of electricity access in the country (x.1.3).

The two subsections that follow review ongoing government plans, targets and policies driving renewable energy deployment in the power sector. First, a summary of government planning scenarios and the targets derived from those scenarios are reviewed and discussed (x.1.4). Second, the policies and measures deployed in the country to incentivise renewable energy deployment in the power sector are provided (x.1.5).

Section 2, "Prospects for renewable power towards 2040", discusses selected electricity system transition scenarios drawn from the IRENA report series, Planning and prospects for renewable power. After briefly explaining methodologies and assumptions (x.2.1), IRENA electricity capacity expansion scenarios are presented (x.2.2), focusing on the deployment potential of renewable energy given projected electricity demand growth, and already-committed projects and measures. Implications for decarbonisation are also discussed. The section concludes with an assessment of investment needs to realise the renewable deployment potentials as identified in the IRENA scenarios (x.2.3).

Section 3, "Systemic innovation needs and opportunities", argues that a systemic approach covering innovations in power generating and enabling technologies, market design, business models and system operation is needed to go beyond the potentials quantified in the previous section. Adopting a systemic approach allows for even more ambitious targets such as 100% renewable-based power systems. The section explores innovations in support of a power sector transformation towards a much higher share of renewable energy in two subsections: the first discusses innovations for renewable power systems (x.3.1); the second examines innovations for renewable-based electrification of end-use sectors (x.3.2).

Section 4 provides conclusions and areas for further consideration.

1.3 Methodologies for the five country studies

The five country studies build on a number of recent IRENA analyses. The sections below describe the methodologies used for the case studies, including references to key publications and data sources used.

1.3.1 Statistics and data sources

The information presented in section 1 summarises key energy and electricity statistics. The World Energy Balances, issued by the IEA (IEA, 2019c), are used to provide methodologically-consistent insights into the supply and demand structure of energy commodities. The latest data available for these balances are for 2017. As a result, that is the year most frequently referenced when referring to “current” energy or electricity structures of supply and demand.

IRENA collects and publishes global renewable capacity and generation statistics, with more than 50 renewable technologies specified. These statistics are complemented by less detailed non-renewable technology data in the IRENA statistics database to complete the portfolio of electricity generation technologies used by country. Capacity and generation data in the case studies reflect the latest release of this IRENA database (IRENA, 2020f), covering generation statistics until 2018 (with certain country generation data available for 2019) and capacity statistics to 2019.

1.3.2 Analysis of targets and policies

The renewable energy targets reported in section 1 of the country studies reflect the targets set in national energy plans (or strategies), as well as the commitments in countries’ Nationally Determined Contributions (NDCs). These data are collected by IRENA for almost 200 countries and are regularly updated to ensure accurate and timely information. It should be noted that while national targets provide an indication of renewable energy deployment plans and their timelines, their implementation requires clear strategies and supportive policies (IRENA, 2015b).

In addition, the targets included in countries’ original NDCs only represent snapshots of their commitments under the Paris Agreement at a given point in time, in most cases at the moment of ratification of the agreement. As the “ratcheting mechanism” built into the Paris Agreement requires countries to submit progressively more ambitious NDCs over time, the first round of NDCs lays out minimum targets that represent starting points from which to increase ambitions in the future.

The policies, regulations and measures in support of renewable energy deployment in the power sector in the five case studies are either national or sub-national (not continental or regional) and reflect their status as of July 2020. These are collected in IRENA’s repository of knowledge on policies and measures.

In addition, among the countries studied in this report, some have been analysed extensively in other IRENA reports (e.g. Morocco and South Africa in analyses on renewable energy auctions; and Ghana in a Renewables Readiness Assessment) and this report includes some of the key findings from those analyses.

While IRENA’s policy framework for a just and inclusive transition has been presented as a recommendation for all countries studied, it should be noted that there is no standard policy mix that can simultaneously fulfil all the renewable objectives of every country. Comprehensive policy packages must be tailored to each specific national and local context, following a more detailed and comprehensive review of the existing policy mix.

1.3.3 IRENA scenarios for renewable prospects

The forward-looking scenarios discussed in section 2 of the country studies are based on IRENA’s Planning and Prospects for Renewable Power report series. In this work, IRENA applied its in-house electricity capacity expansion model – the System Planning Test (SPLAT) model[1] – to develop power system scenarios of renewable prospects out to 2040 for five African power pools and 47 countries within those pools.

The analysis provides a view of grid-level power system development based on IRENA insights into renewable resource availability, technology costs and performance characteristics. The retirement schedule of current generation capacity fleets, as well as committed project pipelines at the time of the analyses, are also taken into consideration. Beyond committed retirements and deployments, the rest of the grid-level power system is optimised out to 2040 according to cost minimisation principles, subject to the physical energy flow and operation constraints of a power system. Optimisation is performed at the regional level, i.e. for a power pool with its member countries treated as a homogeneous entity. The optimisation results may or may not be substantially different from the optimal power mix for a single country when trade is not considered. Non-renewable features of power system development were calibrated according to official regional power pool masterplans, when available.

In this report, the scenarios for South Africa and Rwanda reflect the least-cost power sector optimisation of a combined Southern and Eastern power pool region. A full description of the assumptions and results behind that analysis will be made available in a corresponding report, soon to be released by IRENA (IRENA, forthcoming).

The scenarios for Ghana and Ivory Coast reflect the least-cost optimisation of the Western African Power Pool. The scenarios were presented by IRENA (IRENA, 2018b) to 2030, and that horizon was extended to 2040 for this report.

The scenarios for Morocco were developed as a single country model for this report. The Moroccan scenarios will be further developed as part of an overall update to IRENA’s North African power pool modelling, to be featured in a future IRENA publication.

[1] The SPLAT model was developed using the modelling software MESSAGE, developed by the International Institute for Applied Systems Analysis (IIASA) and adapted by the International Atomic Energy Agency (IAEA) for national energy planning purposes (IAEA, 2017).

The results presented reflect those of the specific analyses carried out above, and should not be interpreted as the highest ambition for each country in terms of renewable energy deployment. For example, all fossil fuel power projects that have come to financial closure are assumed to proceed as planned, and all existing and pipeline projects are assumed to fulfil their expected life without early retirement. Renewable energy costs also continue to decline at a rapid pace, and integrating the most up-to-date cost data in future long-term modelling could result in even greater economic potential for renewable energy. What is more, system-wide innovations are emerging rapidly that could enable even higher shares of renewables. Section 3 in each country case study provides an overview of innovation opportunities that could potentially boost renewable shares beyond the ambitions presented in IRENA scenario analyses. The UNFCCC Paris Agreement has highlighted the need for such increased ambitions – scenarios that meet ambitious action on climate change would also need to expand upon this analysis by exploring much-diminished roles for oil-, gas- and coal-fired power.[2]

1.3.4 Analysis of systemic innovation needs and opportunities

The assessment of key innovations to support the power sector transformation, presented in section 3 of the country studies, is an application of the IRENA toolbox, Innovation landscape for a renewable-powered future (IRENA, 2019e). The toolbox contains 30 key innovations that enable the integration of high shares of variable renewable electricity in power systems. The innovation toolbox follows a systemic innovation approach covering four dimensions: innovations in enabling technologies, regulation and market design, business models and system operation. Tailored, innovative power sector solutions result from combining innovations in these four dimensions. For each country case, a portfolio of innovations has been devised with the aim of further exploring their potential and relevance to the country context.

In addition to country-specific insights, there are naturally more generic opportunities for innovation that are valid across the five countries included in this analysis. IRENA’s Innovation landscape for a renewable-powered future report outlines such opportunities in an eight-step innovation plan which is used as the basis for some of the common findings presented in the following section of this introduction.

1.4 Findings common to all five countries

1.4.1 Basic conclusions emerging from the analyses

Each of the five country case studies contains specific conclusions related to the level of ambition for renewables, the framework for a just and inclusive transition, and innovation needs and opportunities. In addition, there are common conclusions that emerge from the analyses, which are presented here in order to frame the country-specific discussions that follow.

Countries can take advantage of the abundance and competitiveness of renewables

Large unused renewable electricity generation potential exists in all five countries. Based on resource assessments and zoning analyses of wind and solar energy sources, the theoretical potential among non-hydro renewables are generally largest for solar conversion technologies (PV and CSP) followed by onshore wind and biomass.

Existing capacities and current generation practices are not reflective of the techno-economic potentials of resources, particularly in the context of renewable energy. The speed at which previous technical potentials have turned renewables into economically competitive contenders has outpaced the rate of actual investments in deployment.

Pathways that include large shares of renewables are not only technically feasible and attainable but also offer the lowest costs – indeed, despite countries’ varying demand outlooks and resource endowments, significant shares of renewables are cost-competitive across all scenarios analysed.

However, each country has different socio-economic starting points, political ambitions and levels of current dependence on fossil fuels, so the pace and exact path of the energy transition will also be different in each country.

Countries can align ambitious renewable energy and climate change mitigation targets

The economically viable renewable potentials identified in the analyses can exceed current national expansion plans – often considerably. Likewise, the submitted NDCs are often out of sync with committed capacity expansion projects or project plans in the pipeline. Simply matching implementation efforts to higher ambitions represented in NDCs and energy plans would generate considerable investment opportunities.

Countries can continue supporting the development of regional markets

Cross-border electricity trade can be a crucial element that affects the timing and extent of renewable capacity expansion. Regional electricity markets (i.e. regional power pools) based on cross-border market integration, transparent rules and harmonised regulations across various borders help balance generation surpluses and shortages in national power systems, as well as enable the matching of complementary generation profiles of renewables. Regional integration can increase the market for large-scale additions of solar PV and wind, and result in lower overall generation system costs. A bottleneck affecting cross-border trade, as well as the large-scale implementation of VRE, is the slow pace of infrastructure investments in transmission, distribution and storage capacities – countries can continue their concerted efforts to improve this vital infrastructure.

[2] More ambitious scenarios would also be well-aligned with goals of global partners, as reflected, for example, in the European Commission’s joint communication, “Towards a comprehensive strategy with Africa” (European Commission 2020b).

Countries can leverage renewables and distributed energy resources (DER) to achieve universal energy access

Access to electricity has been expanding in all countries and universal access (Sustainable Development Goal 7) appears within reach if centralised grid connections are supplemented with distributed energy resources (DER) and renewables. However, progress towards universal access has focused mainly on providing electricity to private households. It is also important to ensure access to levels of electricity that are higher than those generally required by households. Those higher amounts are required for productive uses – such as in agriculture, commerce and industry – that are vital for economic development and job creation. Progress towards universal access should therefore include assessments of these productive user groups and their respective energy needs.

To meet this expanded view of universal access, there is considerable potential for the rollout of innovative solutions like renewable mini-grids, solar home systems and micro turbines, which can contribute to national climate and energy goals, and provide services to power system operators. However, these DERs sometimes receive lower priority than large-scale projects in national plans, and could also be better represented in NDC pledges.

Electricity demand growth is also expected to continue beyond the point of simply providing universal access to electricity. Alongside measures that improve energy efficiency, countries could consider how DERs can align with electricity demand increases due to demographic growth, higher living standards and further penetration of electricity-consuming devices and equipment, including electric vehicles (EVs).

Countries can develop tailored power sector transformation plans based on a systemic innovation approach

High shares of VRE in power systems across all countries will need to be accompanied by accelerated and systemic innovation. While specific innovation needs will vary by country, innovations are generally required in electricity generation technologies, new enabling technologies, regulation and market design, business models and system operation practices. IRENA's Innovation landscape for a renewable-powered future report outlines an eight-step innovation plan to provide a better sense of how such innovation can be fostered (see Box 1). Section 1.4.2 goes into further detail on these opportunities for innovation across all five countries.

1. Develop far-sighted policy frameworks that anticipate future power system needs.
2. Adopt a systemic approach, drawing together innovations in technology, market design, business models and operation.
3. Foster learning by doing through ongoing trial and demonstration.
4. Account for changing roles and responsibilities in the operation of the power system.
5. Make market design innovation a priority, as it fosters flexibility at relatively low cost.
6. Create synergies between renewable power supply and electric mobility, heating and cooling.
7. Turn smart innovations into smart solutions using digital technologies.
8. Adopt an open and cooperative approach to innovation.

Box 1 – IRENA innovation landscape report – Eight-step innovation plan

A key requirement to ensure new innovations are well integrated into power systems is to develop and maintain long-term plans and planning practices that are tailored to country circumstances. For example, as elaborated in the case studies of this report, the emergence of a global hydrogen economy could open long-term opportunities for countries in this analysis to make even greater use of low-cost renewable electricity. Major actors in Europe are already taking significant steps in this area – both the European Commission and the German government, for example, have released hydrogen strategies. This early experience shows that a long-term plan is required to understand how new power demand could evolve, and to identify the innovations required to ensure that generation technology, social and technical regulations, and system operation evolve alongside it.

Countries can build on policy frameworks for just and inclusive transitions

The starting point and policy actions to support a just and inclusive energy transition vary from country to country. They depend on diverse country-specific factors, including socio-economic conditions, fossil fuel and other dependencies, institutional frameworks and capabilities, investment patterns and trade positions. For example, Morocco, which has reached universal access to electricity, albeit with a low share of renewables, faces different energy transition challenges to Rwanda, which has yet to provide electricity to all of its citizens. Moving forward, policy design needs to be holistic and consider the impact of deployment policies not only on the energy sector but also on society, the environment and the economy at large. In the non-access context, long-term stable deployment policies are needed to attract investments in renewables. However, such instruments need to continuously adapt to changing market conditions. Although some of the countries in the analysis have made important progress, more efforts are needed to achieve the plans that have been set.

Section 1.4.3 provides more detail on how future policy can build on those examples, but such policies are part of a comprehensive package that connects deployment policies with integrating and enabling policies. The latter include: **1) industrial policies** that aim to leverage and enhance domestic capabilities; **2) education and skills policies** that increase technical capacities and technological learning; **3) labour market policies** that facilitate labour opportunities, rights and mobility; **4) financial policies** that encourage revenue streams that benefit more people; and **5) social protection measures** that provide support for vulnerable workers and their communities and prevent them from shouldering an unfair burden during the energy transition.

Countries can work to overcome common structural barriers

IRENA's analysis shows that there are a number of structural barriers to the energy transition that are common to many African countries, including: a lack of capacity in key institutions; weak or missing regulatory and legal frameworks; electricity grids with high rates of loss and limited ability to integrate high levels of variable renewable electricity; high costs for some distributed generation technologies like mini-grids; and grid operators and service providers that may not be able to expand access or invest in decarbonisation solutions. As a result, there is a clear need for African countries, supported by their development partners, to address and work toward removing these structural barriers.

1.4.2 IRENA's eight-step innovation plan adapted for the five African countries studied

Here are the details of the eight-step innovation plan adapted from IRENA's Innovation landscape for a renewable-powered future report (IRENA, 2019e) for Côte d'Ivoire, Ghana, Morocco, Rwanda and South Africa:

Anticipate future power needs

To achieve this, regularly updated national plans and planning processes can explore scenarios that consider the latest renewable energy technology developments, including their continuously falling costs, increased efficiencies and increased competitivity compared to conventional technologies.

Currently, at first sight, some technology-driven innovations identified for the countries in this analysis might seem far-fetched today in the African context. However, after closer inspection – and while adopting a farsighted approach – these can be highly relevant in the medium- and long-term. African countries can leapfrog development based on polluting fuels and fully embrace the energy transition based on renewables. For example, artificial intelligence (AI) and 'big data' might seem as unrealistic to apply in some African countries today, but Côte d'Ivoire is already testing them for use in grid maintenance.

Adopt a systemic approach to innovation

Innovations do not emerge in isolation. By considering innovations in a) generating and enabling technologies (like digital technologies, electric vehicle smart charging or renewable-power-to-X technologies), b) regulatory frameworks, c) business models and d) new system operational practices, policy makers can devise practical solutions for their national power sectors.

Synergies can also be explored between multiple technologies by adopting "hybrid" approaches that combine several renewable generation technologies into practical solutions. For example, pumped hydropower plants can be equipped with floating solar photovoltaic panels in Côte d'Ivoire, Morocco, Rwanda and South Africa. That can reduce installation and operation costs since the existing grid connections can be shared. Similarly, decentralised energy resources – like behind-the-meter batteries, distributed generation and demand response – can contribute to the stability of the grid by providing ancillary services, provided that a regulatory framework that allows them to do so is in place.

At the same time, on- and off-grid strategies can be pursued in parallel, and wire and non-wire solutions can be complementary. For example, grid congestion in Côte d'Ivoire and South Africa could be tackled not only by the construction of new transmission lines, but also by energy storage systems and digital technology applications, like virtual power lines.

Foster learning by doing

Given the importance of a reliable electricity supply, experimenting with the power system can be challenging to defend publicly. However, regulatory "sandboxes" – frameworks that allow stakeholders to experiment without restrictions in a given time frame or in a specific part of the grid – can prove to be beneficial in the long term. For example, in Morocco, the Akhawayn University is piloting the first hybrid fuel cell powered with wind electricity in Africa.

Moreover, patent data available for Morocco and South Africa show that those countries are already innovating significantly in the power sector – especially in CSP, thermal energy storage and hydrogen in the case of Morocco; and solar, bioenergy and hydrogen in South Africa. Such innovation can be sustained with supportive policies and regulatory sandboxes.

Account for changing roles and responsibilities

The energy transition calls for a shift away from the traditional power system – in which generation follows inflexible demand – towards a system in which flexibility also is provided from (existent or planned) interconnections and the demand side. Therefore, roles and responsibilities are changing not only for the incumbents, but also for consumers, who can play more active roles in the power sector. In the more highly-developed future power systems of the countries anticipated in this analysis, consumers will be able to react to price signals, provide services to the grid via aggregators, and also generate their own power, provided that the necessary frameworks are in place and that consumer empowerment and awareness are promoted.

New business models like peer-to-peer electricity trading, community ownership models, aggregators, pay-as-you-go models and energy-as-a-service are all being tested in various African countries. However, to scale them up, policy makers and independent regulators (where they exist) would need to allow and promote these new models. They also need to seize the opportunities created by new technologies, which will attract new actors into the power sector.

Create synergies through sector coupling

New electrification strategies – either employing the direct use of renewable sources or the indirect use of renewable power-to-hydrogen and renewable power-to-heat technologies – can be beneficial not only for the power sector, but also for end-use sectors like industry, transport and buildings.

In industry in Rwanda, for example, renewable power could be generated on-site for mining and quarrying, while on-farm biodigesters and solar pumping could be used for irrigation in agriculture. Similarly, residues from sugar, palm oil and cotton operations in Côte d'Ivoire and other countries could be used to generate bioenergy, which would bring additional revenues to the plant owners. In Ghana, aluminium production could be electrified with renewables in the future if enough reliable and very low-cost electricity is made available.

Some promising industrial initiatives and national strategies include the hydrogen strategy in South Africa (HySA), as well as an upcoming hydrogen strategy in Morocco. Both countries have significant potential to become green hydrogen producers. In Morocco, fishing, mining, green ammonia and phosphate-based fertiliser production could greatly benefit from domestic renewables. Morocco could also switch from importing carbon-based ammonia to producing green ammonia domestically.

In transport, pilots to electrify transport, such as Côte d'Ivoire's adoption of three-wheeled electric vehicles, could be expanded into ambitious national plans that take advantage of increased solar energy. Regulations that ban imports of older cars and set strict emissions standards, like those in Morocco, can be adopted in other countries.

In the buildings sector, and especially in rural areas with no or poor access to electricity in Côte d'Ivoire, Ghana and Rwanda, renewable mini-grids and a higher uptake of solar water heaters, solar water pumps, clean cooking stoves and solar home systems for mobile charging and lighting could be especially beneficial. Morocco already has a "Green and Smart Building Park" effort and a "Green Mosque Programme". Other countries could implement similar programmes.

Make regulatory updates and improved market designs higher priorities

Until new capital-intensive transmission and generation capacities can be constructed, it is possible to make significant gains simply by updating existing regulatory frameworks and adopting new market designs. One example is Ghana, which has liberalised its power sector. It is also important to harmonise trading rules across borders, which would reduce system costs over the long term and lower bills for consumers. For example, changes to the procurement rules for generation by municipalities in South Africa, or allowing more Independent Power Producers (IPPs) to enter various African power sectors, could be cost efficient in the short and medium term, with minimal public investments. Also, policies in support of renewable power should expand beyond increasing the installed generation capacity, and also allow consumers to own and operate community-owned renewable mini-grids.

Turn smart innovations into smart solutions

For policy makers to devise tailor-made, practical, implementable and "smart" innovative solutions, two aspects are key: first, solutions need to combine several innovations across various dimensions, such as enabling technologies, business models, regulation and market design and system operation; second, it is important to find the most suitable applications for individual technologies.

For example, in more robust future energy systems, green hydrogen can be exported by Morocco and South Africa, and at the same time can be used for the indigenous ammonia industry. South Africa could specialise in the manufacturing and export of fuel cells, given that it has the world's largest platinum reserves, which are important in the production process.

Adopt an open and cooperative approach to innovation

An open and inclusive approach to innovation requires collaboration and cooperation not only between the public and the private sectors, but also at the international level. Examples include the partnership between Morocco and Côte d'Ivoire within the pan-African Green Africa Innovation Network, as well as the German-Moroccan-Energy Partnership. Such exchanges of lessons learned should be actively pursued, because these are beneficial to everyone in the long term. This is especially crucial, since the challenges faced by humanity, like climate change, know no borders.

1.4.3 Deeper discussion and examples of policy opportunities common to all countries

The countries in this analysis have taken important steps toward building policy frameworks that promote a just and inclusive energy transition. As the governments of these countries continue to build on those frameworks, they can draw upon a number of regional good practices and lessons learned. It is important for governments to constantly adapt to changing market conditions. Ghana, for example, shifted from an administratively-set tariff-based mechanism to a competitively-set mechanism to limit the cost of support. Moreover, Ghana adopted fiscal and financial incentives to reduce the upfront costs of investment.

Morocco and South Africa are pioneers in designing policies that maximise the socio-economic benefits of renewable energy deployment. Both Morocco's Noor-Ouarzazate solar complex and South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPP) use renewable energy auctions to promote socio-economic benefits beyond procuring electricity at the lowest price (IRENA, 2019g). Morocco, for example, encouraged the use of local materials and labour; as a result, 30-35 percent of the project's

components and services were sourced locally and 70 percent of the workers are Moroccan, including many women. To create a skilled labour force, government agencies trained people in the region to become electrical and mechanical technicians, solar field operators or mirror cleaning operators.

Similarly, South Africa's local content requirement has boosted local manufacturing and helped create a small export industry of solar PV and wind turbine components. South Africa's REIPPPP also projects that it will create more than 100 000 job-years for local citizens and lead to more black-owned businesses.

A just and inclusive energy transition would also provide support to communities affected by new developments. As compensation for the land lost to develop the Noor complex, for example, Morocco invested in basic amenities and social services in the surrounding community, such as drainage and irrigation channels, drinking water facilities, community centres and mobile health caravans. Indeed, social, health and gender equality are important factors of a just and inclusive energy transition.

Challenges still remain. Morocco and South Africa have learned that it is difficult to achieve goals for increasing the participation of women in the energy sector, and South Africa is still working to create more long-term and meaningful jobs for black citizens that go beyond meeting the short-term labour requirements of developers.

In addition, for countries that are working to provide universal access to electricity, it is necessary to have overarching integrated plans that support all of the different electrification modes – including grid extensions, mini-grids and stand-alone systems – and prevent conflicts among them. Such plans, like those adopted in Rwanda, then need to be combined with financing for both suppliers and end-users. End-users, in particular, need innovative financing and business models to cover connection costs, leasing or owning stand-alone systems and purchasing appliances. Rwanda, for example, has secured dedicated funds from organisations like the Climate Investment Funds (CIF) and the Abu Dhabi Fund for Development.

Finally, it is crucial to tie energy supply to productive end-uses like agriculture and local manufacturing, and to public services like water, healthcare and education in order to improve livelihoods and maximise the socio-economic benefits of energy access (IRENA, 2016b). Productive uses go beyond the consumption of electricity in households. Therefore, broadening the understanding of electricity access needs in commercial and industrial applications is crucial to maximise the productivity of electricity at all stages of value chains. Work has been done to extend frameworks for measuring energy access to include such critical aspects, along with necessary reliability and quality of supply (Fraunhofer ISI, 2018). Those access strategies need also to advance other Sustainable Development Goals (SDGs), including gender, health and education (IEA, IRENA, UNSD, World Bank and WHO, 2020).

In sum, for Côte d'Ivoire, Ghana, Morocco, Rwanda and South Africa to achieve the ambitions set in their energy plans, their targets need to be translated into policies and measures that can support deployment inclusively in all end-uses. Inevitably, there will be trade-offs between achieving socio-economic objectives and procuring electricity at low prices in the short term. But in the long run, the overall benefits of creating a more just and inclusive transition far exceed the extra costs of short-term electricity prices.

2 Côte d'Ivoire country analysis

Key messages

Côte d'Ivoire has significant opportunities to accelerate the share of renewable electricity (mostly solar PV) in its power sector, to further strengthen its position as an electricity exporter in the region, and to provide electricity access to the 67 percent of rural areas that currently lack it by both expanding the grid and building solar PV mini-grids. In any case, the energy supply should be linked to productive end-uses, such as agriculture and local manufacturing, and public services like water, healthcare and education to improve livelihoods and maximise the socio-economic benefits of energy access. Adding coal capacity is not needed from an economic standpoint and should be reconsidered if Côte d'Ivoire aims to increase its ambitions to cut greenhouse gas emissions.

2.1 Status quo of the power sector in Côte d'Ivoire

2.1.1 Brief introduction of the overall energy landscape

In 2017, Côte d'Ivoire's primary energy supply (TPES) was 438 PJ, dominated by primary solid biofuels[3] (60 %), followed by crude oil (35 %) and natural gas (18 %) (Table 1). The country produces crude oil and natural gas, and is a net exporter of oil products. Crude oil (152 PJ) is mainly used in the refinery process and natural gas (79 PJ) is used for electricity generation.

In the same year, crude oil (oil and condensate) production was 12.8 million barrels, with an average production of 35 126 barrels per day and 1 068 406 barrels per month (MPEER, 2020). The country is also historically a net exporter of electricity.

In 2017, total final energy consumption (TFEC) was 299 PJ. It was made up of biofuels (primary solid biofuels and charcoal at 61 %), petroleum products (27 %) and electricity (8 %), with the remainder from natural gas (Table 2). The biofuels are used only in the buildings sector (residential and commercial).

The residential sector accounts for the majority of final energy consumption at 60 percent (Table 2). That dominance reflects the sector's high dependence on biomass for cooking and heating. These end-uses are less efficient than modern fuels like electricity or liquefied petroleum gas (LPG).

Electricity consumption in Côte d'Ivoire has grown at an average growth rate of 5.8 percent per year since 1971. Electricity consumption in 2017 was split almost evenly between the commerce and public services sector (35 %), the industry sector (33 %) and the residential sector (32 %). Electricity provides only four percent of the energy in the residential sector. Electricity makes up 26 percent of the energy in the industry sector and 25 percent in the commercial and public service sector. Compared to neighbouring countries, Côte d'Ivoire has a more reliable supply in terms of low blackout frequency and duration.

Total electricity consumption in 2017 was 6 617 GWh. In 2017, per capita consumption was 279 kWh per person per year (IEA, 2019c). Greenhouse gas (GHG) emissions from fuel combustion have risen from 8 Mt of CO_2 in 2012 to 10 Mt in 2017, with the most recent data showing roughly 4 Mt of CO_2 emissions from natural gas and 6 Mt from oil in 2017 (IEA, 2019c).

	Crude, NGL and feedstocks	Oil products	Natural gas	Hydro	Primary solid biofuels	Electricity	Total
Production	86	0	79	6	264	0	**435**
Net imports	66	-46	0	0	0	-7	**13**
Others	0	-13	0	0	0	0	**-10**
TPES	152	-57	79	6	264	-7	**438**

Table 1 – TPES in 2017 in PJ — Source: (IEA, 2019c)

	Oil products	Natural gas	Primary solid biofuels	Charcoal	Electricity	Total
TFEC	79	13	139	45	24	**299**
Industry	10	13	0	0	8	**30**
Transport	50	0	0	0	0	**50**
Residential	8	0	128	36	8	**179**
Commercial and public services	5	0	11	9	8	**34**
Agriculture/forestry	6	0	0	0	0	**6**
	26 %	4 %	46 %	15 %	8 %	**100 %**

Table 2 – TFEC in 2017 in PJ — Source: (IEA, 2019c)

[3] Defined in IEA statistics as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes and other solid biofuels).

2.1.2 Electricity generation and use

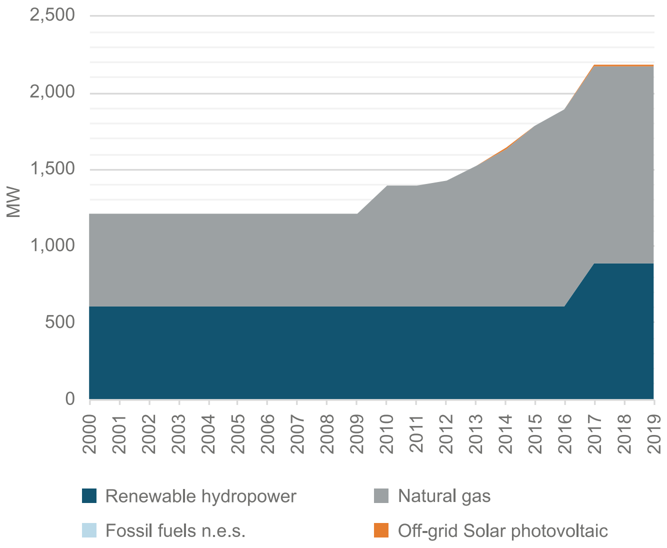
Côte d'Ivoire has the third largest installed electricity capacity, after Nigeria and Ghana, in the West Africa Power Pool (WAPP) (IRENA, 2018b). In 2017, the total was 2 185 megawatts (MW) (see Figure 1). Of this, thermal plants (largely natural gas) accounted for 59.4 percent, with the remainder coming from renewables – almost entirely hydropower (IRENA, 2020f). These sources generated 9 955 GWh in 2017, with natural gas dominating at 82.7 percent of the total. Hydro was far behind at 14.9 percent, followed by biofuels at 1.7 percent and oil at 0.7 percent.

As a result of increases in natural gas generation, CO_2 emissions have been on the rise (IEA, 2019a). The future role of natural gas is thus central to the discussion of reducing carbon emissions, particularly in scenarios aligned with the ambitions of the Paris Agreement.

Between 2017 and 2018, no additional capacity has been recorded. Hydropower generation increased 3.0 TWh in 2018 due to the additional output of the newly-commissioned Soubré dam (in 2017),[4] while the output from fossil-fuel-powered plants dropped to 7.0 TWh (IRENA, 2020e). The share of renewable energy in the generation mix increased from 21.5 percent in 2017 to 29.7 percent in 2018. According to the Ministry of Petroleum, Energy and Renewable Energy (MPEER), this production in 2018 required the consumption of 1 776 million cubic metres of natural gas, estimated at FCFA 207.4 billion (MPEER 2019).

The MPEER is also focusing on reducing unmet load ("Energies Non Distribuées") in the system, which has been significant in the past. Unmet load in 2018 was 20.8 GWh, a reduction of 2.1 percent from the 21.3 GWh in 2017 (MPEER, 2019).

Côte d'Ivoire is a key exporter of electricity to other countries in the region, exporting 10-20 percent of its electricity production in recent years to Ghana, Burkina Faso, Mali, Benin, Togo and Liberia (JICA, 2019).



Source: (IRENA, 2020e)

Figure 1 – Installed generation capacity between 2000 and 2019

2.1.3 Access to electricity

Like other sub-Saharan African countries, Côte d'Ivoire has been slow to increase access to electricity. Overall access of the population is only 67 percent. There also is a large disparity between urban areas, which have 100 percent access, and rural areas, at only 33 percent access (World Bank, 2020a).

Providing universal access to electricity is a key goal of the Sustainable Development Goals (SDGs) and the Sustainable Energy for All (SE4ALL) Initiative. Under the umbrella of these initiatives, the Government of Côte d'Ivoire has launched the Programme Électricité Pour Tous (PEPT) and Programme National d'Electrification Rurale (PRONER) to make universal access a reality (JICA, 2019).

Measures the government has pledged to increase access include lowering the cost of grid connections, providing service concessions to firms that offer off-grid solutions, and using feed-in tariffs to encourage different energy sources (MPE, 2016b). Off-grid electrification is a top policy priority (ECREEE, 2019), given that the low rural access rate has remained virtually unchanged since 2008-2009. In one sign of progress, 326 communities were electrified in 2018 (MPEER 2019).

	2017		Latest data	
	Generation (TWh)	Capacity (MW)	Generation (TWh) 2018	Capacity (MW) 2019
On-grid	10	2 178	10	2 178
Natural gas		1 293		1 293
Fossil fuels n.e.s.	8	5	7	5
Hydropower	2	879	3	879
Off-grid	0.007	8	0.007	8
Off-grid Solar photovoltaic	0.007	8	0.007	8

Table 3 – Electricity generation and capacity

Source: (IRENA, 2020f)

[4] There are also planned hydropower plants in Louga (280 MW) in cascade with the existing Buyo hydropower plant, Gribo-Popoli (112 MW), Singrobo (44 MW), etc. (CNP-PPP, n.d.). In addition, Côte d'Ivoire plans a joint hydropower plant with Liberia in Tiboto (225 MW).

2.1.4 National planning scenarios, NDC and key emissions/renewable energy targets

Government plans

Côte d'Ivoire launched a programme in 2011 to double installed electricity generating capacity by 2020. From 2011 to 2017, the country invested FCFA 7 trillion (more than USD 11 billion), according to data from the Ministry of Energy (MPEER, 2020). In addition, in 2013, it launched the National Rural Electrification Programme (PRONER) with a goal of electrifying of all localities with more than 500 inhabitants (over 5 000 localities) by 2020.

In terms of the capacity mix, the 2014 Master Plan for Hydropower aimed to double the country's hydroelectric capacity to 2 017 MW by 2030. CI-Energies has identified large-scale and small-scale hydro projects that can help reach the country's targets. The government also plans to diversify the capacity mix beyond natural gas and hydropower. It plans to add other renewables (mainly solar PV[5] and biomass), and is even considering the construction of coal-fired power capacity.

While an official power sector masterplan is currently under development and therefore not yet available, insights into the planned power sector development can be gained from the country's Nationally Determined Contribution (NDC) and the National Action Plan for Renewable Energy (PANER), which was released in 2016 and adopted by the government in 2019. Table 4 summarises PANER's renewable energy objectives (MPE, 2016b).

As the 2014 Plan Directeur du Réseau de Transport d'Électricité (Tractebel, 2014) acknowledges, the national grid is aging and needs an upgrade and extensions to accommodate higher demand and higher shares of solar PV electricity. Investments in transmission and distribution are planned so that the grid can accommodate more variable renewable energy and become more efficient (World Bank, 2017).

The PANER also stresses the importance to Côte d'Ivoire of further expanding interconnections with neighbouring countries in the West African Power Pool (WAPP). These include cross-border infrastructure such as the CLSG interconnection with Liberia, Sierra Leone and Guinea, as well as an improved connection with Ghana and by extension Benin, Togo and Nigeria (though Ghana has dropped out of this discussion). The recent update to the ECOWAS regional power system master plan has confirmed that further regional grid integration is a top priority. It is a rational energy security and affordability strategy under any future explored in the plan, and also reduces the risks of curtailed hydropower generation during extended drought periods (MPE, 2016b; Tractebel, 2018).

The National Determined Contribution and key emissions targets

In 2016, Côte d'Ivoire confirmed its Nationally Determined Contribution (NDC) to the Paris Agreement with the UNFCCC. The NDC targets for renewable energy reflect those of the country's 2016 PANER, including a future generation mix of 26 percent large hydropower (above 30 MW) and 16 percent other renewables. The total share of renewables would thus amount to 42 percent by 2030 (Republic of Côte d'Ivoire, 2015).

Despite this greater share of renewables in power generation, however, overall greenhouse gas emissions could still increase because of the country's national socio-economic development aspirations and strong demographic growth. At an estimated gross domestic product (GDP) growth of 8.4 percent by 2030 (before the COVID-19 crisis), the NDC shows GHG emissions per capita potentially rising from 0.81 tCO_2e to 1.17 tCO_2e.

According to the NDC, the power sector in 2012 accounted for 21.6 percent of all greenhouse gas emissions (16 $MtCO_2e$), largely from natural gas use. In the NDC's Low Carbon scenario, power sector emissions would drop from about 11.9 $MtCO_2e$ in a business-as-usual scenario to a little over 9.2 $MtCO_2e$ (representing 37.5 percent of the country's overall emissions) by 2030. The power sector would contribute 27.6 percent of the total emissions reductions in the Low Carbon scenario. The agricultural sector would contribute 24.1 percent of the reductions, and the transport sector 20.3 percent.[6] The power sector is, therefore, a key sector in Côte d'Ivoire's plans to reduce emissions (Republic of Côte d'Ivoire, 2015).

Installed capacity (MW)	2010		2020		2030	
Units	MW	%	MW	%	MW	%
Renewable installed capacity (including hydro ≥ 30 MW)	604	43 %	1 894	51 %	3 259	57 %
On-grid electricity generation (GWh)	**2010**		**2020**		**2030**	
Units	**GWh**	**%**	**GWh**	**%**	**GWh**	**%**
Electricity generated through renewable sources (excluding hydro ≥ 30 MW)	273	8 %	1 893	11 %	5 354	16 %
Electricity generated through middle and large hydro capacity (≥ 30 MW)	1 345	20 %	3 292	23 %	6 380	26 %
Electricity generated through renewable sources	1 618	28 %	5 148	34 %	11 293	42 %

Table 4 – Renewable energy targets in Côte d'Ivoire PANER (in % of total installed capacity and total electricity generation)

[5] Seven solar PV projects are already under development for a cumulative 258.5 MW, and additional 700 MW are planned by 2030 (JICA, 2019).
[6] The emissions avoided cover the three main gasses carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O).

Côte d'Ivoire also signed the Marrakesh Communique of the Climate Vulnerable Forum in 2016, which sets the goal of achieving 100 percent renewable energy between 2030 and 2050 (CCAC, 2016; Climate Vulnerable Forum, 2016a).

2.1.5 Overview of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector[7]

The table below provides an overview of the key policy instruments, regulations and measures that have supported the renewable energy targets and priorities discussed above.

Name	Launch	Details
Project to Improve Access to Electricity in Rural Areas (PAEMIR)	2018	The PAEMIR falls within the National Rural Electrification Programme (PRONER) and aims to extend the grid to reach most rural localities now without electricity access. That approach is preferred over off-grid electrification, such as with small solar PV plants, or providing solar kits to households, because it is seen as providing higher quality and more reliable electricity. However, 86 localities are located too far off-grid for cost-effective grid connections and will be electrified by off-grid solutions.
Electricity Code	2014	The Code was implemented to encourage, among other goals, the private sector to develop small-scale and grid-connected solar PV and biomass projects by including policies to support the sale of electricity to the grid. It also promotes distributed applications, including off-grid and energy self-supply options. More broadly, the code allows private operators to enter transmission, distribution, commercialisation, import and export activities. The Code represents a first step towards the liberalisation of the sector.
Auctions	TBD	Auctions have been discussed under the EU's Energos 2 project, but they have not been implemented yet. Nevertheless, this initiative has provided support in auction design, such as in selecting IPPs, and also has conducted feasibility studies, as well as providing legal and financial support in drafting PPAs.

Table 5 – Key policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector
Note: The Plan d'Actions de l'Electrification Hors Réseau (PAEHR), Politique sectorielle de développement des énergies renouvelables et de l'efficacité énergétique (PSDEREE) and The Renewable Energy strategy adopted in December 2019 could not be analysed as these documents are not available publicly.

2.2 Prospects for renewable power towards 2040

IRENA analysed Côte d'Ivoire's power system as part of its regional study Planning and prospects for renewable power: West Africa (IRENA, 2018b).[8] The study developed several scenarios to assess renewable energy deployment potentials in Côte d'Ivoire's power sector by 2030. The assessment is based on the Agency's in-house generation capacity expansion modelling, which builds on inputs developed by regional experts in a six-month regional IRENA training programme in 2016.[9]

The study shows that the combination of national renewable energy targets and rapidly declining costs for renewable energy technologies can significantly increase the role that renewables can play in the power sector.

2.2.1 Methodology and assumptions

Demand projections: the assessment presented here is an update of IRENA's 2018 analysis (IRENA, 2018b) and incorporates more recent electricity demand projections from the official ECOWAS update to the regional power generation masterplan (Tractebel, 2018). The demand update involves a simple extension of the demand projection from the 2018 masterplan to 2040. It transforms that projection to final sectoral demand values using the same T&D losses and sectoral split as in IRENA (2018).[10]

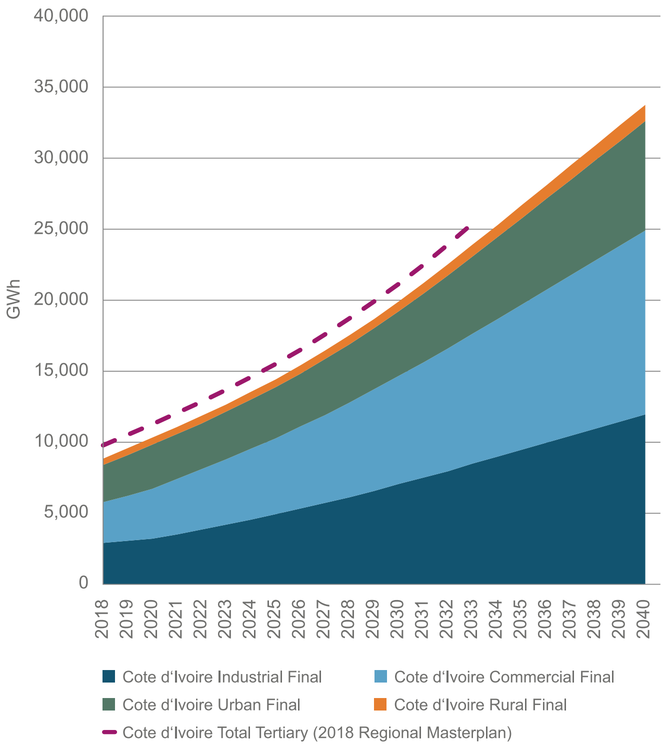


Figure 2 – Electricity demand projection in 2018 ECOWAS regional masterplan and IRENA analysis

[7] Based on IRENA's repository of knowledge on policies and measures, (AfDB, 2019) and (IFC, 2018).
[8] In this analysis, IRENA used publicly available information as well as inputs from national representatives, with a base year of 2015. Further validation by local experts would always serve to enhance the robustness of model results. The assessment is based on certain assumptions, including, but not limited to, fuel costs, infrastructure and policy developments, which various stakeholders in the region might regard differently at different times.
[9] IRENA's in-house capacity expansion model is the System Planning Test model for Western Africa (SPLAT-W, or SPLAT for short), which enables analysts to explore power system development that meets various system requirements, including reliability amid growing and fluctuating electricity demand, taking into account investment and running costs. The SPLAT-W model is built on a database of the West African Power Pool (WAPP) system, consisting of existing generation units and international transmission lines, and a range of future technology options. A more detailed description of the model can be found in (IRENA, 2018b).
[10] For more detail on the assumptions behind these projections, see the specified reports for reference.

The results (Figure 2) show that demand would grow at about six percent per year between 2020 and 2040, from 10.4 TWh in 2020 to 34 TWh in 2040. The largest shares of electricity demand would be seen in the industry, commercial and urban sectors. Electricity access is assumed to reach 90 percent for urban areas and 65 percent for rural areas.

Renewable energy resource potential: Table 6 presents the technical resource potentials of key RE sources in Côte d'Ivoire.[11] Estimates of solar photovoltaic (PV) and wind potentials are based on the analysis carried out in IRENA (2016).[12] While these estimates do not represent the exact economic potential of these resources in the specific context of Côte d'Ivoire's electricity system, the potentials are very large compared to the current total installed capacity of just over 2 GW. In addition, six large hydropower projects in Côte d'Ivoire being planned at the time of the IRENA analysis (base year of 2015) would add up to 1 179 MW. They are anticipated to come online mainly in the 2020s.

RE resource	Technical potential (MW)
Solar PV	28 920
Wind	2 550
Biomass	3 260[13]
Small hydro	41[14]

Table 6 – Renewable energy resource potential

SPLAT-W model: IRENA applied the in-house SPLAT-W model for this analysis. For Côte d'Ivoire, the assumptions were derived from the country's power sector data and summarised in Table 7.[15]

Assumption	Description	Sources
Load profile	Hourly annual electricity demand data provided by Côte d'Ivoire was used to develop a representative overall load shape, then aggregated into daily time slices, with sector-specific load profiles developed for rural, urban, commercial and industrial demand	IRENA – see more detailed methodology in IRENA (2018).
Existing and planned generation projects (GW)		Existing: as of 2015, based on the 2011/12 WAPP Master Plan (WAPP 2011), updated by IRENA and national experts present at IRENA's 2015-2016 regional SPLAT-W training workshops. Committed/candidate: IRENA analysis at time of publication, incorporating data from the 2016-2019 WAPP Business Plan (WAPP 2015).
Existing	2.21	
Committed site-specific	0	
Candidate site-specific	1.63	
Cross-border transmission lines for Côte d'Ivoire (MW)		IRENA analysis at time of publication, incorporating data from the 2011/12 WAPP Master Plan (WAPP 2011) and the 2016-2019 WAPP Business Plan (WAPP 2015).
Existing	Ghana – Côte d'Ivoire (327); Côte d'Ivoire – Burkina (327)	
Committed	Dorsale (650); CLSG (330); Hub Intrazonal (320)	
Candidate	NA	
Fuel cost projections (USD 2015/GJ)	(2015 → 2040)	IRENA analysis at time of publication; see detailed methodology in IRENA (2018).
Coal (import)	4.9 → 5.5	
Diesel (delivered to coast)	11.2 → 24.3	
HFO (delivered to coast)	6.6 → 14.3	
Natural Gas (domestic)	7.1 → 8.5	
Natural Gas (pipeline)	8.6 → 10.3	
CAPEX projections to 2040 (USD 2015/kW)	(2020 → 2040)	IRENA internal cost database at time of publication (IRENA, 2018b).
Solar PV (Utility)	1 325 → 745	
Onshore Wind	1 525 → 1 015	
Biomass	2 715	
Natural Gas (Combined Cycle)	1 160	
Coal (Supercritical)	2 615	

Table 7 – Summary of IRENA's assumptions in the SPLAT-W model

[11] Technical potential estimates the capacity of RE technology available for development by applying constraints such as e.g. topography in order to filter out geographic areas that are technically unfeasible for development.
[12] For further detail on methodology and underlying data, see (IRENA, 2016a). In this analysis, instead of categorising land in a binary way, as either "available" or "unavailable" for development, an opportunity-based approach is used to measure resource potential, by ranking the quality of areas for development according to scores assigned to a range of relevant factors. Several factors were included in the investment suitability analysis, such as the renewable energy resource intensity, distance to the grid, population density, topography, land cover, and protected areas.
[13] Estimated based on previous analyses done by IRENA (IRENA, 2014b; 2014a) and represent conservative technical resource potential for co-generation.
[14] Based on estimates from the United Nations Industrial Development Organisation and the International Center on Small Hydro Power (UNIDO and ICSHP, 2016).
[15] It is important to note that renewable power capacity costs have continued to decline at a rapid pace since the time of this analysis, and integrating the most up-to-date and localised cost data is necessary to assess the possibility for even greater economic potential for renewable energy.

2.2.2 IRENA electricity capacity expansion scenarios

Two main scenarios for Côte d'Ivoire's power sector are explored in this analysis. Both allow for cross-border electricity trade within IRENA's SPLAT-W model:

- **The Reference Scenario** describes renewable energy deployment in the absence of national or regional targets, based on a detailed project pipeline with cost competitiveness as the key driver for technology deployment. Other than updated demand projections, all assumptions can be found in IRENA (2018).[16]
- **The National Targets Scenario** sets minimum country-level targets for the percentage of renewable energy in total domestic generation. Based on national SE4ALL Action Agenda documents, the target at the time of the analysis was 16 percent renewables penetration by 2030, excluding large hydropower, the same target as in the NDC. To meet the overall target, the model can explore the most economically attractive combinations given costs and performance.

The figures below show the results, in both system capacity and generation (see also Table 8).

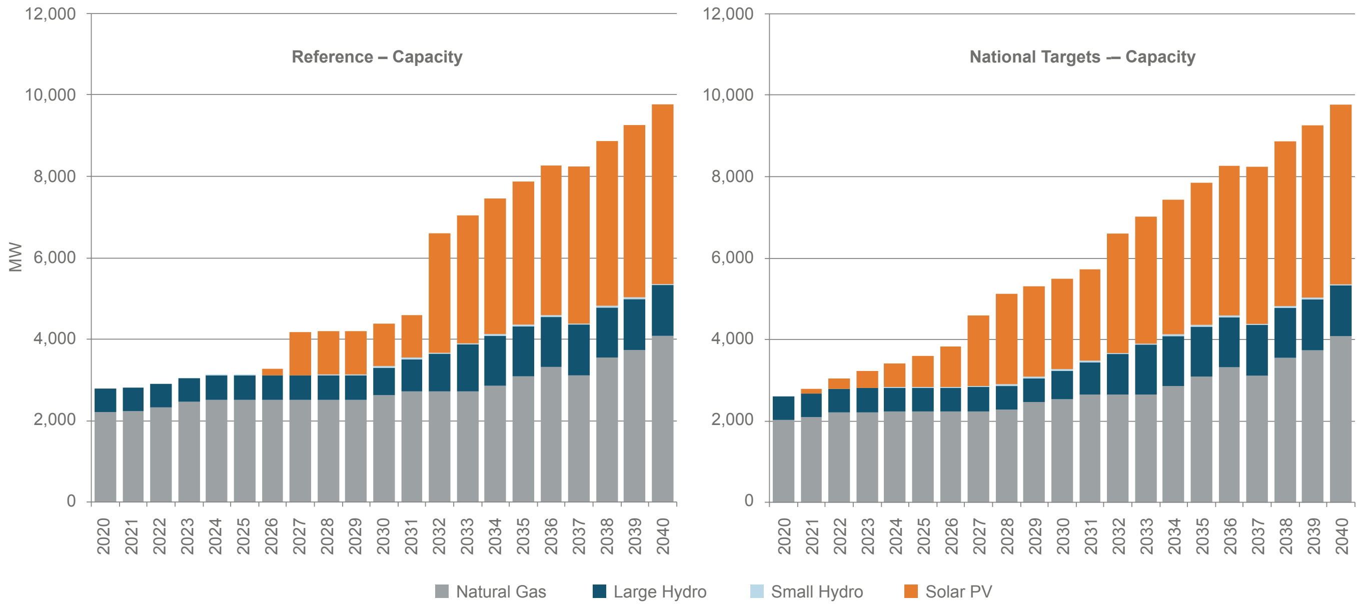


Figure 3 – Capacity mix in Côte d'Ivoire in the Reference and National Targets scenarios

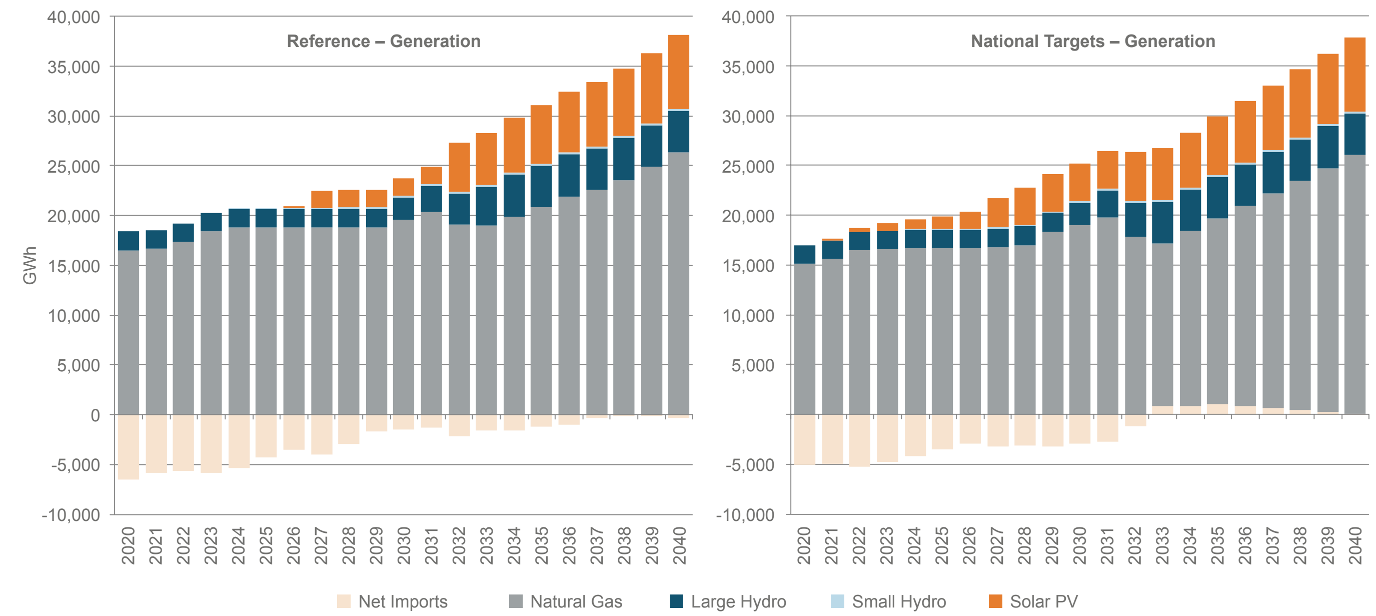


Figure 4 – Generation mix in Côte d'Ivoire in the Reference and National Target scenarios

[16] One important assumption to note is the use of a conservative "dry-year" capacity factors for large-scale hydropower plants across all scenarios, which results in lower than average hydro generation through the modelling horizon. This underplays the role of hydropower in the region, but is considered to be prudent in view of the vulnerability of West Africa to drought years.

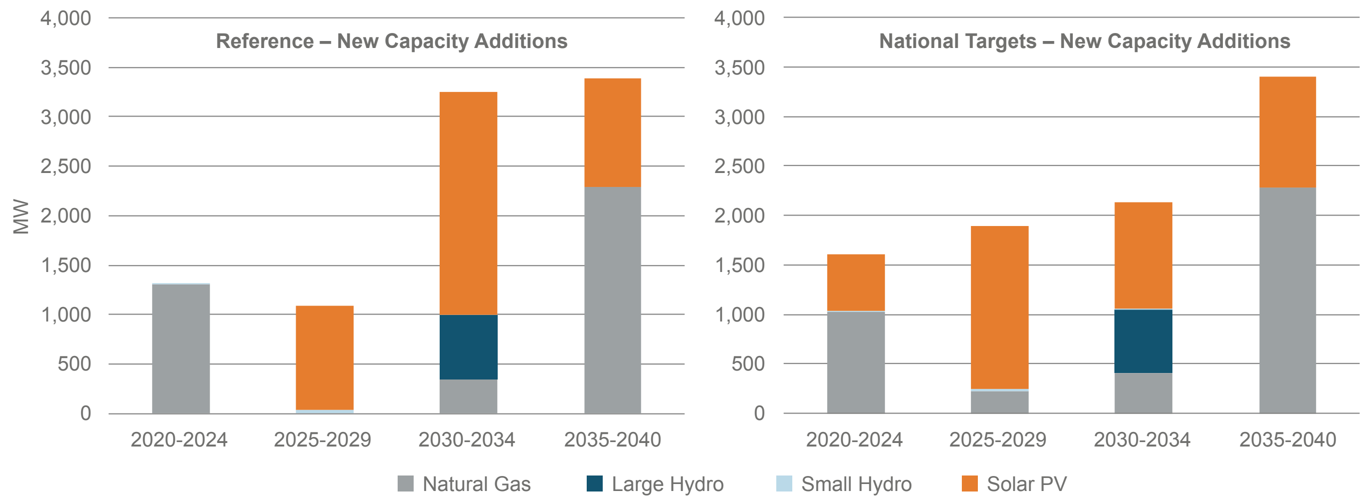


Figure 5 – Gross capacity additions in Côte d'Ivoire in the Reference and National Target scenarios

The key insights from the analysis are:

- Utility-scale solar PV is an economically competitive solution in the Reference scenario, and capacity would rise to 4.4 GW by 2040. By 2030, however, solar PV would represent only a seven percent share of generation in the Reference scenario, below the target of a 16 percent non-hydro renewable share. But by 2040, cost declines would accelerate deployment so both scenarios would have the same share of VRE (20 %) and total RE generation (32 %).
- Hydropower and natural gas generation grow in both scenarios. A total of 3.9 GW of natural gas and 646 MW of large hydropower would be added between 2020 and 2040.
- The power sector mix is less diversified in the modelling results than in the country's NDC projections; but the results also show that coal capacity additions are not necessary.
- Achieving more ambitious action on climate change would require expanding this analysis to explore feasible renewable alternatives to natural gas capacity, such as solar PV plus storage.
- As demand increases, the country's renewable and gas generation would be increasingly used to supply domestic demand and net exports would decline. By the late 2030s, the country would be a hub for regional trade rather than a substantial net exporter or importer.
- In both scenarios, regional developments will have important impacts on Côte d'Ivoire's power system evolution. The Intrazonal Hub linking Ghana, Burkina Faso, Côte d'Ivoire and Mali could be expanded to allow exports of gas-generated power and hydropower from Côte d'Ivoire to Mali, and could become the second largest conduit of cross-border electricity flows, after the Coastal Backbone/Dorsale infrastructure between Nigeria, Benin, Togo and Ghana. Meanwhile, the CLSG infrastructure connecting Côte d'Ivoire, Liberia, Sierra Leone and Guinea could become more important because of its ability to exploit the diurnal complementarity between low-cost hydropower in Sierra Leone and solar power in Guinea. Côte d'Ivoire could take advantage of such complementarity if more regional infrastructure is developed.

Reference									
	Capacity (MW)				Generation (GWh)				
	Natural gas	Large hydro	Small hydro	Solar PV	Natural gas	Large hydro	Small hydro	Solar PV	Electricity net imports
2025	2517	585	5		18802	1842	20		(4293)
2030	2621	672	40	1056	19577	2197	173	1779	(1458)
2035	3093	1231	41	3499	20826	4178	178	5876	(1165)
2040	4089	1231	41	4414	26329	4178	178	7419	(320)
National targets									
	Capacity (MW)				Generation (GWh)				
	Natural gas	Large hydro	Small hydro	Solar PV	Natural gas	Large hydro	Small hydro	Solar PV	Electricity net imports
2025	2235	585	10	773	16703	1842	42	1302	(3526)
2030	2538	697	40	2226	18956	2298	173	3750	(2909)
2035	3093	1231	41	3488	18627	4178	178	5862	1048
2040	4089	1231	41	4414	25893	4178	178	7419	115

Table 8 – Capacity and generation mix in the Reference and National Target scenarios

2.2.3 Investment needs

The investment needs, as shown in this analysis, are substantial relative to the current size of the Côte d'Ivoire electricity system. By 2040, system generation more than triples from current levels to over 35 TWh to meet increasing demand. The total new capacity of about 9 GW built between 2020 and 2040 in the Reference scenario is more than four times the current total installed capacity of just over 2 GW. That new capacity is made up of 4.4 GW of utility-scale solar PV, 3.9 GW of natural gas (replacing older, less-efficient plants over time) and 0.7 GW of large hydropower.

In the modelling exercise, the total investment in new generation capacity from 2020 to 2040 would be USD 13.6 billion. This far exceeds the required investments in transmission and distribution, which would be USD 3.6 billion.

Including fuel, and operation and maintenance costs over the 2020-2040 modelling period, the total system costs would be nearly USD 44.6 billion. The share of fuel costs declines from 62 percent in 2020 to 47 percent by 2040 despite the significant demand growth because of the expansion of solar PV.[17]

Expanded natural gas capacity, however, means that overall costs remain highly dependent on and sensitive to natural gas fuel costs.[18]

2.3 Systemic innovation needs and opportunities

Côte d'Ivoire already has an ambitious plan to raise the share of renewable power in the generation mix to 42 percent by 2030, composed of 26 percent large (above 30 MW) hydropower, 10 percent bioenergy and six percent solar PV (Republic of Côte d'Ivoire, 2015; JICA, 2019). Those targets are feasible, IRENA's long-term planning scenarios show.

Going beyond that level of renewable power will require a new paradigm, with clear vision and new implementation policies, regulatory measures and innovations, such as those in Figure 7.

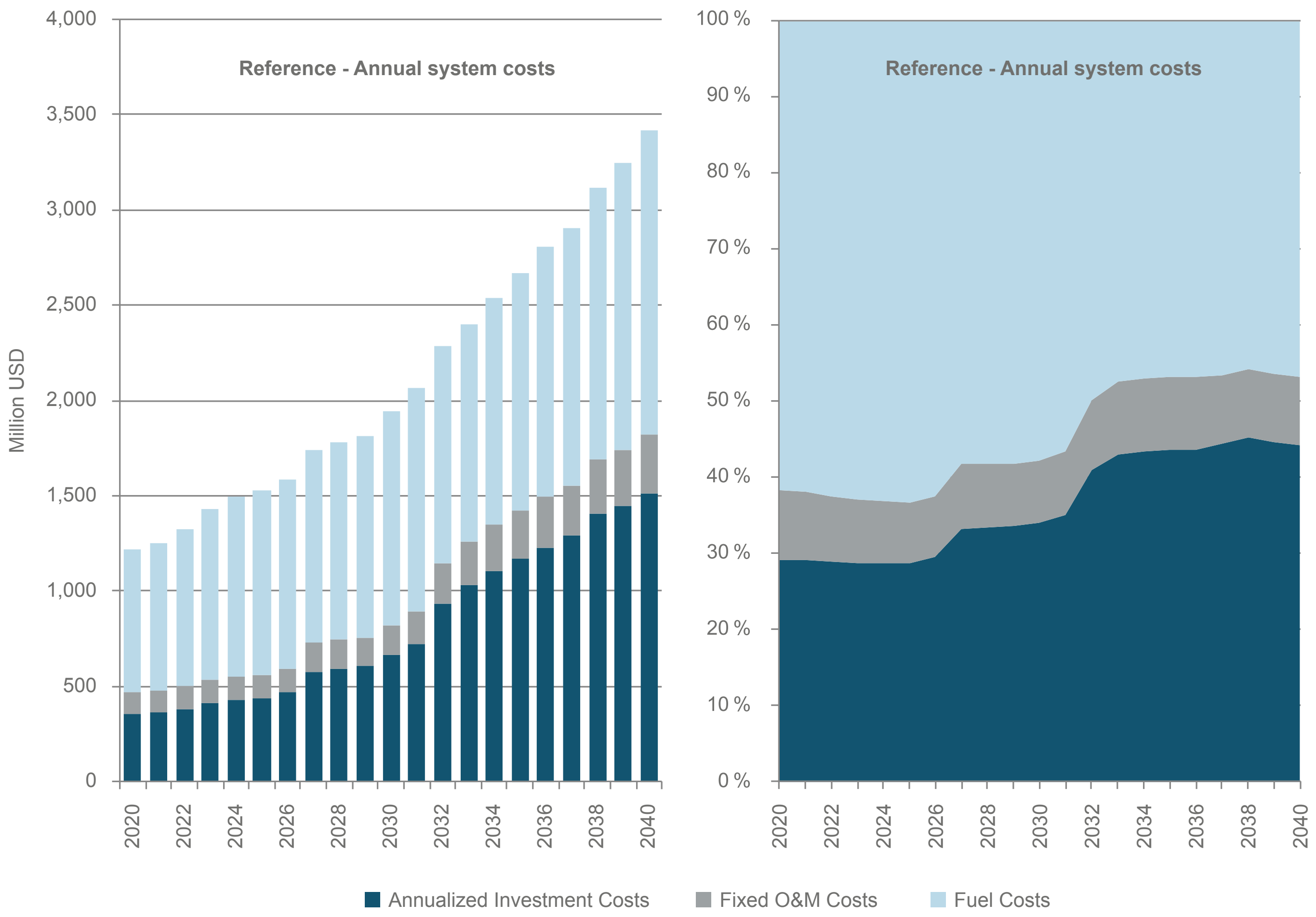


Figure 6 – Annual system cost

[17] It should be noted that these system costs do not capture all potential investment needs in such a large-scale transition – for example, studies have shown that investing in greater system flexibility through hydropower upgrades in West Africa could bring significant benefits and reduce overall long-term costs (see Smart renewable electricity portfolios in West Africa [Sterl et al., 2020]). The following chapter will also discuss emerging innovations which could have a significant influence on investment needs and overall system costs.

[18] For reference, gas prices used in the modelling exercise were as follows (in 2015 USD): domestic 7.1/GJ in 2015 to 8.5/GJ in 2030; pipeline 8.6/GJ in 2015 to 10.3/GJ in 2030; and LNG 9.2/GJ in 2015 to 11/GJ in 2030.

New paradigm of the energy supply chain in Côte d'Ivoire

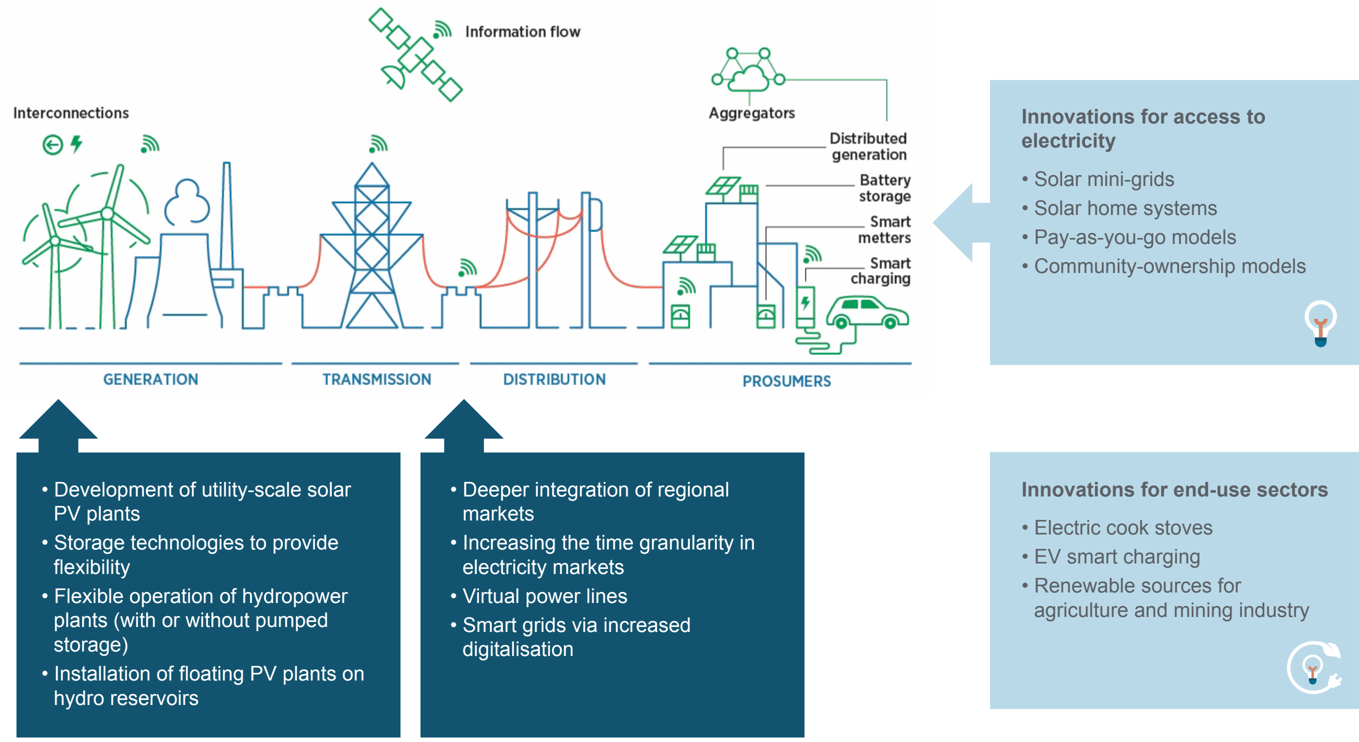


Figure 7 – Innovations to be considered for a future renewable power sector in Côte d'Ivoire

2.3.1 Innovation to support a renewable power system

Innovation to allow higher levels of solar PV generation, including mini-grids

Côte d'Ivoire has a large solar resource – especially in the North[19] – but it remains largely untapped because of the variability of solar power and the misalignment in time between peak generation during the day and peak electricity demand in the evening (Republic of Côte d'Ivoire, 2015; MPE, 2016a). However, these problems can be addressed with cost-effective innovations, such as storage technologies and more flexible operation of hydropower plants (with or without pumped storage). Natural gas power plants can also provide more flexibility with minimal refurbishments or changes in operation.[20]

Another innovation would be to install floating solar PV power plants on hydropower reservoirs. Benefits include taking up less space than conventional utility-scale, ground-mounted solar PV; reducing costs by sharing the connection to the transmission grid; increasing efficiency by cooling the solar cells; and reducing evaporation losses by providing shade to the water.

Meanwhile, solar mini-grids coupled with community ownership business models could offer faster access to electricity in rural areas, compared to building transmission lines. And where solar mini-grids can be connected to the central power system, they can help keep the system in balance.

Deeper integration of the regional electricity market and new enabling technologies to reduce congestion and help maintain an interconnected power system

Within the West African Power Pool (WAPP), Côte d'Ivoire could continue to export its surplus electricity, but it could also reap benefits from increasing the solar generation in the North by importing complementary hydropower from Guinea. Currently, the exchange is done via long-term bilateral contracts, but increasing the time granularity would make it possible to establish day-ahead, and even intra-day trades.

Then, as the power system becomes more complex, innovations such as virtual power lines can reduce congestion[21]. In addition, drones and artificial intelligence software to analyse the drone images are already being tested to help improve maintenance of the transmission network (AfricaNews, 2018).

[19] Direct horizontal irradiation North of Bouaké is estimated at 1.850 kWh/m2 and above 2.050 kWh/m2 North of Korhogo (JICA, 2019).

[20] While natural gas-fired power plants like combined-cycle gas turbines are less flexible in operation than open-cycle gas turbine facilities, both can cover peak load.

[21] Virtual power lines are essentially batteries located at both sides of a congested transmission network line.

2.3.2 Innovations for renewable-based electrification of end-use sectors

Buildings

Buildings are the largest energy-consuming sector, using mainly firewood and charcoal. Possible innovations and options include:

- adopting efficient and clean electric cook stoves;
- increasing decentralised solar generation, like rooftop solar PV, to provide electricity for cooking, lighting and cooling; and
- improving energy efficiency to slow demand increases, given that cooling (air conditioning) is expected to increase.

Transport

Côte d'Ivoire has already begun to explore innovations for the electrification of transport. They include:

- The city of Jacqueville has added three-wheeled electric vehicles to the taxi fleet. The EVs have a range of 140 km and their batteries are charged by solar panels. In addition to bringing environmental and health benefits, the EVs cut the price of a trip in half compared to conventional taxis (Le monde de l'énergie, 2018).
- Morocco and Côte d'Ivoire are collaborating on a new EV smart charging technology within the pan-African Green Africa Innovation Network[22], which was launched by the Moroccan Research Institute for Solar Energy and New Energies (IRESEN) in 2020 (Aujourd'hui le Maroc, 2020).
- Côte d'Ivoire is building a 37.5 km elevated and electrified railway line in Abidjan connecting the airport to the northern part of the city, which will reduce air pollution and traffic congestion (Jeune Afrique, 2019).

Industry

Agriculture plays an important role in Côte d'Ivoire, so generating reliable renewable heat and electricity locally is an option worth exploring further (MPE, 2016a). Currently, there is already about 80 MW of installed off-grid combined heat and power (CHP) capacity, including four sugar mills (50 MW). Generation also comes from residues of palm oil production (25 MW), cotton seed residues (2 MW), sawmills (1.5 MW) and coconut residues (1 MW).[23]

Industrial demand from new mining projects can also potentially make use of reliable and high-quality solar resources combined with energy efficiency measures.

2.4 Conclusions and areas for further consideration

IRENA's scenarios show that earlier and faster expansion of non-hydro renewable generation could be a critical step in meeting or exceeding Côte d'Ivoire's target of 16 percent penetration of non-hydro RE in generation by 2030. Rather than the 1 GW of new solar PV that would be built by 2030 in the Reference scenario, meeting the targets will require building 2.2 GW of solar PV by 2030 and 4.4 GW by 2040 in IRENA's modelling exercise.

The analysis also shows that adding coal capacity is not needed from an economic standpoint and should be reconsidered if Côte d'Ivoire aims to increase its ambitions to cut GHG emissions. Additional decarbonisation will also require substituting future natural gas capacity with alternatives such as additional hydropower, biomass or solar PV plus storage.

Increasing ambitions to raise the share of renewable energy in the power sector would bring significant benefits, including less exposure to volatile natural gas costs.

Côte d'Ivoire also has an opportunity to further strengthen its position as an electricity exporter in the region and to benefit from harmonisation of trading rules within the WAPP. That would enable cheaper electricity to be imported when local demand is high.

A key challenge will be managing a more complex and interconnected power system, with higher shares of variable renewables. However, a large transmission network might not always be the most cost-efficient solution to provide access in rural parts of Côte d'Ivoire. Instead, solar mini-grids owned and operated under community-ownership business models may be an option to explore. Such systems can be built quicker, using fewer resources, that can new transmission lines.

Given that the vast majority of energy is consumed by buildings – and especially the residential sector – the adoption of energy efficiency measures combined with electrification using renewable power should be a top priority. In industry, CHP from agricultural residues provides an opportunity, while the transport sector can benefit from leapfrogging to electric vehicles.

[22] Partner countries include Benin, Burkina Faso, Côte d'Ivoire, Mali, Morocco, Senegal, Soudan and Tunisia (L'Observateur, 2020).
[23] As this capacity is off-grid, note it is not reflected in the grid-level statistics and analysis presented earlier in this chapter.
[24] Based on IRENA (2020b; 2019h; 2019i)

Meanwhile, to ensure that the transition to a more renewable-based energy system is just and inclusive,[24] Côte d'Ivoire could consider the following steps:

- Create a clear pathway to universal access using all electrification modes, including grid extension, mini-grids and stand-alone systems. That will require policies and regulations to reduce the risks of conflict between the electrification modes. For mini-grids, dedicated regulations are needed to address risks associated with main grid arrival, licensing and tariff setting. Access strategies should leave no one behind and could be designed to advance other Sustainable Development Goals (SDGs), including gender, health and education.
- Provide dedicated funding facilities that enable inclusive and accessible financing for both suppliers and end users. For instance, end users require innovative financing and business models to cover connection costs, leasing or owning stand-alone systems and appliance purchases.
- Tie energy supply to productive end uses, such as agriculture and local manufacturing, and public services like water, healthcare and education, to improve livelihoods and maximise the socio-economic benefits of energy access.
- In the general context, adopt long-term stable deployment policies to frame public investment and also attract private investment in the sector. These can be selected and designed according to the specific context and broader development objectives. Auctions, for example, can be used for market price discovery, but they are most suitable for large-scale projects in the presence of competition. Auctions can also be designed to ensure that projects come online on time or to achieve socio-economic and development objectives.
- Design policies to broadly share positive outcomes, such as new employment opportunities, while limiting adverse effects like the loss of jobs in fossil fuel-related industries. That will require education and retraining, as well as measures to facilitate labour mobility and support vulnerable workers and their communities so that they do not shoulder unfair burdens during the energy transition.

Further studies could be performed in collaboration with IRENA that would offer additional solutions tailored specifically for Côte d'Ivoire. The studies could identify key enabling technologies and stakeholder responsibilities, along with the costs and benefits of implementing the solutions.

3 Ghana country analysis

Key messages

Ghana has abundant renewable resources – including over 20 GW of technical solar PV potential – a liberalised power sector and supportive policies for large-scale renewable electricity generation. The country's most recent power sector masterplan reflects these advantages by offering a compelling "Enhanced NDC" scenario that leads to 30 percent renewables and 14 percent VRE generation by 2035. IRENA's analysis suggests that long-term ambitions could be raised further, if the energy sector's short-term financial issues related to overcapacity can be solved by recent reform measures. Overall, Ghana's power system could reach 77 percent renewable generation by 2040, thanks to the addition of cost-competitive solar PV, along with wind and biomass, and the flexible operation of hydropower capacity. Meanwhile, distributed renewable generation, like solar mini-grids, could bring affordable electricity to the 33 percent of Ghanaians who currently lack access. An important means to tap into the full potential of these solutions is to link them to productive end-uses, such as agriculture and local manufacturing, to improve local economies and help advance progress across several of the Sustainable Development Goals. Other benefits of higher shares of renewables include reduced exposure to volatile fossil fuel prices and potentially lower electricity bills.

3.1 Status Quo of the Power Sector in Ghana

3.1.1 A brief introduction to the overall energy landscape

Total primary energy supply (TPES) in the Republic of Ghana was 387 Petajoules (PJ) in 2017, made up of substantial solid biofuel[25] (42 %) followed by oil products (35 %), natural gas (11 %), crude oil (6 %) and the remainder (5 %) from hydropower (see Table 9).[26]

In 2017, total final energy consumption was 284 PJ, consisting of petroleum products (51 %), solid biofuels (23 %) and electricity (15 %), with the remainder from charcoal (see Table 10).

The sector with the highest final energy consumption is the residential sector (38 %), followed by transport (35 %), industry (20 %) and commercial and public services (6 %). The residential sector is highly dependent on biomass (wood fuel and charcoal) for cooking and heating, which has low conversion efficiencies compared to modern fuels such as liquefied petroleum gas (LPG) or electricity.

Ghana produces a large amount of crude oil (348 PJ), which is almost all exported. The country imports most of the oil products it uses for road transportation and aviation, and to a lesser extent in the industrial and residential sectors.

	Crude, NGL and feedstocks	Oil products	Natural gas	Hydro	Solar PV	Primary solid biofuels	Charcoal	Electricity	Total
Production	348	0	32	20	0.1	163	0	0	**563**
Net imports	-337	144	11	0	0	0	-0.1	-0.1	**-182**
Others	13	-7	0	0	0	0	0	0	**6**
TPES	23	137	43	20	0.1	163	-0.1	-0.1	**387**

Table 9 – TPES in 2017 in PJ Source: (IEA, 2019c)

	Oil products	Natural gas	Primary solid biofuels	Charcoal	Electricity	Total
TFEC	144	1	66	30	44	**284**
Industry	26	1	17	0.1	11	**56**
Transport	99	0	0	0	0	**99**
Residential	10	0	47	27	22	**107**
Commercial and public services	2	0	2	3	10	**17**
Agriculture/forestry	3	0	1	0	0	**3**
Fishing	3	0	0	0	0	**3**
	51 %	0 %	23 %	11 %	15 %	**100 %**

Table 10 – TFEC in 2017 in PJ Source: (IEA, 2019c)

[25] Defined in IEA statistics as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes and other solid biofuels).
[26] For consistency with other country studies, the latest IEA data are used in this analysis, but Energy Commission Ghana produces up-to-date National Energy Statistics reports with their own methodology. National statistics show growth in both final energy supply and consumption by 2019, but the breakdown of TPES is roughly similar with solid biofuels at 38 %, followed by oil products at 29 %, natural gas at 18 %, crude oil at 9 % and the remainder from hydropower at 6 % (Energy Commission, 2020).

3.1.2 Electricity generation and use

Electricity consumption in Ghana has grown at an average rate of 3.3 percent per year since 1971. In 2017, the per capita consumption was 379 kWh per person per year (IEA, 2019c).

Half of electricity demand comes from the residential sector, while industry and the commercial sector account for one quarter each. The penetration of electricity use in end-use sectors is highest in the commercial sector at 61 percent, followed by residential with 21 percent (IEA, 2019c).

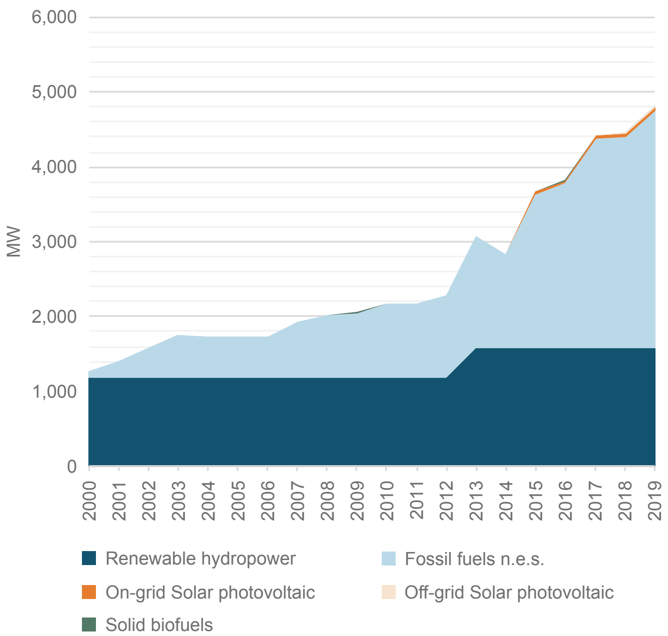
Ghana has the second largest installed electricity capacity in the West Africa Power Pool (WAPP) after Nigeria and leads the WAPP in electricity access (see the following section) (IRENA, 2018b). The total installed electricity capacity is 4 809 MW. Power plants fuelled by oil products and natural gas make up 66 percent of total capacity, with the remainder coming from renewable energy technologies – largely hydro (Table 11).[27]

However, Ghana now faces significant issues of overcapacity, because recent expansions of capacity have exceeded growth in peak demand, which reached only 2 700 MW in 2019. Those issues include paying capacity charges to plants that may not be fully dispatched, and having contracts for more natural gas than is needed (Energy Commission, 2019b; Ministry of Energy, 2019). For example, the country has supply contracts for more than 800 million cubic feet per day (mmcfd) of gas when demand is forecast to be only 350 mmcfd in the power sector and 100 mmcfd in other sectors in 2023 (ibid.).

These excess capacity issues are expected to persist until the mid-2020s and are contributing to significant financial difficulties in the country's power sector. The sector is also facing high costs for fuel used by thermal power plants, high payments for installed capacity to emergency power plants (EPPs) and independent power producers (IPPs), high distribution losses, low revenue collections by the Electricity Company of Ghana (ECG) and the Northern Electricity Distribution Company (NEDCo), and non-payment by government entities. To address these issues, the government adopted an Energy Sector Recovery Programme in 2019 to govern the sector's short- to medium-term strategic actions (see section 3.1.4).

Ghana's power sector generated 16 262 GWh in 2019, with oil and gas plants supplying the majority (63 percent). Hydro contributed 37 percent of generation and other renewables contributed only 0.4 percent. As a result of increasing electricity generation from oil products and gas starting in 2015, CO_2 emissions from the power sector are rising. The future role of natural gas and other fossil fuels in the power sector is therefore important to consider in the discussion on how best to reduce carbon emissions, particularly in future scenarios aligned with the ambitions of the Paris Agreement.

Within the WAPP, after net imports of 0.6 TWh in 2016 and 0.05 TWh in 2017, Ghana recently returned to being a net electricity exporter (which it had been since 2008) as a result of sector overcapacity, with 1.3 TWh of exports in 2019 (Energy Commission, 2020).



Source: (IRENA, 2020e)

Figure 8 – Installed generation capacity between 2000 and 2019

	2017		Latest data	
	Generation (GWh)	Capacity (MW)	Generation (GWh) 2019	Capacity (MW) 2019
On-grid	**14 083**	**4 419**	**16 262**	**4 809**
Fossil fuels	8 424	2 796	10 195	3 161
Hydropower	5 616	1 584	6 017	1 584
On-grid solar photovoltaic	25	31	33	55
Bagasse	0	0	NA	NA
Wood waste	3	2	3	2
Other vegetal and agricultural waste	14	6	14	6
Marine energy	1	0	NA	0
Off-grid	**11**	**8**	**11**	**8**
Off-grid solar photovoltaic	11	8	11	8

Table 11 – Electricity generation and capacity

Source: (IRENA, 2020e)

[27] Similar to the energy statistics, power sector statistics are published by Energy Commission Ghana in its up-to-date National Energy Statistics reports, with slight differences in measurement. The main difference from figures shown in this analysis is in thermal plant capacity, where national statistics show a total of 3 549 MW (Energy Commission, 2020).

3.1.3 Electricity access

Compared to most sub-Saharan African countries, Ghana's access to electricity was moderately high at 82 percent of the population as of 2018 (World Bank, 2019a). Access was 67 percent in rural areas and 94 percent in urban areas.

Ghana established the National Electrification Scheme (NES) in 1989, which helped raise access from 20 percent in 1990 to the current high level. Achieving universal access is a key goal of the Sustainable Development Goals (SDGs) and the Sustainable Energy for All (SE4ALL) Initiative. Ghana aims to reach it by 2030, mainly through grid expansion, with off-grid technologies used mostly on islands (Ministry of Energy, 2019).

3.1.4 National planning scenarios, NDC, and key emissions/renewable energy targets

Government plans

For decades, renewable energy has been included in a diverse set of national plans and strategies in Ghana. In 1995, Vision 2020 promoted research and expansion of solar and biogas energy. From 2003 to 2005, the Ghana Poverty Reduction Strategy (GPRS) aimed to diversify the energy mix and implement rural energy programmes through renewables. Similarly, in 2006, the Growth and Poverty Reduction Strategy set a goal of reducing environmental impacts through increased use of renewables and energy efficiency. Between 2006 and 2009, the Strategic National Energy Plan (SNEP) identified renewables – mainly wind, solar and biomass – as key sources for long-term development and sustainable electricity supply. However, the SNEP was not a binding document and was not formally adopted (IRENA, 2015a).

In 2010, the Energy Sector Strategy and Development Plan established three objectives: 1) increase the share of renewables in the energy mix, 2) adopt a renewable energy law and create complementary legislation and 3) manage municipal industrial waste for energy production.

Also in 2010, the National Energy Policy envisaged the development of an "Energy Economy" – one that would thrive on a reliable, high quality and sustainable energy supply – and explored fiscal and pricing incentives. Then, in 2012, the Ghana SEforALL Action Plan contained provisions for renewable energy-based off-grid solutions for remote communities (USAID, 2019).

In 2016, Ghana introduced the Renewable Energy Master Plan (REMP). Updated in 2019, it includes plans for off-grid electrification with targets for the deployment of stand-alone solar systems, lanterns and mini-grids. In terms of specific targets, the plan includes goals to increase renewable power installed capacity to 1 364 MW by 2030 (1 095 MW from grid-connected systems) and produce off-grid renewable electricity in 1 000 communities (Energy Commission, 2019a).

While these plans are ambitious, bringing off-grid solutions to remote areas has been challenging. Consumers often prefer to connect to the grid, even though the connection status is uncertain, and poor mobile network coverage limits the practicality of pay-as-you-go (PAYGO) systems (World Bank Group, 2017).

In 2018 and 2019, the Energy Commission of Ghana (ECG) (with the support of USAID) developed an initial and updated version of a long-term integrated power sector masterplan (IPSMP) to 2037. The plan explores the capacity expansion that would be needed to reliably meet Ghana's electricity demand in a cost-effective manner and support the country's sustainable development, building on the Renewable Energy Masterplan (Energy Commission, 2019b).

The IPSMP explores a "least regrets" scenario designed to perform well with a broad range of potential future conditions. New capacity in the scenario would be 47 percent renewables, and by 2035 about 25 percent of power generation would be by renewables (though only 9 % would not be large hydro). This scenario is in line with the government plans to scale up renewable energy, although it does not meet the 10 percent non-hydro renewables generation target set in Ghana's NDC (see next section). An "Enhanced G-NDC" scenario explored in the latest plan does meet the target, with 30 percent renewable energy generation (and 14 % non-large-hydro renewables) by 2035.

Figure 9 shows IPSMP's build plan under the "least-regrets" scenario. However, the power sector's current overcapacity and related financial issues have led the government to order a moratorium on power purchase agreements (PPAs) for conventional and renewable projects, so no new large-scale grid-connected renewable projects are likely to be to be developed until 2023.

Instead, the focus is on policies and actions in the Energy Sector Recovery Program (ESRP) of 2019 that are designed to help the sector to recover financially. Those include adopting a least-cost fuel procurement strategy, addressing oversupply and resulting generation capacity payments, and establishing a stronger linkage between energy sector planning and timely procurement of energy infrastructure investments (Ministry of Energy, 2019). The ESRP therefore mandates that future procurement is to be more directly linked to the IPSMP and competitive processes, which both favour renewables once construction of new capacity resumes.

2019-2021	2022-2023	2024-2025	2026-2027	2028-2029	2030-2032	2033-2037
Generation 0 MW	**Generation** 125 MW	**Generation** 235 MW	**Generation** 645 MW	**Generation** 505 MW	**Generation** 450 MW	**Generation** 1915 MW
	50 MW Solar	100 MW Solar	210 MW Solar	160 MW Solar	270 MW Solar	300 MW Solar
	75 MW Wind	75 MW Wind	75 MW Wind	100 MW Wind	100 MW Wind	100 MW Wind
		60 MW S. Hydro				
			360 MW CC	245 MW CC	80 MW CC	1375 MW CC
						140 MW Solar w. Storage
	Transmission 50 MVA	**Transmission** 100 MVA	**Transmission** 120 MVA	**Transmission** 150 MVA	**Transmission** 200 MVA	**Transmission** 1375 MVA

2019-2021	2022-2023	2024-2025	2026-2027	2028-2029	2030-2032	2033-2037
Generation 0 MW	**Generation** 360 MW	**Generation** 1025 MW	**Generation** 1465 MW	**Generation** 990 MW	**Generation** 705 MW	**Generation** 3070 MW
	200 MW Solar	210 MW Solar	360 MW Solar	160 MW Solar	270 MW Solar	620 MW Solar
	10 MW Solar w. Storage	50 MW Solar w. Storage	120 MW Solar w. Storage		70 MW Solar w. Storage	220 MW Solar w. Storage
	150 MW Wind	75 MW Wind	75 MW Wind	100 MW Wind	100 MW Wind	100 MW Wind
		60 MW S. Hydro				
		630 MW CC	910 MW CC	410 MW CC	265 MW CC	2130 MW CC
	Transmission 170 MVA	**Transmission** 140 MVA	**Transmission** 170 MVA	**Transmission** 460 MVA	**Transmission** 300 MVA	**Transmission** 2130 MVA

Figure 9 – 'Least regrets' build plan under the IPSMP reference scenario (top) and high demand scenario (bottom)

NDC and key emissions targets

As with many African countries, Ghana's current contribution to climate change in the form of greenhouse gas emissions is negligible. However, the potential future emissions from deforestation, agriculture, energy use (petroleum products and natural gas) and land use, create a large enough carbon footprint for Ghana to devise a mitigation response.

According to Ghana's National Measurement, Reporting and Verification (MRV) System Assessment Report, total GHG emissions were estimated to be 42.15 $MtCO_2e$ in 2016 (MESTI, 2019). Carbon dioxide (CO_2) was the dominant GHG at 65.5 percent of total emissions. The energy sector emitted the most CO_2 (13.97 Mt), followed by agriculture, forestry and other land use (AFOLU) at 12.91 Mt (MESTI, 2019).

Ghana's NDC sets a goal of unconditionally reducing GHG emissions by 15 percent relative to business-as-usual (BAU) scenario emissions of 73.95 $MtCO_2e$ by 2030. With a condition of external support, that target is raised to a reduction of 45 percent. The targets cover emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as hydrofluorocarbons (HFCs) (Republic of Ghana, 2015).

A key policy action to meet the emissions targets is the pledge to scale up the share of renewable energy in generation to 10 percent by 2030, excluding large hydropower (Republic of Ghana, 2015). Options described in the NDC include increasing small-medium hydro capacity up to 150-300 MW, increasing utility-scale wind power capacity up to 50-150 MW, and increasing utility-scale solar electricity capacity up to 150-250 MW. The NDC also describes establishing 55 solar mini-grids with an average capacity of 100 kW and installing up to 200 000 solar home systems for lighting in urban and selected non-electrified rural households.

3.1.5 Overview of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector[28]

The table below provides an overview of the key policy instruments, regulations and measures that have supported the renewable energy targets and priorities discussed above.

[28] Based on IRENA's repository of knowledge on policies and measures (IRENA, 2015a) and (AfDB, 2018).

Name	Launched	Details
Ghana Investment Promotion Centre Act	1994	– Provided import duty exemptions on renewable energy generators, including solar generators, wind turbines and technologies for generating energy from municipal waste. – Exempted renewable energy products from import VAT if they were imported as a unit (not if a solar system's batteries and inverters were imported separately, for example). – Exempted customs import duties on renewable plants, machinery, equipment and accessories that are specifically imported to set up an enterprise. – Was repealed by the Ghana Investment Promotion Centre act 2013 (Act 865).
Energy Commission Act 1997 (Act 541)	1997	– Promotes the development and efficient use of renewable energy (ECREEE 2015).
Public Procurement Act 2003 (Act 663)	2003	– Promotes direct investment in renewable energy (ECREEE 2015).
Renewable Energy Act	2011	– Introduced a Feed-in-Tariff (FiT) scheme, a Renewable Energy Purchase obligation, net-metering and a framework for a Renewable Energy Fund, and licensing for renewables providers.
Value Added Tax Act 2013 (Act 870)	2013	– Provides VAT exemptions for renewable energy equipment imported in parts, amending the Ghana Investment Promotion Centre Act's "units" provision (see above) (ECREEE, 2015).
Mini-Grid Electrification Policy	2016	– Intended to incorporate mini-grids into the National Electrification Strategy (NES). – Under this regime, mini-grids would be run and owned by public agencies and utilities (Volta River Authority, Power Distribution Services, and the Northern Electricity Distribution Company). – Under the rural electrification arrangement, mini-grid customers would be subject to the same prices as those on the main grid (Energy Commission, 2019a).
Feed-in tariff	2013	– Provided ten year contracts to renewable generators, to be reviewed every two years. – The FiTs ranged from GHS 40.2/kWh (USD 18.97/MWh) and GHS 32.1/kWh (USD 15.15/MWh) for solar and wind, respectively, to GHS 22.7/kWh (USD 10.7/MWh) for hydro projects between 10 and 100 MW. Smaller hydro, landfill gas, sewage gas and biomass plants were also eligible for the FiT (PURC, 2013). – Starting in 2014, the FiT introduced project size restrictions to ease the integration of renewables to the grid. For instance, solar PV and wind plants could not exceed 150 MW and 300 MW, respectively. Similarly, solar PV plants without grid stability or a storage system received a lower FiT and could connect to the distribution grid if smaller than 10 MW (maximum peak per plant) or to the transmission grid if larger than 20 MW (PURC, 2014). – By 2016, provisions for 20-year FiT contracts were introduced, depending on grid impact studies, while the project size restrictions and differentiation for grid stabilisation and storage systems were dropped. – By 2016, the FiTs had increased compared to 2013. For instance, the solar PV FiT was GHS 59.78/kWh and wind FiT was GHS 65.35/kWh.
Renewable energy purchase obligation (PURC, 2011)	2013	– Requires a distribution utility or bulk customer to procure a pre-determined percentage of their electricity purchases from renewable energy sources – established by the Public Utilities Regulatory Commission (PURC) in consultation with the Energy Commission. – To establish each share, the PURC had to consider the financial integrity of each public utility, the effect of the cost of the renewables on consumer (end user) tariffs, and the renewable technologies available.
Net Metering (Energy Commission, 2015)	2015	– The Net Metering Sub-Code allowed renewable energy generating systems to connect to the distribution network at medium voltage (1 kV to 36 kV).
Auctions (Lucas, del Rio, and Sokona 2017)	2015	– Ghana launched a 20 MW auction in November 2015 to deploy renewable energy at the least cost. GIZ provided technical assistance to design the auction, which included distinctive design elements such as a 20 % local content requirement. The full 20 MW was awarded. – Because cost reduction was a major objective, Ghana conducted a minimum price auction. – The awarded bid offer of USD 0.117/KWh was lower than the FiT of about USD 0.18 US/KWh. – A second round is expected. In fact, IPPs are expected to be procured only through auctions in the future (Bellini, 2018)
Renewable Energy Fund	NA	– Aims to mobilise financial resources to promote, develop, sustainably manage and utilise renewable energy resources. – Is expected to offer financial incentives, capital subsidies, production subsidies and equity participation for renewable energy power generation. – The support and operation scheme are yet to be clearly defined.
Review of Thermal and Renewable Energy PPAs (Ministry of Energy, 2019; GhanaWeb, 2020; Ghanaian Times, 2019; van Dyk, 2020)	2017 - present	– Unsolicited and negotiated PPA transactions over the 2012-2016 period derived in a high-cost system with overcapacity. – In 2017, the PPA Review Committee concluded that certain PPAs needed to be terminated and/or modified (deferred or downsized). – In 2019, the government reduced total signed renewable energy PPA capacity from 2 265 MW to 515 MW. Moreover, it re-negotiated the average price of these PPAs from USD O.19/KWh to USD 0.12/KWh – The take-or-pay contracts are being renegotiated to take-and-pay. Since August 1, 2019, the government has only paid for the energy (and gas) it consumes. – A moratorium on contracting new PPAs was set in 2020 and will remain until the 515 MW are executed and a more sustainable contracting framework is developed (such as competitive bidding processes for utility-scale solar power plants).

Table 12 – Key policy instruments, regulations and measures supporting national plans and driving renewable energy deployment

3.2 Prospects for renewable power towards 2040

IRENA analysed Ghana's power system as part of its regional study Planning and prospects for renewable power: West Africa (IRENA, 2018b).[29] The analysis shows that if the energy sector's short-term financial issues related to overcapacity can be solved by recent reform measures, Ghana could increase the share of renewables in the power sector to 86 percent of capacity and 77 percent of generation by 2040, driven by both increasing cost-competitiveness of renewables and national renewable energy targets.

3.2.1 Methodology and assumptions

Demand projections: the assessment performed in IRENA's study (IRENA, 2018b) has been updated for this present analysis to incorporate more recent demand projections used in the official ECOWAS update to the regional power generation masterplan (Tractebel, 2018). The update extends the demand projection in the 2018 masterplan to 2040 and transforms that projection to final sectoral demand values using the same T&D losses and sectoral split in IRENA (2018b).[30] The average annual growth rate of demand is projected to be 3-4 percent (from 17 TWh in 2020 to 38 TWh in 2040), with the largest shares of electricity demand seen in the industry, commercial and urban residential sectors (Figure 10). The rate of electricity access in that assessment is assumed to reach 90 percent for urban areas and 65 percent for rural areas (though Ghana has already met this urban electrification rate).

Renewable resource potential: Table 13 presents the technical resource potentials of key RE sources in Ghana, as derived from previous IRENA analysis.[31] Estimates of solar PV and wind potentials are based on the analysis carried out in IRENA (2016).[32] While these estimates do not represent the exact economic potential of these resources in the specific context of Ghana's electricity system, the potentials are significant (e.g. in comparison to current total installed capacity of roughly 5 000 MW).

Other key assumptions: The SPLAT-W model used by IRENA for the analysis includes a number of important assumptions (Table 14). It also is important to note that renewable power capacity costs have rapidly declined since the time of this analysis, and integrating the most up-to-date and localised cost data is necessary to assess the possibility of even greater economic potential for renewable energy. Various stakeholders in the region may also regard certain assumptions differently and local experts are advised to continue exploring different assumptions in order to develop and compare their own scenarios.

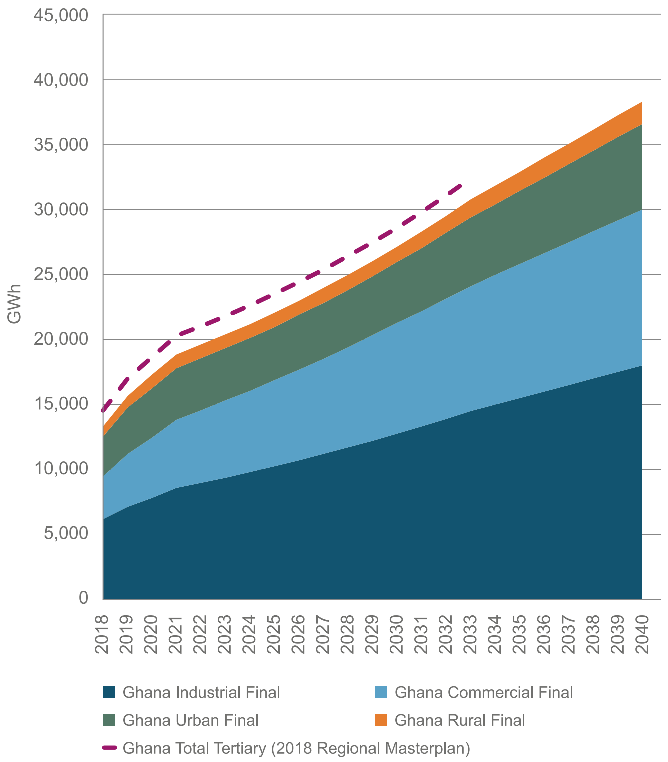


Figure 10 – Electricity demand projection in 2018 ECOWAS regional masterplan and IRENA analysis

RE resource	Technical potential (MW)
Solar PV	20 295
Wind	2 015
Biomass	4 450[33]
Small hydro	1 245[34]

Table 13 – Renewable energy resource potential

[29] In this analysis, IRENA used publicly available information as well as inputs from national representatives, with a base year of 2015. Further validation by local experts would always serve to enhance the robustness of model results. The assessment is based on certain assumptions, including, but not limited to, fuel costs, infrastructure and policy developments, which various stakeholders in the region might regard differently at different times.
[30] For more details on the assumptions behind these projections, see the specified reports for reference.
[31] Technical potential estimates the capacity of RE technology available for development by applying constraints such as topography in order to filter out geographic areas that are technically unfeasible for development.
[32] For further detail on methodology and underlying data, see IRENA (2016). In this analysis, instead of categorising land in a binary way, as either "available" or "unavailable" for development, an opportunity-based approach is used to measure resource potential, by ranking the quality of areas for development according to scores assigned to a range of relevant factors. Several factors were included in the investment suitability analysis, such as the renewable energy resource intensity, distance to the grid, population density, topography, land cover and protected areas.
[33] Estimated based on previous IRENA analyses (IRENA, 2014b; 2014a) and represent conservative technical resource potential for co-generation.
[34] Based on estimates from the United Nations Industrial Development Organisation and the International Center on Small Hydro Power (UNIDO and ICSHP, 2016).

Assumption	Description	Sources
Load profile	Hourly annual electricity demand data provided by Ghana was used to develop a representative overall load shape, then aggregated into daily time slices, with sector-specific load profiles developed for rural, urban, commercial and industrial demand.	IRENA – for more detailed methodology see: IRENA (2018).
Existing and planned generation projects (GW)		Existing as of 2015, based on the 2011/12 WAPP Master Plan (WAPP 2011), updated by IRENA and national experts present at IRENA's 2015-2016 regional SPLAT-W training workshops. Committed/Candidate: IRENA analysis at time of publication, incorporating data from the 2016-2019 WAPP Business Plan (WAPP 2015).
Existing	2.58	
Committed site-specific	1.1	
Candidate site-specific	0.42	
Cross-border transmission lines for Ghana (MW)		IRENA analysis at time of publication, incorporating data from the 2011/12 WAPP Master Plan (WAPP, 2011) and the 2016-2019 WAPP Business Plan (WAPP, 2015).
Existing	Ghana – Côte d'Ivoire (327);	
Committed	Ghana – Togo (438) Dorsale (650); Hub Intrazonal (320)	
Candidate	Dorsale Mediane (650)	
Fuel cost projections (USD 2015/GJ)	(2015 → 2040)	IRENA analysis at time of publication; see detailed methodology in IRENA (2018b).
Coal (import)	4.9 → 5.5	
Diesel (delivered to coast)	11.2 → 24.3	
HFO (delivered to coast)	6.6 → 14.3	
Natural Gas (domestic)	7.1 → 8.5	
Natural Gas (pipeline)	8.6 → 10.3	
CAPEX projections to 2040 (USD 2015/kW)	(2020 → 2040)	IRENA internal cost database at time of publication (IRENA, 2018b).
Solar PV (Utility)	1 325 → 745	
Onshore Wind	1 525 → 1 015	
Biomass	2 715	
Natural Gas (Combined Cycle)	1 160	
Coal (Supercritical)	2 615	

Table 14 – Summary of IRENA's assumptions in the SPLAT-W model

3.2.2 IRENA electricity capacity expansion scenarios

Two main scenarios for Ghana's power sector are explored in this analysis. Both scenarios allow for cross-border electricity trade within the regional SPLAT-W model, based on existing cross-border transmission lines and those chosen for further development:

1. **The Reference Scenario** describes renewable energy deployment in the absence of national or regional targets, based on a detailed project pipeline and range of assumptions, with cost-competitiveness as the key driver for the deployment of various technologies. Other than demand projections, which have been updated in this present analysis, detailed assumptions behind this scenario can be found in IRENA (2018).[35]
2. **The National Targets Scenario** sets minimum country-level targets for the percentage of renewable energy in total domestic generation, based on national SE4All Action Agenda documents. For Ghana, the target at the time of the analysis was a 10 percent renewable share by 2030, excluding large hydropower. No specific technology deployment targets are enforced, so the model can explore the most economically attractive combinations given cost and performance assumptions.

The figures and table below show the main results of both scenarios, in terms of both system capacity and generation.

[35] One important assumption to note is the use of conservative "dry-year" capacity factors for large-scale hydropower plants across all scenarios, which results in lower than average hydro generation through the modelling horizon. This underplays the role of hydropower in the region but is considered to be prudent in view of the vulnerability of West Africa to drought.

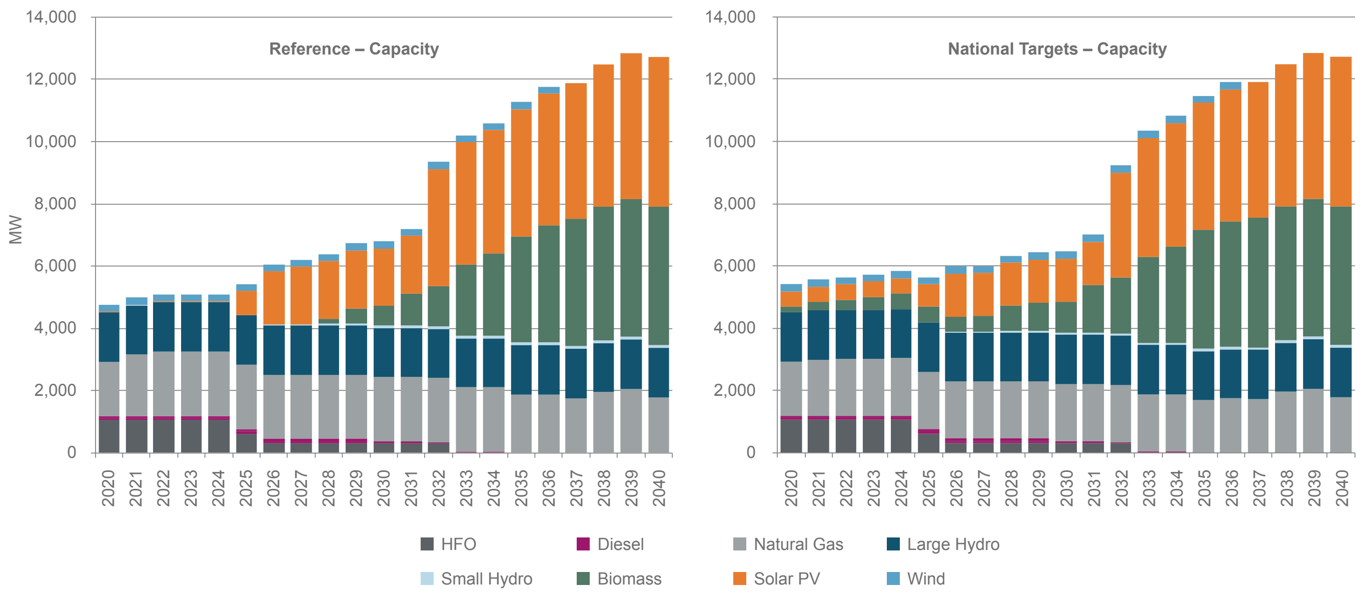


Figure 11 – Capacity mix in Ghana in the Reference and National Targets scenarios

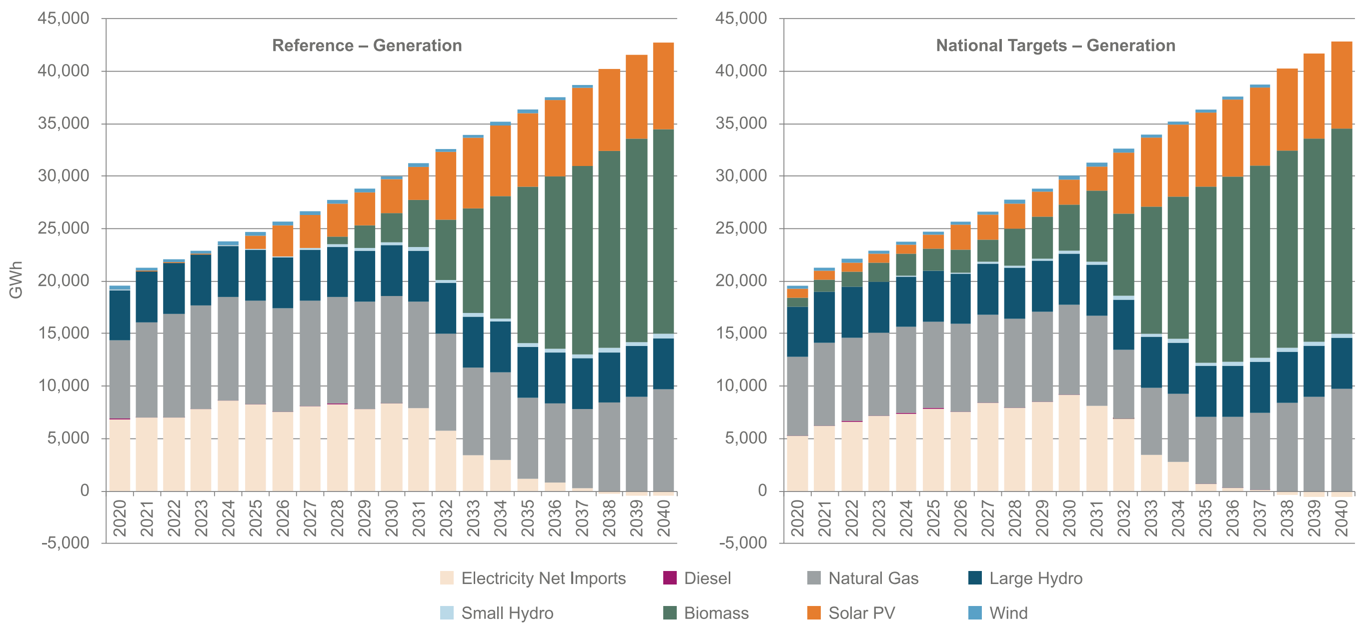


Figure 12 – Generation mix in Ghana in the Reference and National Target scenarios

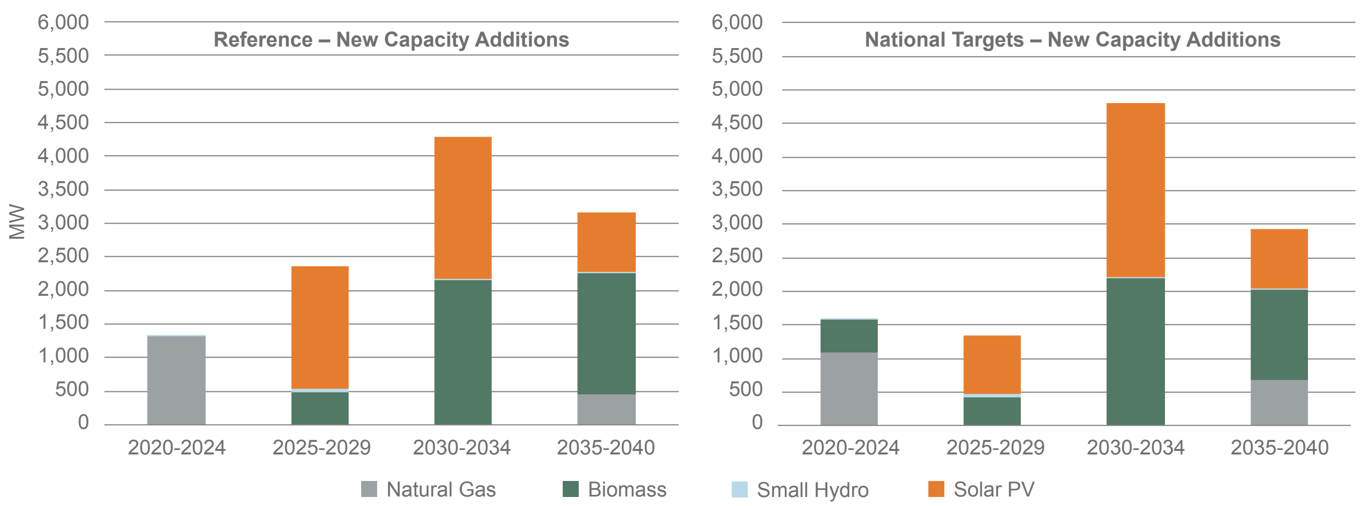


Figure 13 – Gross capacity additions in Ghana in the Reference and National Target scenarios

Key insights emerging from the results include:

- Ghana's relatively low target of 10 percent generation for non-hydro renewables is already met in the Reference scenario; in fact, by 2040, both scenarios result in the same share of VRE, with nearly 5 GW of solar PV producing roughly 20 percent of the system's total generation.
- In both scenarios, solar PV and biomass replace roughly 1.2 GW of heavy fuel oil (HFO) and diesel plants during the 2020s and thereafter grow to meet sustained demand growth in the 2030s. By 2040, renewables represent 86 percent of capacity and 77 percent of generation in both scenarios.
- The increase in renewable energy generation gradually displaces electricity imports from neighbouring countries in the 2030s, with Ghana largely meeting its demand through domestic resources by 2040.
- Both scenarios take advantage of Ghana's assumed biomass potential, with capacity buildout mainly in the 2030s and reaching roughly 4.5 GW by 2040. Given the importance of assumptions about land suitability and fuel cost, it would be valuable for local stakeholders to explore this result further under a different set of assumptions. Similarly, large hydropower capacity is assumed to be maintained throughout the modelling horizon, and alternatives to this baseline assumption may be of interest given potential future climate or operational uncertainties. Scenarios reflecting more ambitious action on climate change would also need to explore a range of increasingly feasible renewable alternatives to natural gas capacity, such as solar PV with storage.
- The timing of the results in the analysis is affected by the actions of neighbouring countries meeting their own national renewable targets. For example, Nigeria's accelerated solar PV expansion to meet its 2030 target of 30 percent renewable generation enables Ghana to take advantage of lower cost electricity imports from Nigeria; in fact, there is less VRE capacity and generation in Ghana's national target scenario in 2030 (25 % and 13 %, respectively, vs. 31 % and 16 % in the Reference scenario) because of those imports.
- Regional developments have an important impact on Ghana's own system evolution. The scenarios include expansion of the Coastal Backbone/Dorsale interconnection between Nigeria, Benin, Togo and Ghana, which would allow for greater exports of Nigeria's relatively low-cost hydro, gas and solar resources.

Reference	Capacity (MW)								Generation (GWh)								
	HFO	Diesel	Natural gas	Large hydro	Small hydro	Bio-mass	Solar PV	Wind	HFO	Diesel	Natural gas	Large hydro	Small Hydro	Bio-mass	Solar PV	Wind	Electricity net imports
2025	620	147	2 063	1 580	17	0	772	225	0	16	9 852	4 830	73	0	1 322	326	8 266
2030	300	70	2 063	1 580	69	636	1 851	225	0	16	10 219	4 830	302	2 787	3 169	326	8 354
2035	0	0	1 883	1 580	84	3 409	4 081	225	0	0	7 720	4 830	366	14 933	7 010	310	1 166
2040	0	0	1 777	1 580	97	4 449	4 829	0	0	0	9 738	4 830	425	19 487	8 244	0	(434)

National targets	Capacity (MW)								Generation (GWh)								
	HFO	Diesel	Natural gas	Large hydro	Small hydro	Bio-mass	Solar PV	Wind	HFO	Diesel	Natural gas	Large hydro	Small Hydro	Bio-mass	Solar PV	Wind	Electricity net imports
2025	620	147	1 837	1 580	9	486	726	225	0	16	8 188	4 830	40	2 131	1 244	326	7 921
2030	300	70	1 837	1 580	69	1 000	1 383	225	0	16	8 599	4 830	302	4 380	2 367	326	9 182
2035	0	0	1 678	1 580	84	3 818	4 081	225	0	0	6 378	4 830	366	16 722	7 012	308	719
2040	0	0	1 776	1 580	97	4 449	4 829	0	0	0	9 764	4 830	425	19 487	8 244	0	(460)

Table 15 – Capacity and generation mix in the Reference and National Target scenarios

3.2.3 Investment needs

The investment needed to achieve the results in this analysis is substantial relative to the current size of the Ghanaian electricity system. Based on the investment cost assumptions underlying this modelling exercise, the cumulative investment that would be required to build the 11.2 GW of new mostly renewable generation capacity in the Reference scenario from 2020 to 2040 (and reach more than 40 TWh of total generation by 2040) is USD 26.1 billion. That new capacity would include 4.8 GW of utility-scale solar PV, 4.5 GW of biomass, 1.8 GW of natural gas and 0.1 GW of small hydropower.

In addition, the cumulative transmission and distribution investment needed would be USD 4.2 billion over the same time period.

Adding in fuel and operating and maintenance costs over the modelling period, total system costs from 2020 to 2040 would be nearly USD 49.1 billion. Because of the growth in solar PV, which has relatively higher up-front investment costs but no fuel costs, the share of fuel costs for the Ghanaian system would substantially decline, from 30 percent in 2020 to 15 percent by 2040, despite the significant demand growth (Figure 14). Ghana's dependence on natural gas and oil fuels also would decline.[36]

3.3 Systemic innovation needs and opportunities

As described in the "National plans" section above, Ghana has set several ambitious targets, such as increasing renewable energy generation capacity from 42.5 MW in 2015 to 1 363.3 MW by 2030 (Energy Commission, 2019a). IRENA's scenarios show that achieving those targets is feasible.

However, it is possible to go beyond those targets with a clear vision and new implementation policies, regulatory measures and ambitious priorities that take advantage of a wide range of innovations that will help address the challenges that lie ahead (Figure 15).

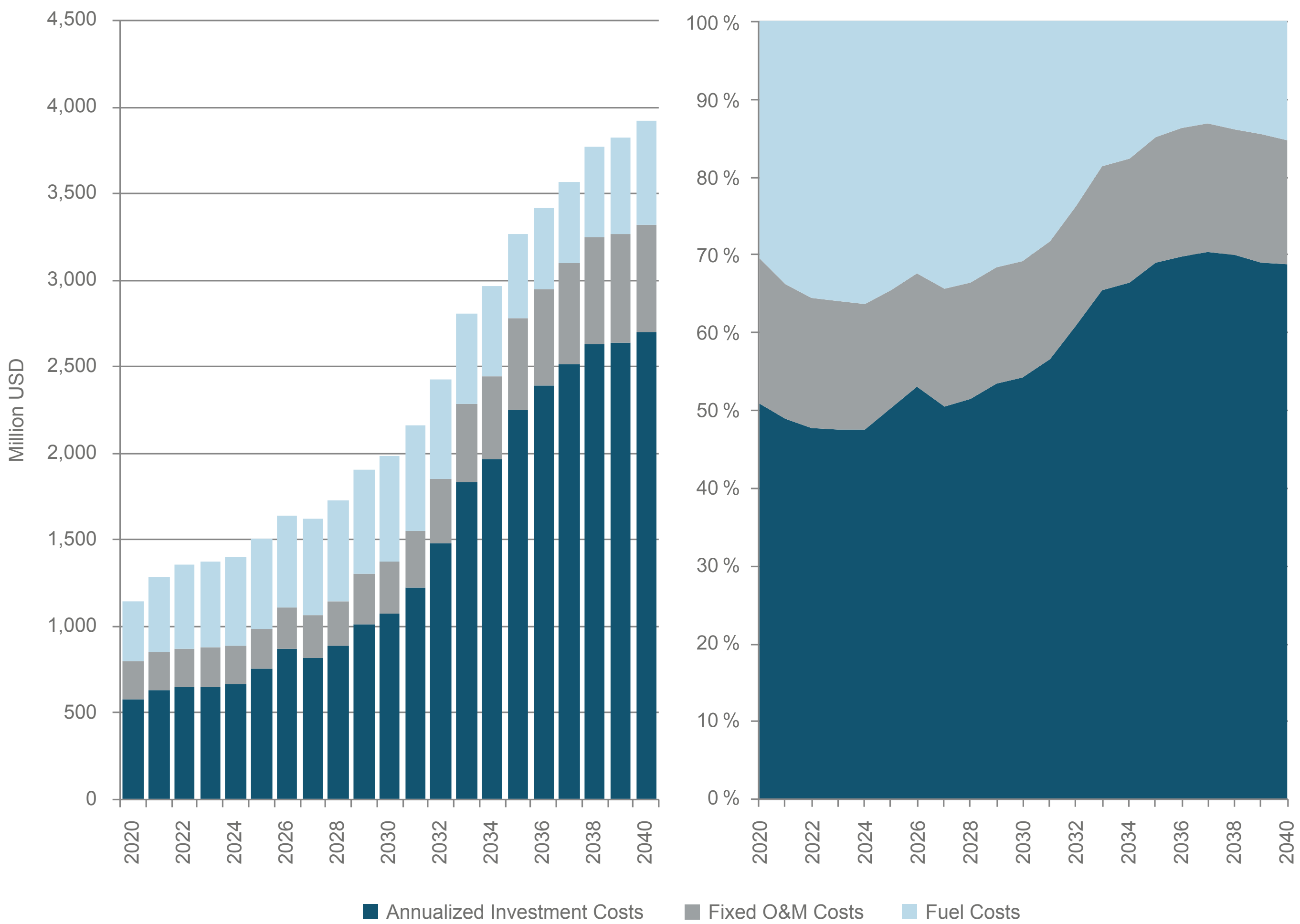


Figure 14 – Annual system costs

[36] It should be noted that these system costs do not capture all potential investment needs in such a large-scale transition – for example, studies have shown that investing in greater system flexibility through hydropower upgrades in West Africa could bring significant benefits and reduce overall long-term costs (see Smart renewable electricity portfolios in West Africa [Sterl et al., 2020]). The following chapter will also discuss emerging innovations which could have a significant influence on investment needs and overall system costs.

New paradigm of the energy supply chain in Ghana

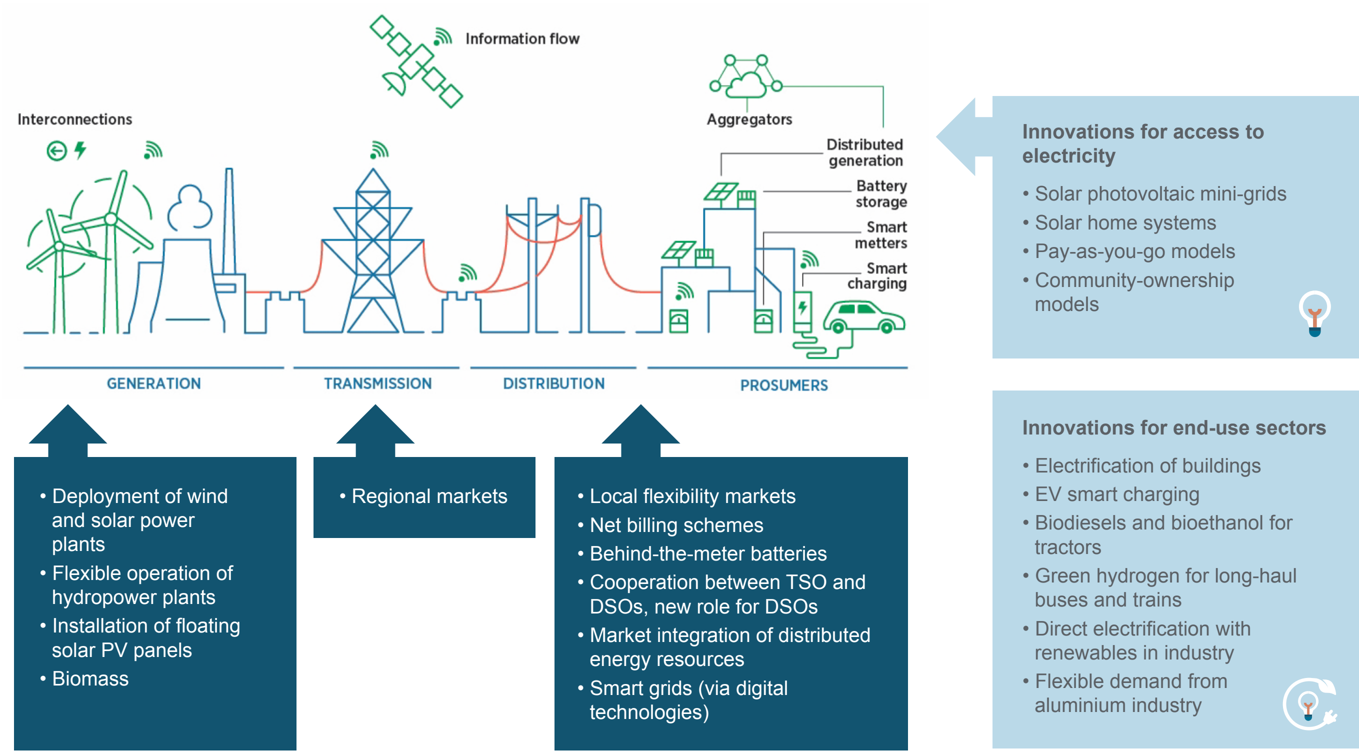


Figure 15 – Innovations to be considered for a future renewable power sector in Ghana

3.3.1 Innovation to support a renewable power system

Operating hydropower plants more flexibly for more integration of solar and wind, and installing floating solar photovoltaic plants

Over the last 20 years, Ghana has made a drastic shift in its electricity generation mix from 99 percent large hydropower in 1997 to 63 percent oil and natural gas in 2019 (IRENA, 2020e). Reasons include droughts and the fossil fuel generation expansion in 2015-2020 to address generation inadequacy issues that had hindered economic growth but which also created system overcapacity (IRENA, 2015a)[37]. Now there is an opportunity for Ghana to significantly expand the share of renewables by adding more decentralised VRE capacity, like solar PV and small wind turbines, while also operating hydro and gas power plants more flexibly to enable more integration of grid-scale VRE.

One specific innovative strategy could be to install floating solar PV power plants on hydro reservoirs. This would cut capital investment costs – since the solar plant would share the hydro's grid connection – and improve efficiencies for both solar and hydro generation, since the PV panels both reduce evaporation and benefit from water cooling (IRENA, 2020c).

Although there is an important solar PV project in the pipeline[38], solar remains marginal with only two utility-scale solar PV power plants installed in Ghana. Key challenges that undermine the development of new renewable capacity are the current surplus supply of electricity and the perception that new renewables construction would add to already-high electricity tariffs (The Africa Report 2019). In the long run, however, increased solar PV and wind generation can provide cheaper electricity to citizens.

Increasing the use of biomass

Residues from the production of maize, rice, millet, sorghum, cassava and other crops could have significant potential in Ghana (with one estimate at 146 PJ of energy supply by 2030), and some can be used for electricity generation (Collins-Sowah, 2017). Other possible energy resources for cost-effective power generation in Ghana are animal waste, municipal and industrial waste, and forest biomass (Gielen et al., forthcoming).

Deeper integration of the regional electricity market (WAPP)

Ghana already trades electricity with Members of WAPP and is part of the "Coastal backbone" transmission project that passes through Ghana, Togo and Benin, linking the countries along the coast between Nigeria and Côte d'Ivoire. But Ghana could greatly benefit from strengthening the North-South "Median backbone" transmission line that crosses Ghana (Tractebel, 2018) and from increasing the time granularity in electricity markets to facilitate more trading.

[37] In the 2014-2015 period, the industrial sector's contribution to GDP fell from 27 % to 25 %, which also recorded important employment cuts, especially in the mining and quarrying subsector (World Bank Group, 2018).

[38] The solar photovoltaic pipeline consists of 102 MW of decided projects, 490 MW proposed for development, such as the Ghana North (Tamale and Wa) with 250 MW. In the period 2023-2029, an additional 2.4 GW of solar PV projects are planned for implementation, mainly consisting of 11 large-scale projects of over 100-150 MW each. In the period 2030-2033, an additional 2.75 GW solar PV projects are planned with a capacity between 200-400 MW each, as well as one wind power plant of 200 MW (Tractebel, 2018).

Decentralisation of renewable power generation and new roles for the three DSOs

Ghana has a liberalised, vertically unbundled power sector with private generation (IPPs) as well as three private distribution system operators (DSOs).[39] GridCo is the electricity Transmission System Operator (TSO). A key market design innovation would be the integration of distributed energy resources[40] into the market, either by allowing these to participate in the future regional electricity market (WAPP) or by creating local flexibility markets that could be operated by the DSOs. Another is "net billing", which would pay distributed generators the actual value of electricity added to the grid at a particular time.[41]

Such decentralisation would reduce the need to build new (or reinforce old) transmission lines. Meanwhile, DSOs could better manage local generation and consumption by deploying smart meters, real-time monitoring of rooftop PV, behind-the-meter batteries and other distributed resources.

Renewable mini-grids and new business models providing electricity access in rural areas

Nearly three-quarters of Ghana's people live in small communities of less than 100 people. Bringing grid connections to these tens of thousands of communities is challenging and expensive, which helps explain why 33 percent of the rural population still lacks access to electricity (About Energy, 2018).

A more cost-efficient, rapid and innovative solution would be to build more renewable mini-grids and solar home systems[42], and to implement community-ownership business models. Current plans include 55 mini-grids and 200 000 solar home systems, but more can be done.

3.3.2 Innovations for renewable-based electrification of end-use sectors

Buildings

Electrification of the buildings sector first requires a reliable electricity supply – which could include decentralised renewables like roof-top solar PV and mini-grids – in addition to grid connections. Beyond electrification, renewable energy could also be used directly, as in solar water heaters, and efficient cooking stoves operating on clean fuels would be important in a decarbonised energy system.

Transport

The main means of transport in Ghana are mini-buses ("trotro") providing over 52 percent of total transport services, followed by large buses (10 %), private cars (13 %), walking (12 %), taxis (9 %) and bikes or other (4 %) (Teko, 2018). Replacing this vehicle fleet with electric buses and cars would be challenging, especially given that 80 percent of cars are imported second-hand vehicles (Teko, 2018).

Ghana could, however, begin to support a possible transition by enabling digital technologies like Electric Vehicle smart charging, which could provide EV owners with additional revenue if they are allowed to provide ancillary services to the grid operators. Accra, the capital, is home to 50 percent of all registered vehicles nationwide, which would make the investments in enabling infrastructure relatively easy to implement. In addition, Volkswagen has been exploring transport electrification in Rwanda, and eyes Ghana as the next country to test feasibility (Volkswagen 2019).

Other renewable options are biodiesels and bioethanol for tractors, and green hydrogen as a fuel for long-haul buses and trains.

Industry

Volta Aluminium Company (VALCO) was the largest consumer in 2016 in Ghana with 631 GWh, which represented five percent of total consumption (Tractebel, 2018). Because aluminium production already uses electricity, rather than the fuels that other heavy industrial segments like iron and steel need in order to produce high temperature heat, this represents a major opportunity to switch to reliable sources of renewable electricity. Aluminium smelters also can quickly be ramped up or down, and thus can serve as flexibility providers to the grid if given monetary compensation for those demand response services.

The mining and textile industries, as well as parts of agriculture, could also benefit from direct electrification with renewables. Cement and chemical production are harder to decarbonise, but technological pathways are emerging at the international level (IRENA, forthcoming).

3.4 Conclusions and areas for further consideration

Ghana has abundant and varied domestic renewable resources, including solar, wind, ocean, bioenergy and hydropower. The country's most recent power sector masterplan reflects this strong resource, providing good support for the country's current power sector target of at least 10 percent non-large-hydro renewable generation by 2030. It also offers a compelling "Enhanced NDC" scenario that leads to 30 percent renewables and 14 percent VRE generation by 2035.

Nevertheless, unsolicited and negotiated PPA transactions over the 2012-2016 period derived in a high-cost system with overcapacity. As a result, a moratorium on contracting new PPAs was put in place in 2020 until a more sustainable contracting framework could be developed. Policies and measures, therefore, must first focus on supporting renewables deployment in a financially sustainable manner. Renewable energy auctions, for example, through their ability to discover

[39] The Electricity Company of Ghana (ECG), the Northern Electricity Distribution Co. (Nedco) and Enclave Power Co.
[40] Distributed energy resources (DERs) are small or medium-sized resources, such as distributed generation (rooftop solar photovoltaic), behind-the-meter batteries or controllable loads that can be used to provide services to system operators, including demand response (IRENA, 2019d).
[41] E.g. injecting power stored in batteries behind-the-meter during peak hours would yield higher revenues to the prosumer than injecting solar electricity during the day when demand is low and is supply high.
[42] Pilot projects conducted in Ghana include the largest private mini-grid operated by the company Black Star Energy and the pay-as-you-go business model proposed by the company PEG Africa, which served 400 000 daily users across Ghana, Côte d'Ivoire and Senegal as of 2019 (PEG Africa, 2019; Techcrunch, 2020).

real prices, can help deploy renewables in a cost-effective fashion if designed to achieve that objective. Ghana has already conducted one auction and a second round is expected.

Looking ahead, once the overcapacity and high system costs are addressed, IRENA scenarios suggest that ambitions could be raised further. The Reference scenario shows that it is possible to deploy 1.4 GW of cost-competitive solar PV by 2030, which would represent 15 % of generation, and nearly 5 GW by 2040, making up 20 percent of generation. Overall, Ghana's power system in IRENA's Reference scenario would reach 77 percent renewable generation by 2040, thanks to the flexible operation of hydropower capacity and the addition of biomass and wind along with solar PV.

These higher shares of renewables offer considerable benefits. As Ghana's dependence on natural gas and oil fuels declines in the IRENA scenarios, for example, the share of fuel costs in total system costs drops by half, from 30 percent in 2020 to 15 percent by 2040. That would reduce Ghana's exposure to volatile fossil fuel prices and has the potential to lower the electricity bills paid by consumers. Renewables therefore should be considered as more sustainable alternatives to new natural gas capacity.

Ghana also has important opportunities to take advantage of complementary renewable power generation in other countries, such as Nigeria's hydro and solar power, so power sector decarbonisation ambitions should also be based on a good understanding of regional developments.

With the experience of a major transition in the energy sector over the past two decades from inadequate generation to oversupply, Ghana is well positioned to undertake another fast transformation, this time towards renewables.

Abundant technology-driven innovations are available to help Ghana make this transition. They include:

- solar mini-grids, underpinned by innovative business models enabled by digital technologies, to bring electricity to rural communities;
- floating solar photovoltaic power plants on existing hydropower reservoirs that share the same grid connection, and may therefore reduce costs to consumers; and
- wind and solar PV located close to consumers or distribution systems to save time and resources that would have been needed for grid expansion projects.

In addition, compared to other countries in sub-Saharan Africa, Ghana has the advantage of having a liberalised power sector and supportive policies for large-scale renewables in electricity generation. Moreover, the interconnections and planned transmission projects with neighbouring WAPP countries could bring additional benefits by allowing exports of electricity in times of abundant generation and low demand, and imports of complementary renewable resources when supply is low relative to demand.

However, more effort needs to be put into translating the ambitious targets set forth in the latest energy plans into policies and measures that can support deployment of renewables in all end-uses, as well as in the remote areas not connected to the grid, and in the general context.

It is also crucial that the energy transition is as just and inclusive as possible. More specifically, that could mean:

- In the access context, affordable and sustainable electricity can be brought to all people in Ghana with a combination of grid extensions and off-grid solutions, including mini-grids and stand-alone systems. Supportive policies are needed to reduce the risks of conflicts between the various electrification modes and to ensure viability (e.g. risks associated with licensing, tariff setting and main grid arrival). In addition, dedicated funding and capacity building programmes are required to advance affordable and reliable energy solutions, and efforts related to addressing bottlenecks are needed. One such bottleneck is poor mobile network coverage, which hampers the adoption of pay-as-you-go business models. In designing such an enabling framework, a holistic approach is needed that takes into consideration livelihood needs and the long-term sustainability of renewable energy systems. An important aspect to tap into the full potential of renewables is linking these solutions to productive end uses, such as agriculture and local manufacturing, to improve local economies and help advance progress across several of the Sustainable Development Goals.
- In the general context, deployment policies need to adapt to changing market conditions, such as reducing tariffs to reflect falling technology costs and using auctions as a tool for market price discovery for large-scale projects. In addition, auctions can be designed for a suitable allocation of risks among stakeholders (e.g. developers and off-takers). Those include off-take risks and financial risks such as currency exchange or inflation. Moreover, auctions can be designed to ensure that projects come online on time and that targets are achieved, and to facilitate the integration of renewables into electricity transmission, distribution and end-use applications. Auctions can also help ensure sufficient system flexibility as the share of variable renewables grows, and they can be designed to ensure a just and inclusive transition and achieve socio-economic and development objectives (IRENA, 2019g).

In general, a just and inclusive transition in Ghana would ensure the broad sharing of positive outcomes – such as job creation in renewables industries and in end-uses made possible by universal access to electricity – while limiting adverse implications, such as the loss of jobs in declining sectors like natural gas electricity generation.

4 South Africa country analysis

Key messages

South Africa has a large potential for renewable electricity generation, making it possible to replace much of the country's current dominant coal generation and significantly decarbonise the power sector in a cost effective way. For the power sector, IRENA's analysis shows that an investment of USD 563 billion through 2040 would transform the sector, while integrating higher shares of renewable electricity and reducing CO_2 emissions by more than two-thirds. Wind and solar PV offer cost-competitive replacements for coal. Several innovative solutions can help to address current challenges, such as grid congestion, and make the transport, buildings and industry sectors more sustainable. At the same time, South Africa must ensure that communities and vulnerable workers do not shoulder an unfair burden for the transition. To that end, South Africa has designed policies aimed at creating a just and inclusive energy transition, which so far have brought increases in job opportunities and strengthened local industries while promoting social justice in both racial and gender terms. These policies have provided valuable implementation lessons and require ongoing political support.

4.1 Status quo of the power sector in South Africa

4.1.1 Brief introduction to the overall energy landscape

In 2017, South Africa's total primary energy supply (TPES) was 5534 PJ, the highest in Africa (IRENA, DoE and SANEDI, forthcoming). Nearly 90 percent was fossil-based, with a large domestic production of coal (Table 16). More than half of the coal produced was used to generate electricity, while one third was exported. Oil and natural gas were mostly imported.

In the same year, South Africa's total final energy consumption (TFEC) was 2684 PJ. Only 10% of that was renewable, including renewably sourced electricity (Table 17). The direct use of renewables was predominantly in the form of biomass (primarily solid biofuels and charcoal).

The industry sector consumes the most energy, at 37 percent of TFEC, followed by the transport, residential, and commercial and public service sectors.

Electricity consumption has steadily grown at an average of 3.2 percent per year since 1971. In 2017, per capita consumption was 4004 kWh. Use of electricity is particularly high in the commercial and public sector, at 46 percent of TFEC, and in the industry sector, at 42 percent. Electricity supplies 26 percent of TFEC – which is higher than the global average of 19 percent (IEA, 2019c).

Gross GHG emissions (excluding those from food and land use [FOLU]) were 541 $MtCO_2e$ in 2015, of which the energy sector was responsible for 430 $MtCO_2e$ (79%) (Department of Environmental Affairs, 2019). Historically, the power sector alone is responsible for about 42 percent of total national CO_2 emissions. Eskom, which supplies more than 96 percent of the country's electricity, reported emissions of 229 $MtCO_2e$[43] in the financial year 2018-2019 (Eskom, 2019).

	Coal and coal prod.	Crude and NGL	Oil	Nat. gas	Nuclear	Primary solid biofuel[44]	Charcoal	Hydro	PV	CSP	Wind	Electricity	Total
Total TPES	4113	713	73	178	155	291	-10	3	9	14	18	-24	**5534**
Production	6087	6	0	31	155	291	0	3	9	14	18	0	**6615**
Net imports	-1975	698	241	148	0	0	-10	0	0	0	0	-24	**-921**
Others	0	9	-168	0	0	0	0	0	0	0	0	0	**-159**

Table 16 – TPES in 2017 in PJ Source: (IEA, 2019c)

	Coal and coal products	Oil products	Natural gas	Solar thermal	Primary solid biofuels	Charcoal	Electricity	Total
Total TFEC	720	954	70	7	201	34	700	**2684**
Industry	357	88	70	0	66	0	420	**1000**
Transport	0	751	0	0	0	0	14	**764**
Residential	224	26	0	0	135	34	139	**558**
Commercial and public services	112	6	0.1	0	0	0	101	**219**
Agriculture/forestry	21.9	48	0	0	0	0	21	**90**
Fishing	0	3	0	0	0	0	0	**3**
Final consumption not elsewhere specified	5	32	0	7	0	0	6	**49**
	27%	36%	3%	0%	7%	1%	26%	**100%**

Table 17 – TFEC in 2017 in PJ Source: (IEA, 2019c)

[43] 221 Mt of carbon dioxide and 2.8 kt of nitrous oxide.
[44] Defined in IEA statistics as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes and other solid biofuels).

Entity	Description
Department of Mineral Resources and Energy (DMRE)	Responsible for ensuring development, utilisation and management of South Africa's energy sources.
Department of Environmental Affairs (DEA)	Responsible for the environmental policy of the country. DEA leads the drafting of the Climate Change Bill, and also determines the compliance of energy infrastructure projects through the National Environmental Management Act.
Department of Public Enterprises (DPE)	Has oversight over the state-owned enterprises in South Africa, including Eskom.
IPP Office	A partnership between the DoE, the National Treasury and the Development Bank of Southern Africa.
National Energy Regulator of South Africa (NERSA)	Regulates the energy industry in accordance with the government's laws and policies. NESRA sets electricity tariffs on a multi-year basis through "Multi-Year Price Determination."
Eskom	National utility that dominates power generation, transmission and distribution, and 100 % owns and manages the national grid.
Sasol	Large energy and chemical company.

Table 18 – Main state players in South Africa

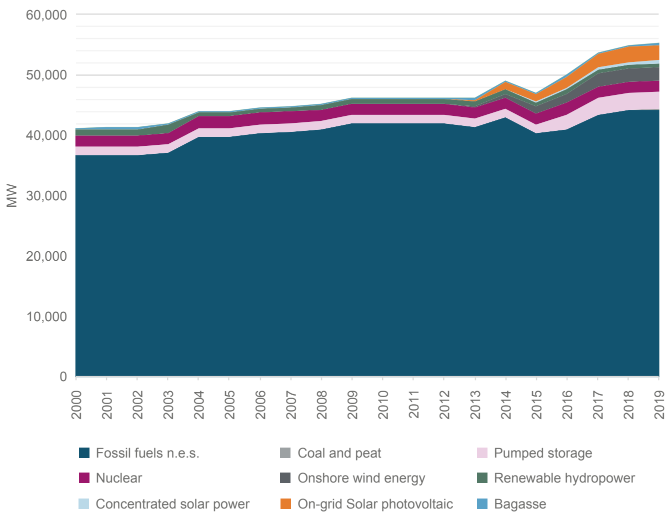
4.1.2 Electricity generation and use

The South African power sector is the largest in Africa, generating approximately 40 percent of Africa's total electricity supply (Eskom, 2019). It therefore follows that South Africa's power sector is the largest player in the Southern African Power Pool (SAPP), contributing over 75 percent of the pool's generating capacity. Not surprisingly, South Africa is the dominant power trader on the SAPP market, for both electricity exports and imports (SAPP, 2019).

Eskom, a vertically-integrated public utility, generates about 90 percent of the country's electricity, with other suppliers being private companies and municipalities (Republic of South Africa, 2018). For the government, key players include the Departments of Mineral Resources and Energy (DMRE), Environmental Affairs (DEA) and Public Enterprises (DPE), along with the National Energy Regulator of South Africa (NERSA) (Table 18).

Total generation capacity has grown from about 40 GW in 2000 to 53.7 GW in 2017, dominated by coal-fuelled generation. Renewable-based power generation capacity started to enter the mix in the mid-2010s; and as of 2017, 10.4 percent was renewably sourced (Figure 16).

In 2017, South Africa's power system generated around 250 TWh of electricity (excluding pumped storage), mainly by on-grid sources (IRENA, 2020a), and net exports were 7 TWh (IEA, 2019c). The share of renewables in the generation mix was 4.2 percent (see Table 19).



Source: (IRENA, 2020f)

Figure 16 – Installed generation capacity between 2000 and 2019

Between 2017 and 2019, 1 000 MW of fossil fuels capacity, 374 MW of solar PV capacity and 100 MW of solar CSP capacity were added to the grid.

	2017		Latest data	
	Total gross generation (incl. pumped storage generation, TWh)	Capacity (MW)	Total gross generation (incl. pumped storage generation, TWh), 2018	Capacity (MW) 2019
On-grid	255	53 682	232	55 265
Fossil fuels	226	43 422	202	44 426
Nuclear	14	1 940	13	1 940
Pumped storage	4	2 732	5	2 732
Hydropower	0.7	747	0.9	747
Onshore wind energy	5	2 094	6	2 094
On-grid Solar photovoltaic	4	2 186	4	2 560
Concentrated solar power	0.7	300	1	500
Bagasse	0.4	242	0.4	242
Off-grid	-	0	-	1
Off-grid solar photovoltaic	-	0	-	1

Table 19 – South Africa's installed electricity capacity and generation

Source: (IRENA, 2020f)

Coal is likely to continue as a major fuel for electricity generation in the medium to long term. About 6 GW of committed coal capacity will come online from 2019 to 2024 (Republic of South Africa, 2019a). Meanwhile, 40 percent of current coal generation capacity is expected to retire by 2030, with coal capacity declining to 21 GW by 2030 and further decreasing to 7 GW by 2040a (Republic of South Africa, 2019a; SAPP, 2017b; Republic of South Africa and National Planning Commission, 2012).

As those coal plants retire and as more renewables are deployed (in part because of policies to reduce carbon emissions), coal's dominance will decrease.

Current challenges include an aging grid infrastructure and severe backlogs in grid maintenance (EE Publishers, 2016). In addition, many existing power plants are currently underperforming. As a result, South Africa experiences electricity supply shortages and power cuts that impact the entire economy and suppress economic growth (Onishi, 2019).

4.1.3 Access to electricity

South Africa has increased access to electricity from 84 percent of the population in 2017 to 91 percent in 2018, with a larger jump from 70 to 90 percent of the rural population (World Bank, 2019b). Still, three million households lack access to grid-based electricity (DoE, 2018a). The goal is universal access by 2030, with 90 percent of that being provided by connections to the grid (Republic of South Africa, 2012).

4.1.4 National planning scenarios, NDC, and key emissions/renewable energy targets

Government plans

The National Development Plan 2030, drafted in 2012, aims to eliminate poverty and reduce inequality by 2030. For the energy sector, the goals are providing reliable energy services, developing infrastructure, expanding access and improving environmental sustainability (Republic of South Africa, 2012). Key details include:

- greenhouse gas emissions peaking in around 2025, then declining (a "peak, plateau and decline" trajectory);
- an economy-wide price on carbon and standards for zero emissions buildings by 2030;
- further emissions reductions in the industry and transport sectors, beyond the power sector;
- procurement of at least 20 GW of renewable electricity by 2030;
- decommissioning of 11 GW of aging coal plants;
- increasing energy efficiency;
- increasing electricity imports;
- reducing carbon emissions from the electricity industry from 0.9kg/kWh to 0.6kg/kWh; and
- accelerating the procurement of electricity from independent power producers and decentralising some of Eskom's functions.

National law also requires South Africa to develop and regularly update an Integrated Energy Plan (IEP) and an Integrated Resource Plan (IRP). Last published in 2016, the IEP provides a roadmap for the energy landscape over at least the next 20 years. The IRP focuses on the power sector and is an infrastructure development plan formulated from a least-cost electricity supply and demand balance. The latest IRP was approved and published in October 2019. Since 2010, the IRP has served as an input for the National Development Plan.

Based on the previous (2010) version of the IRP, the Department of Environmental Affairs commissioned the identification of Renewable Energy Development Zones where solar PV, CSP and onshore wind could be co-located with existing and planned transmission infrastructure in order to connect more renewable energy projects to the grid.

The IRP also developed eight scenarios to explore how the power sector might reduce CO_2 emissions and the negative externalities of CO_2, diversify the electricity mix (including increasing distributed and off-grid generation) and increase the share of renewables (Republic of South Africa, 2019a; IRENA, DoE, and SANEDI, forthcoming).

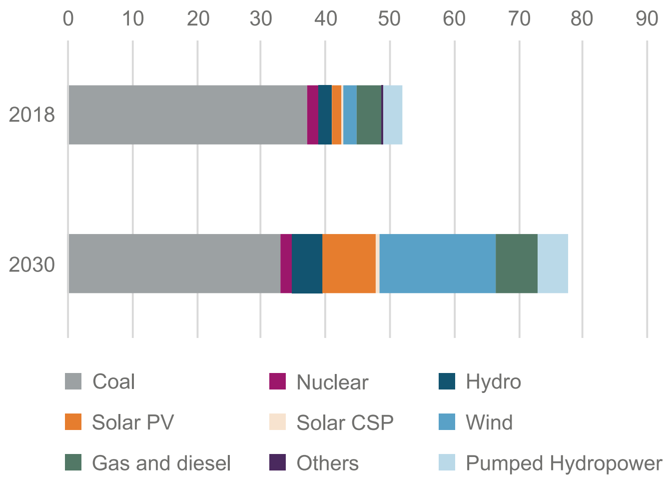
Three of the scenarios investigate varying demand growths. In the median forecast, average annual electricity demand grows 1.8 percent by 2030 and 1.4 percent by 2050, reaching almost 390 TWh in 2050. Other scenarios analyse policies like a carbon budget and a market linked gas price. According to the scenarios:

- coal would still meet most of electricity demand (61-64 %) by 2030, producing about 200 TWh;
- renewables would supply 24 % of demand, with solar producing 26 TWh and wind 42 TWh; and
- carbon emissions would drop from 236 Mt/year in 2020 to 207-217 Mt/year by 2030.

The IRP also considers test cases and the outcomes of modelling and simulations, and proposes an electricity system with the following capacities in its Emerging Long Term Plan (also shown in Figure 17):

- shares of solar PV and wind capacity will increase from about 7 percent (3.5 GW) in 2018 to approximately 36 percent (26 GW) by 2030;
- hydro increases from 2.1 GW to 4.6 GW (6 %)[45]; and
- coal drops from 37 GW to 33 GW.

[45] The 2018 total capacity reported in the IRP slightly differs from IRENA's statistics by approximately 3 GW – mostly in fossil fuels. It is also noted that the IRP is internally inconsistent in representing existing hydropower and it overestimates capacity by 1.5 GW in 2018.



Source: (Republic of South Africa, 2019a)

Figure 17 – Generating capacities (GW) from the IRP's Emerging Long Term Plan

The National Determined Contribution

The Nationally Determined Contribution, submitted to the UNFCCC in 2016, pledges to reach peak GHG emissions by 2025 and then limit emissions in 2025-2030 to between 398 and 614 $MtCO_2e$, compared to 477 Mt in 2016 (World Bank, 2020c; Republic of South Africa, 2015).

It should be noted that the first round of NDCs lays out minimum targets that will be used as starting points from which to expand ambitions in the future.

To achieve electricity decarbonisation targets, the NDC projects that investment of USD 359 billion will be required between 2010 and 2050. It also highlights the need to electrify end-use sectors, with spending on electric vehicles of USD 513 billion and hybrid electric vehicles of USD 488 billion.

As of 2016, South Africa had already approved 5.2 GW of renewable projects (USD 16 billion), with an additional 6.3 GW being considered under the Renewable Energy Independent Power Producer Procurement Programme (REI4P). Table 20 summarises South Africa's key emissions and renewable targets.

The Southern African Power Pool (SAPP) Master Plan

The SAPP Plan published in 2017 covered 12 countries, including South Africa. It examined the plans for generation and transmission in each country until 2040 and presented three main scenarios (also known as components) to achieve a secure and reliable power supply in the region.

The Master Plan concluded that one of the scenarios, called "Realistic" regional integration, would save USD 37 billion compared to the "Benchmark Case" through 2040 and that investments in regional transmission would have quick paybacks. It suggested that national grids should be part of a regional integration effort and that the shares of renewables and natural gas will increase at the expense of coal. Nevertheless, the plan presents a coal-dominated future for South Africa, with up to 90 percent of domestic generation provided by coal in 2030.

Area	Targets
Emissions	"Peak, plateau and decline" trajectory, peaking by 2025. Reduce emissions from the power sector to 0.6kg/kWh, by 2030 (Republic of South Africa 2012). Limit emissions to between 398 and 614 $MtCO_2e$ in 2025-2030 (Republic of South Africa, 2015).
Renewables	Procure 20 GW of renewables by 2030 (Republic of South Africa, 2012). Develop 11.5 GW of renewables under the REI4P (Republic of South Africa, 2015). Increase the capacity of renewables to 30.6 GW by 2030. Increase renewables' share in the generation mix to 24 % by 2030 (Republic of South Africa, 2019a).
Others	Retire 11 GW of coal capacity by 2030 (Republic of South Africa, 2019a; Republic of South Africa and National Planning Commission, 2012). Electrify transport (Republic of South Africa, 2015).

Table 20 – Summary of key national emissions and renewable energy targets

4.1.5 Overview of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector[46]

The table below provides an overview of the key policy instruments, regulations and measures that have supported the renewable energy targets and priorities discussed above.

Name	Launched	Details
The Renewable Energy Feed-in Tariff (REFIT)	2009	– The FEFIT required Eskom to purchase electricity from qualifying renewable energy generators at specified prices. – Starting in 2009, the first phase covered concentrated solar power (CSP), onshore wind, landfill gas and small hydro. – The second phase added CSP without storage, CSP tower with storage, concentrated photovoltaics, large scale solar PV (above 1 MW), solid biomass and biogas. Prices in 2009 were USD 15.6/kWh for wind, USD 26/kWh for CSP and USD 49/kWh for solar PV, with those prices then indexed for inflation (DoE, 2010; IPP Procurement Programme, 2016; NERSA, 2009).
Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)	2011	– The REIPPPP replaced the REFIT. It was designed to lower tariff rates through competitive procurement. By June 2020, the REIPPPP had held five auction rounds for large-scale soil biomass, biogas, CSP, landfill gas, onshore wind, small hydro and solar PV projects. – The programme has awarded 90 projects, all of which are expected to be operational (at a total capacity 6 GW) by November 2021 (IRENA, 2019g). The projects are picked to help achieve goals like job creation, local content and ownership, and broader socio-economic development, and have exceeded most of the targets. Overall, the five rounds of REIPPPP and two rounds of SP-IPPPP (see below) conducted to date have attracted investments of USD 14.64 billion and created 40 134 job-years for South African citizens. – The REIPPPP design elements and outcomes have been extensively analysed by IRENA in the following reports: Renewable energy auctions in developing countries (2013); Renewable energy auctions: Analysing 2016 (2017); Renewable energy auctions: Cases from sub-Saharan Africa (2018); and Renewable energy auctions: Status and trends beyond price (2019).
Small Projects IPP Procurement Programme (SP-IPPPP)	2013	– The SP-IPPPP was designed for small-scale biomass, biogas, landfill gas, onshore wind and solar PV projects, with simplified rules to decrease participation costs.
Carbon Tax Act	2019	– The act implemented a carbon tax of ZAR 120 per ton of CO_2-equivalent emissions in 2019. In a first phase, industry-specific tax-free emissions allowances will allow current emitters to gradually transition to energy efficiency, renewables and other low-carbon measures. The second phase is expected to have higher taxes, depending on an impact assessment of the first phase, and will run from 2023 to 2030 (Gathright, 2019; Duncan, 2019; SARS, 2020).

Table 21 – Summary of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector in South Africa

4.2 Prospects for renewable power towards 2040

IRENA has analysed South Africa's power system as part of a regional study on the Eastern and Southern Power Pools conducted under the framework of the Africa Clean Energy Corridor (ACEC). IRENA assessed the prospects of different technology options, trade among EAPP and SAPP countries, emissions of carbon dioxide, and total system costs, benefits and opportunities. The conclusions from this regional study, along with its methodologies and assumptions, can be found in IRENA's upcoming report on planning and prospects for renewable power in Eastern and Southern Africa. The analyses of South Africa in this and the following sections are excerpts from IRENA's assessment of the two power pools. The analyses assess the economic potential for higher uptake of renewable energy in the country, in relation to the regional power system.

IRENA has also analysed South Africa's energy system to the year 2030 as part of its forthcoming Renewable Energy Prospects: South Africa study in collaboration with the Department of Mineral Resources and Energy and SANEDI, along with other stakeholders. The report concludes that there are significant benefits to an accelerated energy transition and explores both the challenges (such as an aging grid infrastructure and the adoption of new business models) and opportunities (such as improving energy efficiency in energy-intensive industries and increasing energy access) presented by this transition. It also offers recommendations for measures to enable the transition.

4.2.1 Methodology and assumptions

Solar and wind resource potential and zoning analysis: IRENA assessed the renewable energy capacity potential in Southern and Eastern Africa through a geospatial analysis (IRENA and LBNL, 2015b). Potential utility-scale project zones were defined as land areas characterised by adequate resource quality and promising cost estimates. In South Africa, a total of 416 zones were identified for wind, solar PV and CSP (Figure 18). Solar PV and CSP zones are processed from the Renewable Energy Development Zones (REDZs) identified by CSIR. Their total capacities and average capacity factors are displayed in Table 22. Out of these zones, 40 solar PV and wind zones were shortlisted (with 64 MW of solar PV) to be modelled in the SPLAT-ACEC, based on their prospective generation profiles and distances to load centres. Since this study, more REDZs have been identified to provide power in areas where coal power stations would be decommissioned and where new renewables could make use of existing grid and road infrastructure. While IRENA has not considered these REDZs specifically in its modelling, additional renewable options beyond existing zones with slightly lower capacity factors are considered as generic options to be explored.

[46] Based on IRENA's repository of knowledge on policies and measures.

	Wind	Solar PV	Solar CSP
Total number of identified zones	276	65	75
Theoretical total capacity (GW)	305	124	79
Capacity factor – weighted (%)	35	24	51
Shortlisted number of zones	22	18	-
Capacity (MW)	26 175	38 006	-

Table 22 – Characteristics of project zones

SPLAT-ACEC model: IRENA applied the in-house SPLAT-ACEC model for the analyses of South African power systems as well as other countries in the ACEC. The modelling tool used was MESSAGE software (IAEA, 2017).[47] It employs a cost-minimisation algorithm to identify the cheapest electricity supply mix and transmission infrastructure for meeting estimated demand.

For South Africa, assumptions were derived from the country's power sector data and summarised in Table 23.

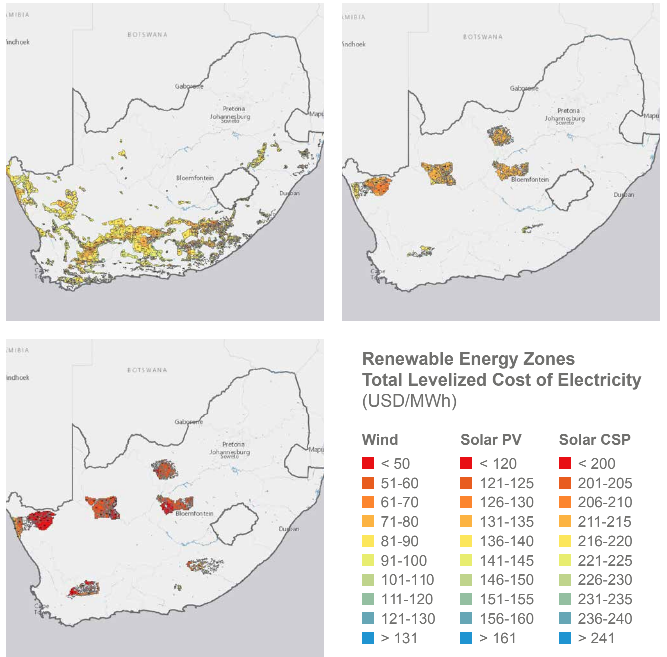


Figure 18 – Solar PV and solar CSP zones
Note: Boundaries and names shown on this map do not imply any endorsement or acceptance by its Authors.

Assumption	Description	Sources
Electricity demand projection	382 TWh in 2040	SAPP Master Plan (SAPP, 2017b).
Load profile	Details in IRENA's forthcoming planning report on Eastern and Southern Africa (IRENA, forthcoming)	IRENA – collected under zoning analysis in 2015 (IRENA and LBNL, 2015b).
Renewables potential (MW)[48]		Solar PV and wind: zoning analysis (IRENA and LBNL, 2015b). Hydropower and geothermal: SAPP Master Plan (SAPP, 2017b). Pumped storage: IRENA research. Biomass: IRENA biomass studies (IRENA, 2014b; 2014a).
Solar PV	38 006	
Solar CSP	700	
Wind	26 175	
Hydropower	738	
Pumped storage	2 912	
Biomass	1 268	
Geothermal	0	
Existing and planned generation projects (GW)		SAPP Master Plan, renewables calibrated to 2019 PLATTS and IRENA. data (IRENA, 2020f; Platts, 2019; SAPP, 2017b).
Existing	52.2	
Committed	10.3	
Candidate	8.7	
Existing and planned cross-border transmission lines (MW)	Details in IRENA's forthcoming planning report on Eastern and Southern Africa (IRENA, forthcoming)	SAPP Master Plan, World Bank-funded and Aurecon-led SAPP-EAPP Interconnector Impact study (Aurecon, 2018; SAPP 2017b).
Fuel costs projections (2017 USD/GJ)	(2015 → 2040)	SAPP Master Plan (SAPP, 2017b).
Coal	3.1 → 3.7	
Diesel	10.7 → 21.8	
HFO	7.3 → 14.9	
Natural Gas	9.1 → 13.7	
CAPEX projections to 2040	Details in IRENA's forthcoming planning report on Eastern and Southern Africa (IRENA, forthcoming)	Solar PV and wind: IRENA cost data, zoning analysis. Other technologies: EAPP Master Plan. Transmission: World Bank-funded and Aurecon-led SAPP-EAPP Interconnector Impact study.

Table 23 – Summary of IRENA's assumptions in the SPLAT-ACEC model

[47] Developed by the International Institute for Applied Systems Analysis (IIASA) and adapted by the International Atomic Energy Agency (IAEA) for national energy planning purposes.
[48] This is not an upper limit of the total potential in the country. Solar PV and wind – capacity identified in zones; hydropower – planned and existing hydropower projects; geothermal – planned and existing geothermal projects. In addition to the potential identified, generic options are also modelled so it is possible for there to be more capacity of a technology than presented here.

Electricity access rates in South Africa are already high, with about 90 percent of the population having access. As the IRP on which the SAPP and IRENA assumptions are based already accounts for future grid-connected demand from electrification, IRENA makes no further projections on the rates of electrification. More details on the assumptions, methodologies and data are described in depth in IRENA's upcoming planning report on the renewables' prospects in Eastern and Southern Africa.

4.2.2 IRENA electricity capacity expansion scenarios

For the analysis of South Africa and other Eastern and Southern African countries from a regional perspective, scenarios for the power sector were constructed through a capacity expansion analysis to reach a cost-optimal generation mix in 2040, using the SPLAT-ACEC model. It used two scenarios:

- **The High RE** scenario describes the trajectory of the regional power supply mix to 2040, with the intention of presenting a more ambitious view of renewables deployment than in the SAPP Master Plan. It does not include any specific renewable energy penetration targets or CO_2 reduction targets. Only currently identified projects for cross-border interconnector expansion are considered. In the scenario, renewable energy reaches 63 percent of the regional generation mix by 2040.
- **The Regional Target** scenario sets a target for regional VRE penetration of 50 percent by 2040, which is higher than the VRE share of 36 percent in the high RE scenario.[49] This scenario explores the levels of regional trade and investment needed to meet that target.

The results of scenarios are summarised in Figure 19 and Table 24.

Figure 19 – Generation, imports and capacity in the High RE and Regional Target scenarios

[49] Since this is a regional constraint, with trade, not all countries would have to reach 50 %.

		High RE		Regional target	
		2030	2040	2030	2040
Capacity (GW)	Solar PV – utility	15.5	31.8	17.1	38.0
	Solar thermal	0.7	0.7	0.7	0.7
	Wind	9.0	26.2	11.7	26.2
	Large hydropower	0.6	0.0	0.6	0.0
	Biomass	1.2	1.3	1.2	1.3
	Diesel	2.9	3.6	2.9	3.6
	Natural gas	5.9	25.0	5.9	25.0
	Nuclear	1.8	1.8	1.8	1.8
	Coal	31.3	17.6	31.3	17.6
	Pumped storage	2.9	2.9	2.9	2.9
	Total (incl. storage)	**71.8**	**110.9**	**76.1**	**117.1**
Generation and imports (TWh)	Solar PV – utility	33.5	65.7	36.9	80.2
	Solar thermal	2.2	2.2	2.2	2.2
	Wind	28.6	79.5	36.4	79.6
	Large hydropower	0.3	0.0	0.3	0.0
	Biomass	6.9	7.4	6.9	7.4
	Diesel	1.4	1.6	1.3	1.6
	Natural gas	7.9	27.7	5.4	26.8
	Nuclear	13.4	13.4	13.4	13.4
	Coal	214.8	125.1	214.8	125.1
	Imports	23.5	61.9	15.0	58.3
	Pumped storage	0.7	5.0	1.3	4.1
	Total (incl. storage)	**333.2**	**389.5**	**333.9**	**398.6**[50]

Table 24 – Capacity and generation mix in South Africa in the High RE and the Regional Target scenarios

South Africa has some of the most economically viable solar PV and wind zones in the SAPP and EAPP, and IRENA's analysis shows that high levels of RE deployment are economically sensible and attainable. The cost-optimal pathway for South Africa features high levels of renewable penetration in 2040: 49 percent in the High RE scenario and 51 percent in the Regional Target scenario. As 80 percent of existing coal power plants (28 GW) retire,[51] renewables are expected to fill the resulting supply gap, driven by competitive costs. Electricity production from renewables reaches 160 TWh in the High RE scenario (66 TWh of solar PV and 80 TWh of wind). Solar PV capacity reaches 32 GW, followed by wind at 25 GW.

IRENA's analysis modelled 40 solar PV and wind zones. Of these, 37 would be deployed by 2040. The top three solar PV zones alone would cumulatively generate 26 TWh in 2040, with 12 GW of capacity, and would offer cost-optimal deployment. For wind, the largest zone in South Africa would provide close to 6 TWh, with 1.8 GW of capacity in 2040.

In addition to generating electricity domestically (mainly from solar PV, wind and coal in the two scenarios), South Africa is the largest importer of electricity in the region. Net imports in 2040 would be 62 TWh in 2040 in the High RE scenario and 48 TWh in the Regional Target scenario, up from about 20 TWh in 2020.

Regional integration would make it possible to boost the utilisation of renewable energy in South Africa, for example, if South Africa and the Democratic Republic of the Congo (DRC) were linked with new cross-border interconnectors (such as a high voltage DC line from the Grand Inja dam on the Congo River to Merensky in South Africa). In both IRENA scenarios, transmission infrastructure that allows at least 2.5 GW of direct trading between the two countries would be cost-effective.

In the High RE scenario, CO_2 emissions from electricity production would peak in 2026, then drop to 138 Mt in 2040, well below the 2020 level of 252 Mt. That trajectory is in line with "Peak-Plateau-Decline" CO_2 emissions goals that South Africa has committed to. Most of the remaining emissions would be from coal. Further reductions would be necessary to meet the ambitions of the Paris Agreement.

IRENA's High RE scenario, however, shows much higher renewables penetration and greater emissions reductions than does the SAPP Master Plan. Despite using the same demand projections, the SAPP plan presents a coal-dominated future, with up to 90 percent of domestic generation provided by coal in 2030. The plan grossly underestimates the economic potential of renewables, especially solar PV and wind. In comparison, IRENA's cost-driven analysis shows that renewables can provide 23 % of domestic generation (72 TWh) by 2030, much more than the 4-5 percent (16 TWh) projected in the SAPP Master Plan.

[50] This sum is higher than domestic demand.
[51] Since 2015.

IRENA's High RE scenario also projects a higher level of solar PV in 2030 than the IRP's Emerging Long-term Plan. Both analyses have similar forecasts for demand (332 TWh in High RE and 320 TWh for IRP's median scenario) and for total generation capacity (68 GW in High RE and 73 GW in IRP[52]). But IRENA's scenario projects 7 GW more solar PV capacity by 2030 than the IRP (at 8.3 GW). Total RE capacity would be similar, however, as the IRP favours wind power (18 GW) over solar PV. This is primarily because IRENA has adopted a much more optimistic learning rate for solar PV compared to the IRP, based on the IRENA's database of renewables costs.

The key message from IRENA's analysis is that wind and solar PV offer cost-competitive replacements for coal.[53] In the IRENA scenario, the share of coal in total capacity in 2030 would drop to about 45 percent (31 MW), despite the addition of 6 GW of committed capacities between 2019 and 2022, and the combined wind and solar PV share would rise to nearly 35 percent. The IRP comes to a similar conclusion about the amount of coal capacity, at 33 MW.

4.2.3 Investment needs

In the High RE scenario described above, domestic demand increases by 50 percent from 2020 to 2040, and generation capacity would more than double. Building that new capacity would require USD 110 billion (in 2015 dollars) in capital investments in IRENA's cost-optimal pathway (with a renewables penetration of 49 %). Most of those investments are for solar PV (USD 27 billion), wind (USD 30 billion) and natural gas (USD 26 billion). Figure 20 shows the yearly investment costs and the cumulative investments between 2020 and 2040. The additional 6 GW of solar PV in the Regional Target scenario would require USD 3 billion in additional investment.

About two percent of the capital investments (USD 1.8 billion) would be the transmission costs of connecting renewable projects to the grid.

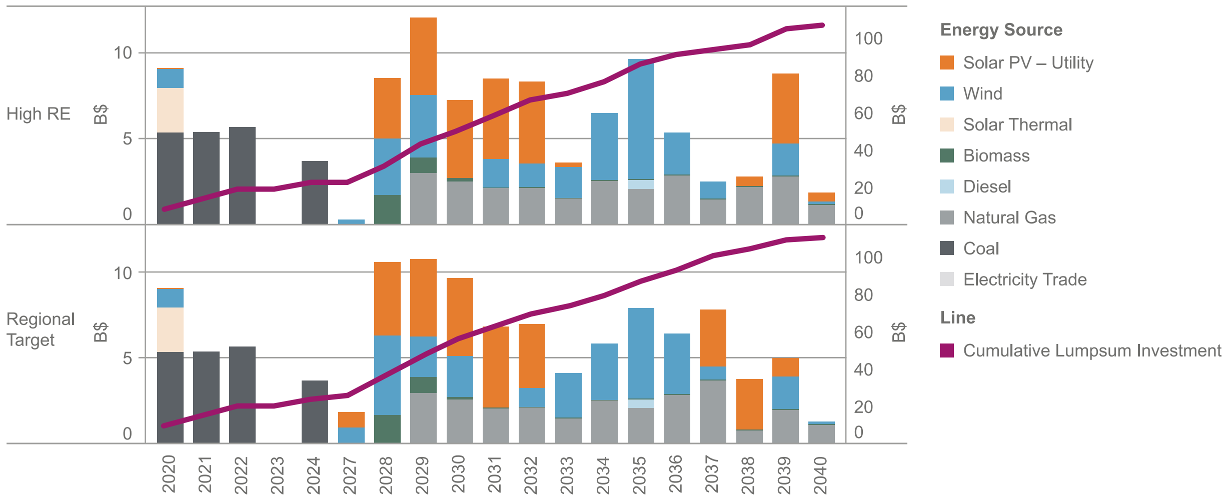


Figure 20 – Yearly system cost and cumulative lumpsum investment cost between 2020 and 2040

In 2040, the annualised capital investment cost (USD 19 billion) would make up the largest share of the overall system cost,[54] which would increase from USD 23 billion/year to USD 31 billion/year from 2020 to 2040, using a discount rate of 10 percent. The next largest system costs would be fuel (USD 7 billion) followed by O&M costs (USD 5 billion). The total system cost[55] from 2020 to 2040 would be about USD 563 billion in the High RE scenario and USD 567 billion in the Regional Target Scenario.

As total traded volume (mostly imports) reaches 63 TWh in 2040, 4.5 GW of new cross-border transmission would arrive online between 2020 and 2040. Of that, 2.5 GW will be on exchanges with the DRC. Table 25 summarises the investment costs for cross-border transmission.

Cross-border transmission	Cost (million USD)
South Africa-DRC	4736
South Africa-Zimbabwe	84
South Africa-Botswana	81
South Africa-Namibia	289

Table 25 – Investment costs (million USD) of cross-border transmission between South Africa and neighbouring countries

4.3 Systemic innovation needs and opportunities

Achieving the high share of renewable power generation in South Africa as shown in IRENA's long-term planning scenarios will require a fundamental paradigm shift and a comprehensive systemic approach to innovation. Key steps in this direction are already sketched out in the Roadmap for Eskom in a Reformed Electricity Supply Industry, which would put Eskom[56] on a new, liberalised path (Republic of South Africa, 2019b) that would see functions like generation, transmission and distribution be separated. Such "unbundling" would further open the door for innovation.

[52] In the scenarios modelled in the IRP, as compared to the final Emerging Long-term plan, installed capacity by 2030 is slightly higher at 78 GW.
[53] In IRENA's analysis, 30 GW out of the 40 GW of total new capacity is cost driven; pipelined projects represent only 10 GW.
[54] It may be noted that the annualised investment cost is significantly higher than the average of total investment costs. This is due to the high discount factor applied (10 %). In addition, the annualised investment cost accounts for the entire modelling horizon including the period 2015-2019, the results of which are not presented in this section.
[55] It should be noted that these system costs do not capture all potential investment needs in such a large-scale transition. The following chapter will also discuss emerging innovations which could have a significant influence on investment needs and overall system costs.
[56] With pre-tax losses of ZAR 29 billion in 2019 (USD 1.76 billion), Eskom is accused of "systemic dysfunction" with "remarkably high" OPEX and CAPEX (Power Futures Lab, 2019). For a comparison between the German and South African power sectors, see: GIZ (2018).

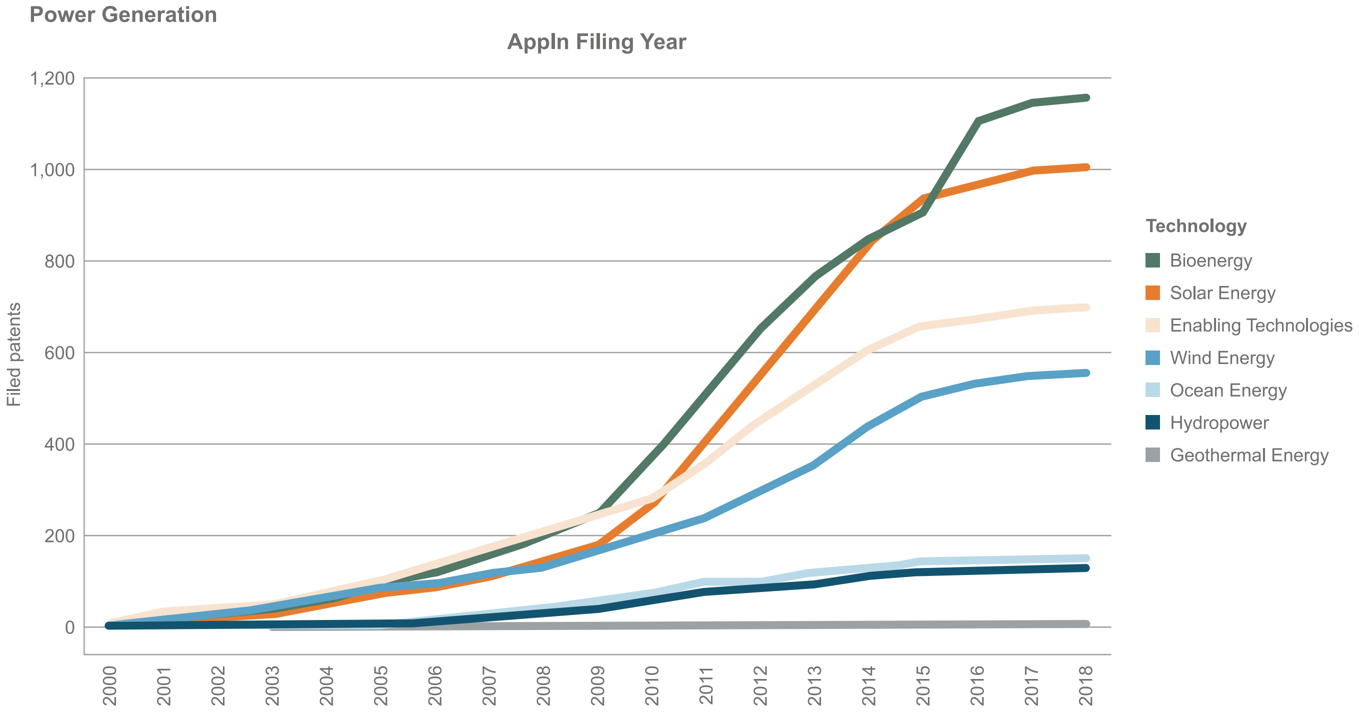


Figure 21 – Cumulative patents filed for the power sector by South Africa (2000-2018)

Source: (IRENA, 2020d)

The large number of patents filed for the power sector between 2000 and 2018 (Figure 21) shows that innovation in the sector is already flourishing in South Africa.

Overall, South Africa's strong intellectual property position means that the country may be able to develop new power sector technologies (such as renewable power-to-hydrogen) locally instead of having to incur technology transfer costs, thus bringing additional socio-economic benefits. Some of the key innovations identified as relevant for South Africa in a preliminary assessment are shown in Figure 22.

New paradigm of the energy supply chain in South Africa

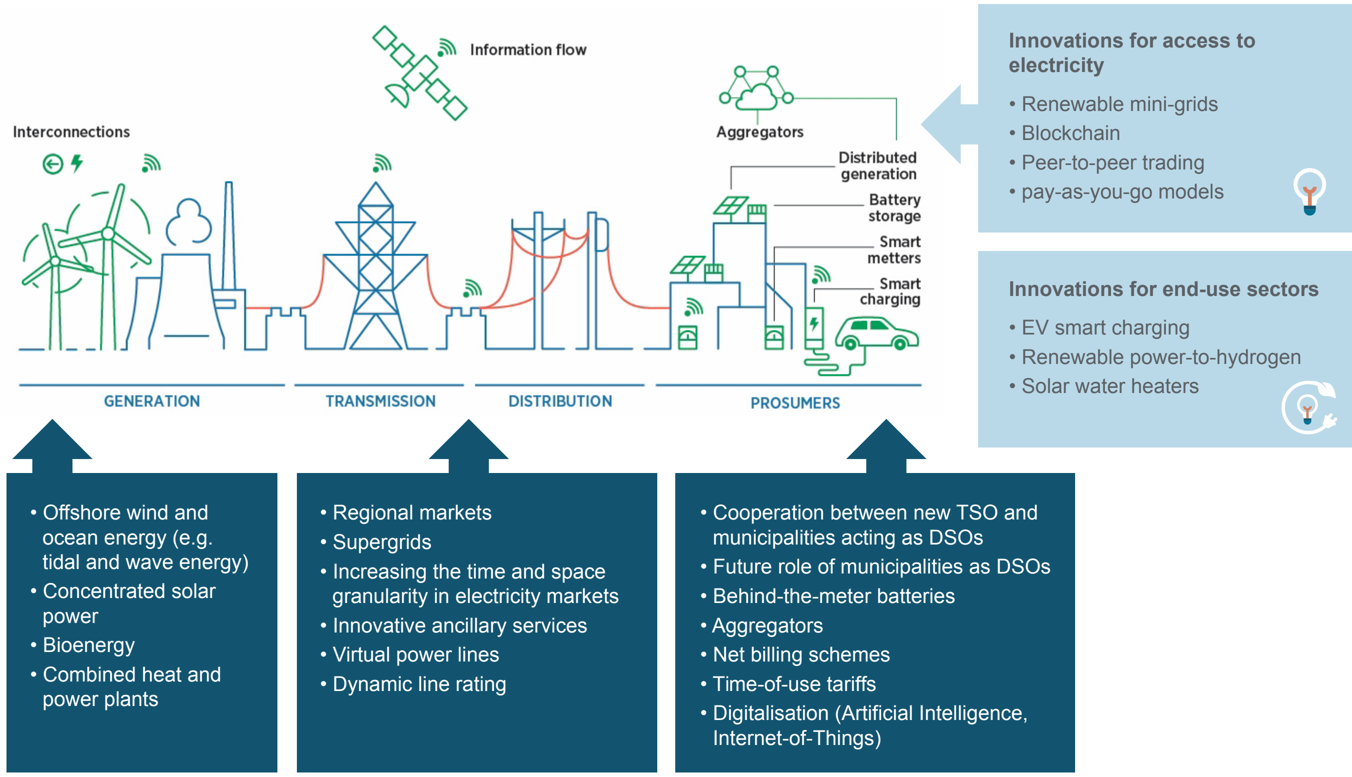


Figure 22 – Innovations to be considered for a future renewable power sector in South Africa

4.3.1 Innovation to support a renewable power system

Innovative renewable power generating technologies addressing generation adequacy concerns

Power generating technologies like solar PV and onshore wind are already mature and abundant, and have experienced rapid declines in costs. Additional renewable power generating technologies that could be harnessed with minimal grid investments[57] include offshore wind and ocean energy, bioenergy and combined heat and power (CHP) plants from sugar mills and the pulp and paper industry[58].

These generating resources can often be coupled with utility-scale batteries to make greater use of the renewable resource and to increase flexibility.

These technologies could address generation adequacy concerns and help prevent power cuts like those on 11 February 2019, when a load of 4 000 MW had to be shed[59] (IRENA, DoE and SANEDI, forthcoming), in addition to reducing power sector carbon emissions.

Shifting towards innovative system operations and a regional market design to address grid congestion

South Africa's power sector is dominated by a vertically integrated utility, Eskom, which has a quasi-monopoly in both power generation and transmission (including cross-border electricity trades). However, new actors such as independent power producers (IPPs), are emerging and more are expected if the liberalisation process is implemented effectively.

It is also possible to unlock the flexibility provided by the regional market by investing in new transmission lines or "super grids" and further harmonising trading rules. For example, hydropower in the DRC could help balance VRE generation in South Africa. Additional flexibility can come from increasing both the space[60] and time[61] granularity in electricity markets both for long- and short-term trading.

Currently, one of the biggest challenges facing the South African power sector is grid congestion, which caused about USD 1 billion in lost value for wind and solar projects between 2017 and 2019 (Financial Review, 2019). Solutions that can be rapidly implemented include new system operation practices, such as "virtual power lines" that use batteries at both sides of a congested transmission line or "dynamic line rating", where transmission line capacities are varied according to weather conditions.

Decentralisation with "embedded generation" and new roles for South African municipalities

Distributed energy resources (DERs), such as rooftop solar and "behind-the-meter" batteries[62], have key advantages that are accelerating their growth. Also called "embedded generation", they can be built quickly, avoiding the long lead times and high capital investments needed for traditional transmission infrastructure, and costs are falling rapidly.

The increasing deployment of DERs could allow South Africa's 180 local municipalities to take on new roles as system operators, in addition to their current role as DSOs.

Enabling this new role, however, requires more cooperation between the utility Eskom and the municipalities. One step forward, therefore, is the unbundling roadmap set by the Government in 2019 for Eskom, which will allow the municipalities to procure electricity from embedded generation, from licenced municipal generators or from a newly established Transmission Entity (TSO).

In addition, digital technologies like artificial intelligence, big data and the Internet-of-things, along with smart meters (starting to be piloted in South Africa) and time-of-use tariffs, can enable new business models. Aggregators could bundle demand and supply from distributed resources, for example, and demand response capabilities could be marketed.

Blockchain, renewable mini-grids and innovative business models for universal access to electricity

Renewable mini-grids, blockchain technology, peer-to-peer trading and pay-as-you-go business models for solar water heaters and solar home systems could also provide alternatives to investments in costly transmission networks, while providing energy to the three million households now without access to grid-based electricity (Republic of South Africa, 2019a).

For example, blockchain technology has been piloted in South Africa since 2016. Through a crowdfunding initiative, students at the Waldorf School in Stellenbosch were able to purchase and lease solar cells to power the school, and are paid in a digital currency called "SolarCoin" that can be converted into hard currency for each MWh of solar generation (Tech Central, 2017). However, there is little space for innovations like this in the current regulatory framework.

[57] While transmission grid expansion benefits from public acceptance, decentralised energy resources are being welcomed by financing institutions in South Africa in the post-pandemic context (ESI Africa, 2020).
[58] In 2015, CHP capacity in pulp, paper and sugar mills amounted to 350 MW (IRENA, 2020).
[59] Load shedding is a persistent problem in South Africa with an estimated total of 1 350 GWh of demand shed in 2019 (South Africa's Energy Transition, 2020).
[60] For example, increasing space granularity in a zonal market design like the SAPP can help reduce re-dispatch costs and drive investments where most needed by defining zones at the sub-national level, instead of treating the entire country like one single zone. In such pricing zones, market participants are able to trade energy without capacity allocation; i.e. the zone is considered to have no grid congestion and trade is therefore not limited by the transmission network (IRENA, 2019b).
[61] For example, shorter time granularity refers to trades in the intraday market timeframe reduced from one hour (at present) to sub-hourly products (30 or 15 minutes) (IRENA, 2019c).
[62] Types of DERs can be clustered into: distributed generation (e.g. rooftop solar PV plants); behind-the-meter batteries; smart charging electric vehicles (EVs); demand response mechanisms; and renewable power-to-heat (e.g. heat pumps) (IRENA, 2019).

4.3.2 Innovations for renewables-based electrification of end-use sectors

Transport

The transport sector is the highest energy-consuming sector in South Africa. The key opportunity to increase the use of renewable energy in the sector is the direct electrification of light-duty transport with electric vehicles (EVs), along with the use of fuel cell electric vehicles (FCEVs) for heavy-duty transport.

In 2018, the Department of Transport of South Africa launched the Green Transport Strategy (GTS) 2050, which aims to reduce GHG emissions from the transport sector by five percent by 2050. The GTS encourages the use of electric vehicles and clean transport fuels, as well as cheaper and more reliable transport options to enable people to shift from private vehicles to public transport. It also aims to support renewable hydrogen production.[63]

Industry

The industry sector is the second largest energy-consuming sector. In the subsector of bulk chemicals and mining, renewables could be used either as sources of power or feedstock, for example to produce "green" hydrogen and its derivatives from renewable electricity via renewable "power-to-hydrogen" technology.

Beyond that, there is an opportunity for South Africa to become a major player in a new global green hydrogen economy (World Bank, 2020d), exporting green hydrogen to countries like Japan and European Union nations. GIZ is already planning an international renewable power-to-X[64] project that includes South Africa, Morocco and Argentina (Mining Weekly, 2020).

Buildings

In the buildings sector, municipalities in South Africa are already requiring that new homes have solar water heaters installed instead of electric ones. Consumers are voluntarily replacing their electric systems with solar water heaters to reduce their electricity bills (Republic of South Africa, 2019a).

Renewable mini-grids and DERs, coupled with digital technologies, including the underlying "smart" infrastructure (like smart meters) could enable the electrification of buildings with renewables. However, any electrification strategy with renewables should also be accompanied by energy efficiency measures.

4.4 Conclusion and areas for further consideration

IRENA's analysis shows that South Africa has a very large potential for renewable electricity generation, making it possible to replace much of the current dominant coal generation and significantly decarbonise the power sector.

Not only are the solar PV and wind resources in South Africa of high quality, but recent declines in renewable costs make deployment of those resources economically viable and even cost optimal.

As a result, South Africa could generate 43 percent of its electricity from renewable sources by 2030.

The total investment required would be USD 563 billion (2015 dollars) through 2040. This is in the same magnitude as an investment of USD 349 billion projected in South Africa's NDC to decarbonise the power sector between 2010 and 2050.[65]

It is commendable that South Africa has pledged to reach peak emissions by 2025, and IRENA's analysis shows that with a 2026 peak it is possible that the decline in emissions will begin immediately thereafter.

Additional decarbonisation can be accomplished through greater imports of electricity generated from renewables. Fifteen percent of South Africa's domestic demand could be met through imports, with a significant amount coming from hydro production in the DRC. Enhanced regional integration of South Africa with other SAPP countries, as well as connections with East Africa through the Clean Energy Corridor, will not only cost-effectively serve domestic demand, it also will enable the use of trade as a balancing mechanism, especially with high shares of variable renewable sources.

Decarbonisation is not the only goal, however. The energy transition must also be just and inclusive, especially given South Africa's reliance on coal for three quarters of its total primary energy supply, making it a significant source of export revenue and employment. A just and inclusive transition must broadly share positive outcomes, such as new employment opportunities, while limiting adverse effects like jobs losses in the coal industry and other disappearing sectors.

South Africa is a pioneer in designing policies to support a just and inclusive energy transition, such as the economic development criteria used in the REIPPPP to award projects. The country has put job creation and the development of local industry at the forefront of its renewable energy development plans, focusing on both racial- and gender-related social justice (IRENA, 2019g).

[63] "HySA Infrastructure" at North West University in Potchefstroom focuses on hydrogen generation, storage, transport, codes and standards, and is piloting a project producing renewable hydrogen and derivatives from solar PV plants to be used as transport fuel (Department of Transport, n.d.). "HySA Systems" and "HySA Catalysis" are the other hubs that constitute the "HySA programme".
[64] "Renewable power-to-X" refers to "renewable power-to-hydrogen" and "renewable power-to-heat" technologies.
[65] There are nuances within this comparison: it is unclear which costs are included in the NDC. Also similar to the NDC, the numbers clarify the order of magnitude of investment requirements and should not be taken as precise investment guidelines.

Thus, the REIPPPP, as a deployment instrument, has been interlinked with enabling policies that aim to minimise the risk of individuals and communities being left behind. These include industrial, labour market, financial and education policies, as well social protection measures.

For example, the REIPPPP established a 40-45 percent requirement for local content spending to leverage and enhance domestic industrial capabilities. This requirement has boosted local manufacturing and helped create a small export industry of solar PV and wind turbine components. Stable long-term deployment policies and regional coordination can continue to expand the market for exported equipment.

Moreover, the REIPPPP has contributed to Broad-Based Black Economic Empowerment and the creation of black industrialists. In an important step forward, the REIPPPP has enabled black South Africans to own, on average, 33 percent of projects that have reached financial close, and black local communities to own nine percent. Similarly, the shares of procurement from "Broad-Based Black Economic Empowered", "Qualifying Small Enterprises" and "Exempted Micro Enterprises" suppliers have exceeded the REIPPPP targets and bidders' commitments. Nevertheless, the involvement of women-owned businesses is lagging and continuing efforts are needed to ensure female participation in the energy transition (Republic of South Africa, 2019b).

Labour policies have also enabled renewable energy projects to promote new employment opportunities. The first four rounds of the REIPPP created more than 100 000 job-years for local citizens, of which almost 85 000 were for black citizens and almost 58 000 job-years were for members of local communities (Eberhard and Naude, 2017). That surpassed the REIPPPP's job creation targets (DoE, 2018b). Nevertheless, most of the labour supplied by black citizens was short-term (McDaid, 2016), which is not a path to sustainable development. Therefore, there is a need for stable long-term deployment plans, for social protection policies for income stability (such as unemployment insurance), and for flexible, longer-term employment contracts. Measures are also needed to provide support for vulnerable workers and their communities, such as incentives for employers to retain (and retrain) workers where possible. Such measures are especially important in South Africa to ensure that workers in vulnerable industries like coal do not shoulder an unfair burden of the energy transition. Moreover, those policies also need to be complemented with education and skills development policies for the industry to absorb and retain the newly created workforce.

The South African experience shows both successes and challenges in ensuring a just and inclusive energy transition. For instance, creating sustainable and meaningful jobs requires more than simply meeting the short-term labour requirements of renewable energy project developers (Baker and Wlokas, 2014), and foreign developers may not have the on-the-ground networks or community liaisons required to build a stable workforce (Wlokas, 2015). It is also difficult to increase the participation of women in the energy sector, despite establishing preferential rules.

But these challenges can be met with continuing political support for programmes like the REIPPPP that have socio-economic objectives beyond procuring electricity at the lowest price. Furthermore, stakeholders' involvement, along with mechanisms to enable feedback loops that allow to test and adapt a set of different solutions, can increase the chances of successful policy implementation (Andrews, Pritchett and Woolcock, 2017).

Another set of challenges centre around increasing the pace and scope of innovation, making it possible to go beyond technologies like onshore wind and solar thermal and PV to promising new approaches like renewable power-to-hydrogen.

The first step is to develop far-sighted policy frameworks that anticipate future power system needs, such as South Africa's Roadmap for Eskom in a reformed electricity supply industry. Such policy frameworks can promote investments in technology-driven innovative solutions and in creating the necessary infrastructure.

A more important additional step is updating national and regional plans to reflect the latest technological-driven innovations in the power sector, along with the falling costs in more mature renewable power generating technologies and other enabling technologies, such as batteries, EVs, smart chargers and demand-side response technologies. For example, South Africa has yet to fully take into account the potential of decentralised resources, given their declining costs and increased competitiveness.

South Africa could also take greater advantage of possible couplings between sectors and innovations beyond conventional power system operation practices. For example, the country is in a unique position to contribute to the creation of an international manufacturing industry for fuel cells using its mineral resources and its abundant renewable energy sources. It also could become a major exporter of green hydrogen that could be used to help decarbonise European economies (European Commission, 2020a). Germany, for example, is planning to invest EUR 2 billion directly in potential export countries to help establish a global market for green hydrogen (BMWi, 2020a).

5 Morocco country analysis

Key messages

Morocco is already a pioneer in solar electricity generation, with the largest CSP plant in the world. It also has achieved universal access to electricity and put in place ambitious goals for reducing the current dominance of coal and increasing the share of renewable energy, along with policies to ensure that the energy transition is just and inclusive. IRENA's analysis, furthermore, shows considerable additional potential. The country has enormous economically viable solar and wind resources, enough to add close to 6 800 GW of solar PV capacity and 190 GW of wind capacity. As a result, Morocco could not only generate close to 100 percent of its electricity from renewable sources by 2040, it would also have enough renewable power to become a global leader in producing green hydrogen and other green products for export and domestic use. However, current programmes that have socio-economic objectives beyond procuring electricity at the lowest price need political support to continue promoting a just and inclusive transition.

5.1 Status quo of the power sector in Morocco

5.1.1 Brief introduction of the overall energy landscape

In 2017, Morocco's total primary energy supply (TPES) stood at 859 PJ (Table 26). Nearly 90 percent of this was fossil-based, and 96 percent of the fossil fuels were imported. The domestic primary energy supply was 76 PJ, of which 97 percent came from renewable sources: solid biofuels[66] (53 PJ); wind (11 PJ); solar thermal (4.5 PJ); and hydro (4.3 PJ).

In the same year, Morocco's total final energy consumption (TFEC) was 653 PJ, with renewables accounting for an 11 percent share (Table 27). Direct use of renewables is predominantly in the form of biomass – primarily solid biofuels and charcoal.

However, the country has massive renewable resources, particularly solar and wind, and is beginning to rapidly ramp up their utilisation. The 510 MW Noor-Ouarzazate plant in central Morocco is the world's largest concentrated solar power plant (CSP), for example. It also has an additional 72 MW of solar PV capacity.

The transport sector is the leading final energy consumer, accounting for 37 percent of TFEC, followed by the residential sector (25 %) and the industry sector (21 %).

Electricity consumption has steadily grown at an average growth rate of 4.4 percent per year since 2010. In 2017, per capita annual consumption was 945 kWh per person (IEA, 2019c). which is lower than Morocco's North African neighbours (IEA, 2019c). Electricity use was 18 percent of TFEC, close to the global average of 19 percent, but was higher in the commercial sector (at 37 %) and the industrial sector (at 31 %). Significant potential exists to increase the use of electricity in the residential and transport sectors, replacing solid biofuels and oil products (IEA, 2019c).

Energy-related CO_2 emissions in 2017 were 70 $MtCO_2e$, nine percent higher than in 2012. Electricity and heat generation emissions in 2017 were 22 $MtCO_2e$, of which 80 percent was from power generation with coal (IRENA, 2020g).

	Coal and coal products	Crude, NGL and feedstocks	Oil products	Natural gas	Hydro	Solar thermal	Wind	Industrial waste	Primary solid biofuels	Electricity	Total
Total TPES	186	0.2	533	43	4	5	11	3	53	21	**859**
Production	0	0.2	0	3	4	5	11	3	53	0	**79**
Net imports	188	0	568	40	0	0	0	0	0	21	**817**
Others	-2	0	-35	0	0	0	0	0	0	0	**-37**

Table 26 – TPES in 2017 in PJ Source: (IEA, 2019c)

	Coal and coal products	Oil products	Natural gas	Industrial waste	Solid biofuels	Charcoal	Electricity	Total
Total TFEC	0.8	478.6	2.6	0.0	0.1	0.0	116.8	**653.4**
Industry	0.8	88.5	2.6	3.0	1.3	0.0	42.6	**138.7**
Transport	0.0	240.5	0.0	0.0	0.0	0.0	1.3	**241.8**
Residential	0.0	105.7	0.0	0.0	22.2	0.5	39.5	**167.8**
Commercial and public services	0.0	6.2	0.0	0.0	27.5	0.1	20.1	**53.9**
Agriculture/forestry	0.0	37.8	0.0	0.0	0.0	0.0	13.4	**51.2**
	0 %	73 %	0 %	0 %	8 %	0 %	18 %	**100 %**

Table 27 – TFEC in 2017 in PJ Source: (IEA, 2019c)

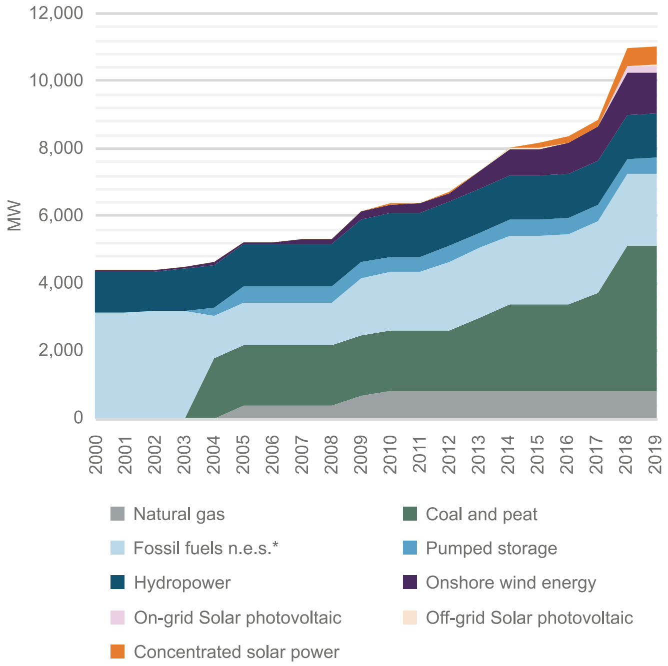
[66] Defined in IEA statistics as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes and other solid biofuels).

5.1.2 Electricity generation and use

Morocco generates 66 percent of its electricity from coal, and more new coal capacity (1.38 GW) was added between 2017 and 2018 than new renewable capacity (350 MW of solar CSP; 180 MW of solar PV; and 200 MW of wind).

Still, the renewable share in generation rose from 15 percent in 2018 to 20 percent in 2019, as renewables crowded out generation from existing oil and natural gas-fuelled plants (see Table 28 and Figure 23). Renewable generation capacity in 2019 was 3.2 GW out of a total of 10.9 GW, with 1.3 GW of hydropower, 1.2 GW of onshore wind, 0.53 GW of CSP and 0.18 GW of on-grid solar PV (IRENA, 2020e).

Morocco switched from being a net importer of electricity in 2018, with net imports of 3 374 GWh, to a net exporter in 2019, with net exports of 928 GWh. Its electricity system is interconnected with Algeria and Spain, making Morocco the only North African country with a power cable linking it to the European grid (although Egypt, Libya and Tunisia are expected to be connected as well by 2025). The 1 400 MW capacity link to Spain is causing tensions, however. Spain has complained to the European Commission about Moroccan coal-fired power undercutting Spanish producers and causing "carbon leakage" because Morocco is not governed by the EU's Emissions Trading System (Rosslow et al., 2020).



Source: (IRENA, 2020e)

Figure 23 – Installed generation capacity between 2000 and 2019

	2017		2019	
	Generation (TWh)	Capacity (MW)	Generation (TWh)	Capacity (MW)
On-grid	**32**	**8 827**	**40**	**10 967**
Coal and peat	18	2 895	27	4 281
Natural gas	6	834	5	834
Oil	3	-	0.8	-
Fossil fuels n.e.s.*	-	2 122	-	2 144
Pumped storage	0.4	464	0.4	464
Onshore wind energy	3	1 023	5	1 225
Concentrated solar power	0.4	180	2	530
Hydropower	1	1 306	1	1 306
Landfill gas	0.01	2	0.01	2
On-grid Solar photovoltaic	0.001	1	0.001	181
Sewage sludge gas	0.001	0	0.001	0
Off-grid	**0.05**	**23**	**NA**	**23**
Off-grid Solar photovoltaic	0.03	23		23
On-shore wind energy	0.02	-		-

Table 28 – Electricity generation (in GWh/year)

Source: (IRENA, 2020e); *n.e.s.: not elsewhere specified

5.1.3 Access to electricity

Morocco reached full access to electricity in 2018 (World Bank, 2019c). Providing access to the rural population was a significant challenge and was mostly responsible for the steady growth of total electricity demand over the last decade.

5.1.4 National planning scenarios, NDC, and key emissions and renewable energy targets

Government plans

In its new 2019-2023 Investment Strategy, Morocco's National Office for Electricity and Drinking Water (ONEE, l'Office National de l'Electricité) plans to add 1 656 MW of wind power, 2 015 MW of solar power and a new pumped hydro project of 350 MW, along with 220 MW in small hydro plants and 22 MW of diesel generators, for a total of 4 262 MW (Les Eco Maroc, 2019a).

Morocco's rural electrification programme PERG (Programme d'Electrification Rurale Global) is also exploring photovoltaic generators, small hydro turbines, wind turbines and hybrid systems as off-grid solutions.

The country has an opportunity to be a major player in emerging world markets for Power-to-X (PtX) products like green hydrogen. Within the framework of the German-Moroccan Energy Partnership (PAREMA), Morocco's Minister of Energy has called for the creation of a national task force to prepare a roadmap for PtX (PAREMA, 2019). Meanwhile, Morocco has signed an MoU with Germany to form an alliance to develop a green PtX sector, which could include building a green hydrogen production facility of around 100 MW.

Morocco has also joined Algeria, Libya, Mauritania and Tunisia in plans to develop a regional Maghreb electricity market by 2025 (WMC, 2020).

The NDC and key emissions and renewables targets

Morocco has committed to reducing its GHG emissions by 42 percent below business-as-usual (BAU) levels by 2030. A 17 percent reduction would be achieved unconditionally, while an additional 25 percent would be dependent on international support (Kingdom of Morocco, 2016). The NDC has a target of raising the share of renewables in total installed electricity production capacity to 52 percent by 2030 (37 percent in 2019), which would require adding about 10 GW of new renewable capacity. The NDC also includes the addition of 3 900 MW of natural gas generation capacity.

In addition, the 2009 National Energy Strategy set targets of 3.1 GW of renewable generating capacity by 2020 and 7.3 GW by 2030. The 2030 targets include 5 520 MW of wind, 740 MW of CSP, 400 MW of solar PV and 400 MW of biomass.

A summary of key national emissions/renewable energy targets is presented in Table 29.

Target	Target year	Document	Note
52 % of electricity generation capacity by renewables (20 % wind power, 20 % solar power and 12 % hydro)	2030	Nationally Determined Contribution	This plan includes the installation by 2030 of additional 3 900 MW natural gas generation capacity.
Additional capacity of 4 262 MW, of which 4 240 MW is based on RE (includes 1 656 MW of wind power, 2 015 MW of solar power, a new pumped hydro project of 350 MW with a capacity of 220 MW in small hydraulic plants	2019-2023	Investment Strategy Plan	Includes also 22 MW of diesel generation.
Reducing GHG emissions by 42 % below business-as-usual (BAU) levels	2030	Nationally Determined Contribution	Specifically, a 17 % reduction would be achieved unconditionally, whereas an additional 25 % reduction is proposed if international support is available
Reaching 42 % of total installed power capacity from renewable energy	2020-2030	National Energy Strategy	For 2030, the below targets were set for different types of renewably sourced power generation: wind 5 520 MW, CSP 740 MW, Solar PV 400 MW and Biomass 400 MW.

Table 29 – Summary of key national emissions/renewable energy targets

5.1.5 Overview of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector[67]

The table below provides an overview of the key policy instruments, regulations and measures that have supported the renewable energy targets and priorities discussed above.

Name	Launched	Details
Law 16-08	2008	– Self-generation, including from renewables, was allowed. Also, private generation capacity limits were increased from 10 to 50 MW, and self-generators could also sell surpluses to Office National de l'Electricité et de l'Eau Potable (ONEE). – In 2015, Law 54-14 broadened self-generation rules by allowing self-producers to complete private transactions among each other, and they were also granted access to ONEE's transmission network.
Renewable Energy Development Law (Law 13-09)	2009	– Partial opening of the retail activity to allow consumers to bilaterally contract energy from renewable IPPs in a "free market", but only at high voltage and very high voltage grids. – Regulated suppliers had an obligation to provide the renewables' consumers with back-up energy.
Decree 2-09-410	2009	– Stipulated the creation in 2010 of the Energy Investment Company (Société d'Investissement Energétique [SIE]). SIE finances, invests and develops renewable energy (and energy efficiency) projects and programmes.[68]
Law 58-15	2015	– An amendment to Law 13-09 allowed renewable IPPs to sell surpluses to ONEE or to a distribution system operator. – Foresaw the opening of the low and medium voltage networks to renewables. Decree 2-15-772 concerned access to the national medium voltage network (see below). No decree has been drafted for low voltage networks as of mid-2020.
Decree 2-15-772	2015	– Introduced a progressive opening of the medium voltage network to renewables, but it has faced resistance from incumbent distribution companies (Usman and Amegroud, 2019).
Law 48-15	2016	– Created the National Electricity Regulatory Authority (ANRE) to be responsible for: 1) defining the electricity market's commercial and technical rules; 2) the adoption of a grid code and grid access rules; and 3) establishing methodologies for network and retail tariffs.
Law 37-16	2016	– The Moroccan Agency for Sustainable Energy (MASEN) was strengthened to conduct activities related to renewable resource assessments, generation capacity planning (together with ONEE) and deployment, as well as promoting local industries, R&D and capacity building in the renewable energy sector.
Auctions	2011	– Morocco is among the pioneers of renewable energy auctions. EPC auctions of wind and hydro projects began in 2004. The first renewable generation auctions resulting in PPAs date back to 2011 for on-shore wind and 2012 for solar thermal projects. – The country has auctioned 510 MW of CSP through three rounds and 72 MW of solar PV in a fourth round for the Noor Power Station. – In 2019, Morocco auctioned the world's first advanced hybrid of CSP and PV (800 MW). – These auctions have resulted in global record low prices; but perhaps more noteworthy is the high degree of localisation accomplished. – The developers' commitments in the bids regarding local labour and materials were higher than the minimum levels specified in the initial auction documents. In fact, in the fourth round, the commitments doubled the threshold level. – IRENA has extensively analysed the renewable energy auctions' design elements and outcomes in Morocco in the following reports: Renewable energy auctions in developing countries (IRENA, 2013); Renewable energy auctions: Analysing 2016 (IRENA, 2017); and Renewable energy auctions: Status and trends beyond price (IRENA, 2019g).
Net-metering	2015	– Morocco introduced a net-metering scheme for solar PV and on-shore wind plants to sell their surplus – no more than 20 percent of their annual production – to the high-voltage grid. Those connected to the middle- and low-voltage levels should be eligible at a later date.

Table 30 – Summary of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in Morocco

5.2 Prospects for renewable power towards 2040

IRENA developed two scenarios to assess renewable energy potential in Morocco. They show a very large solar and wind resource, with a total resource capacity potential of 6 985 GW. If Morocco followed the more ambitious scenario, the country could generate 90 percent of its electricity from renewable sources by 2040 and could produce 4-5 percent of the world's green hydrogen.

5.2.1 Methodology and assumptions

Demand projections: electricity demand grew at an average 5.7 percent per year from 2003 to 2018, but the rate slowed to 4.4 percent per year during the 2010-2018 period. With universal access achieved by 2018, future demand growth will be driven by population increases, economic development and higher living standards, including the growing use of space cooling and other electricity-intensive appliances, although demand growth will also be moderated by efficiency improvements.

[67] Based on IRENA's repository of knowledge on policies and measures.
[68] The Institute for Research in Solar Energy and Renewable Energy (IRESEN) was created in 2011 by the Ministry of Energy, Mining, Water and Environment, but no law or decree was found in that regard. IRESEN is a research institute focused on supporting the national energy strategy by conducting research on solar energy and new energy technologies.

To project future demand, IRENA assumed economic growth would continue at a similar rate as in recent years. The projections show electricity demand growing 3.8 percent per year from 2020 to 2040 (with growth faster in the first decade than in the second), reaching 83 TWh/year by 2040 (Figure 24). The possible increased demand from electric vehicle use was not included.

In particular, electricity demand during summer days is expected to climb, helping to drive the growth of solar power due to the match in timing between such demand and solar generation.

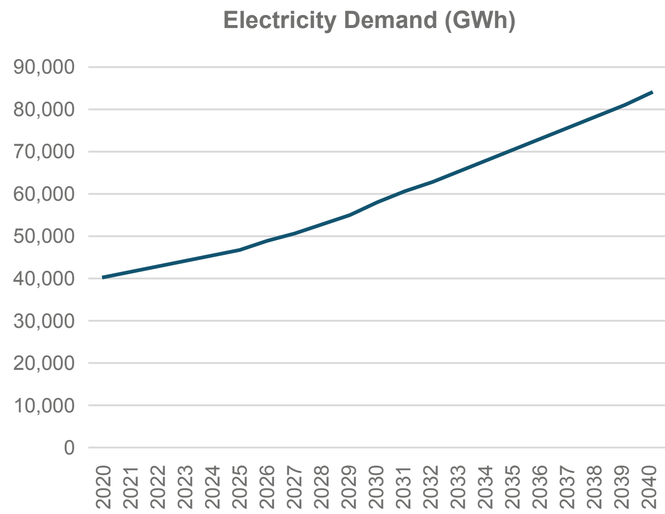


Figure 24 – Electricity demand projection 2020-2040

	Wind	Solar PV	Total
Total number of identified zones	190	252	**442**
Theoretical total capacity (GW)	188	6 797	**6 985**
Weighted average capacity factor (%)	44.4	24.8 (without tracking: 21.6 %)	-

Table 31 – Summary of Morocco's solar PV and onshore wind zones

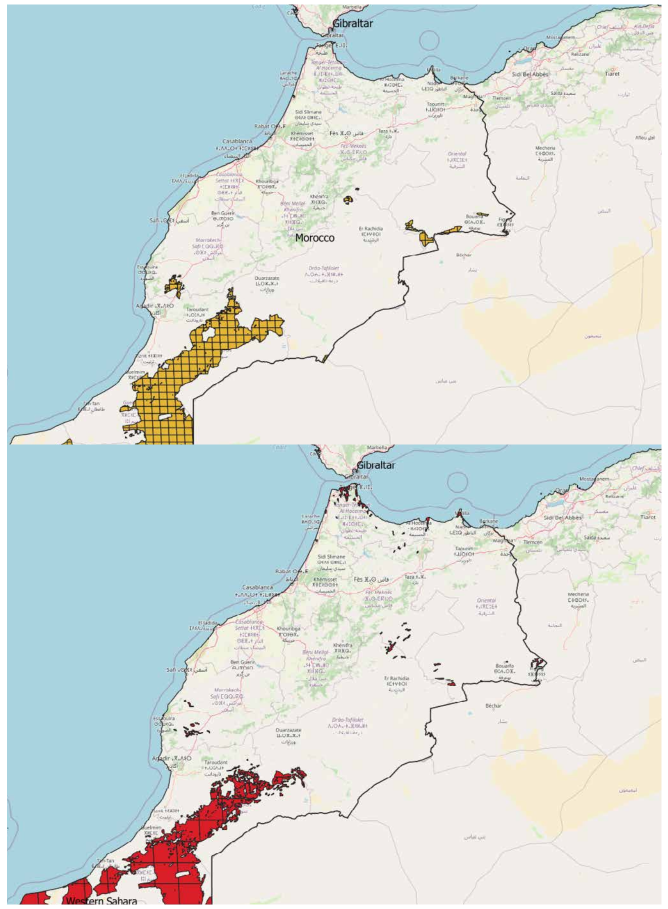


Figure 25 – Examples of solar PV (top) and onshore wind zones (bottom) in IRENA's assessment for Morocco
Note: Boundaries and names shown on this map do not imply any endorsement or acceptance by its Authors.

Renewable energy resource potential: IRENA analysed project-sized solar PV and wind zones, and identified 442 zones with economic potential, with a total potential capacity of 6 985 GW (Table 31). The zones have been ranked based on capacity factors and distance to transmission lines. Figure 25 shows their locations.

SPLAT model: IRENA applied the in-house SPLAT model for the analysis, with assumptions derived from Morocco's power sector data (Table 32).

Assumption	Description	Sources
Electricity demand projection	83 TWh in 2040	IRENA estimates based on ONEE.
Load profile	2010 Load profile	
Existing and planned generation projects (GW)	Existing: 10 443 MW (2019) Committed: 4 263 MW (until 2023)	ONEE annual reports and ONEE master plan 2019-2023.
Existing and planned cross-border transmission lines (MW)	Morocco-Spain: 1 400 MW Morocco-Algeria: 2 900 MW	COMELEC, Bulletin Statistiques du COMELEC, 2016.
Fuel costs projections (USD 2017/GJ)	(2015 → 2040) (2015 USD/GJ) Coal: 2.7 → 2.5 Diesel: 12.3 → 17.6 HFO: 9.2 → 13.1 Natural gas: 6.2 → 8.8	IRENA estimates based on the historical correlation between fuel import prices in Morocco and international indexes and US EIA projections for Brent prices.
CAPEX projections to 2040	Wind: USD 807/kW Solar PV: USD 442/kW Solar CSP: USD 1 760 /kW	IRENA estimates.

Table 32 – Summary of IRENA's assumptions for Morocco's SPLAT model

5.2.2 IRENA electricity capacity expansion scenarios

Two cost-optimal capacity expansion scenarios for the Moroccan electricity system were constructed and analysed to 2040 using the SPLAT model.

- **The Reference Scenario** assumes demand growth similar to the historical trend and achieves the national targets for renewables share and GHG emissions reductions. Electricity trade with Spain continues, but without any expansion of interconnection capacity.
- **The Hydrogen Production Scenario** assesses the potential for production and export of PtX, and specifically of green hydrogen. The scenario assumes hydrogen electrolyser investment costs of USD 896/kW in 2017 and USD 580/kW in 2025; operations costs of three percent of initial investment costs per year; a conversion efficiency of 64-70 percent (or approx. range of 50 TWh per Mt of H_2); and a minimum electrolyser capacity factor of 50 percent (IRENA, 2019a; 2018a).

Scenario results are shown in the following figures and tables.

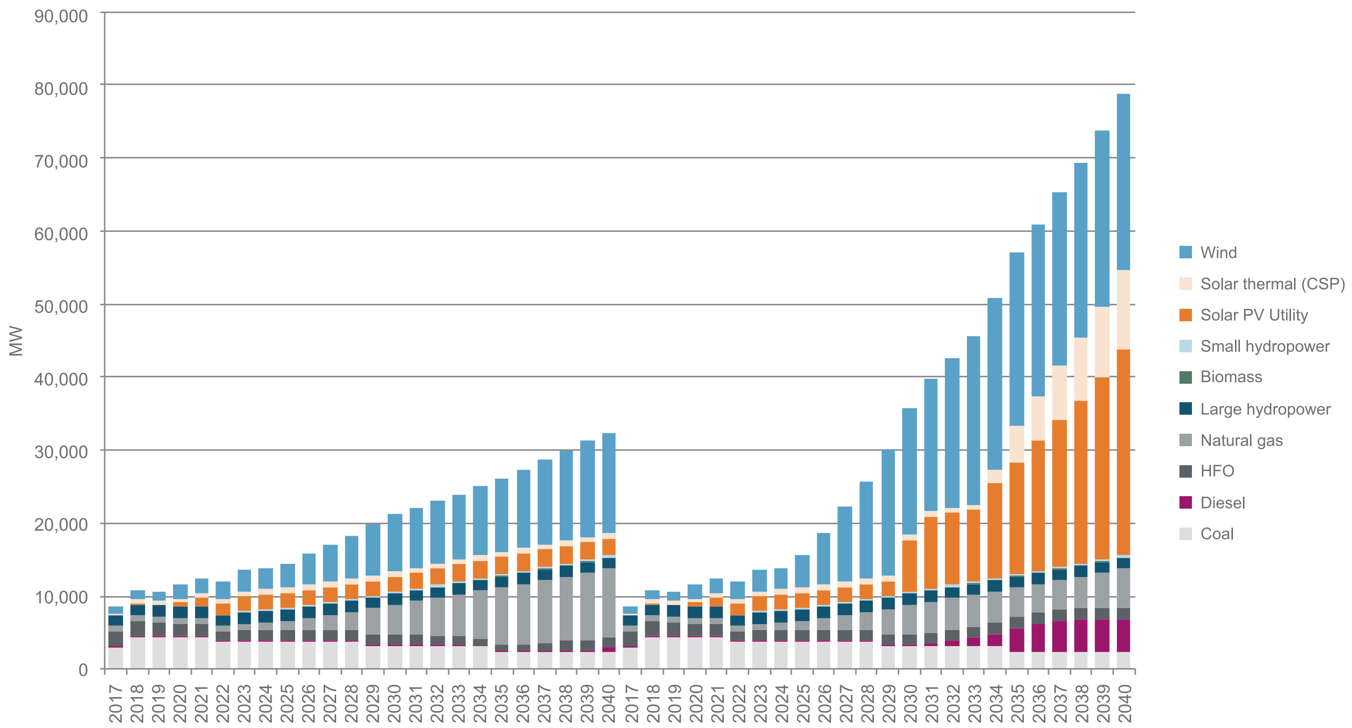


Figure 26 – Installed electricity generation capacity in Morocco for the Reference and Hydrogen production scenarios, 2017-2040

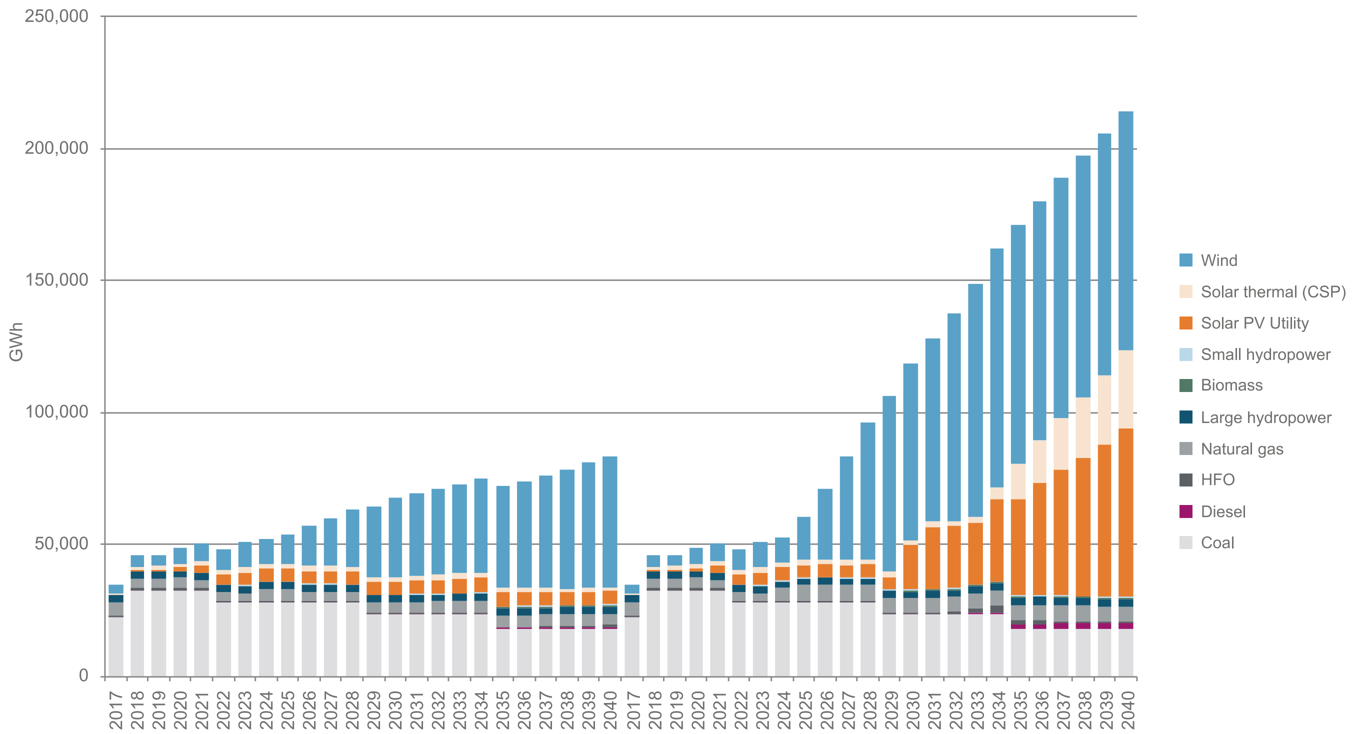


Figure 27 – Electricity generation in Morocco for the Reference and Hydrogen production scenarios, 2017-2040

Reference Scenario		2019	2025	2030	2035	2040
Total installed capacity	GW	10	14.4	21.3	26.2	32.3
Total fossil fuel capacity	GW	6.3	6.7	8.9	11.2	13.7
Total RE capacity	GW	3.7	7.7	12.4	15	18.6
Solar PV capacity	GW	0.18	2	2	2.3	2.3
Solar CSP capacity	GW	0.5	0.7	0.7	0.7	0.7
Wind power capacity	GW	1.2	3.1	7.8	10	13.7
Other renewables	GW	1.8	1.9	1.9	2	1.9
RE share in capacity	%	37 %	53 %	58 %	57 %	57 %
Total electricity generation	TWh	40	53.6	67.7	72	83.2
Imports	TWh	0	0	0	0	1.7
Exports	TWh	0.9	6	8.1	0.069	0
Electricity to hydrogen production	TWh	0	0	0	0	0
RE share in generation	%	21 %	38 %	58 %	68 %	71 %
Hydrogen production	Mt	0	0	0	0	0
Emissions	MtCO$_2$e	22	29.3	24.6	19.7	20.4
Hydrogen production scenario		**2019**	**2025**	**2030**	**2035**	**2040**
Total installed capacity	GW	10.0	15.6	35.7	57.0	78.7
Total fossil fuel capacity	GW	6.3	6.7	8.8	11.3	13.7
Total RE capacity	GW	3.7	9.0	26.9	45.7	65.0
Solar PV capacity	GW	0.18	2	7	15.35	28.2
Solar CSP capacity	GW	0.5	0.7	0.7	4.93	10.88
Wind power capacity	GW	1.2	4.45	17.35	23.63	24.023
Other renewables	GW	1.8	1.8	1.8	1.8	1.9
RE share in capacity	%	37 %	57 %	75 %	80 %	83 %
Total electricity generation	TWh	40	60.29	118.35	171.21	214.23
Imports	TWh	0	0	1.14	11.36	9.7
Exports	TWh	0.9	7.12	0	0	0
Electricity to hydrogen production	TWh	0	8.7	60.98	110.8	138.6
RE Share in generation	%	21 %	43 %	75 %	84 %	88 %
Hydrogen production	Mt	0	0.1	1.2	2.2	2.7
Emissions	MtCO$_2$e	22	29.6	25.1	21.9	21.4

Table 33 – Scenario results, 2019-2040

Key insights from the results include:

In the Reference scenario:

- Total installed capacity reaches 32.3 GW in 2040 and is dominated by wind (13.7 GW) and natural gas (9 GW), with solar power at 3 GW (Figure 26). The renewables share of installed capacity reaches 58 percent in 2030 and 57 percent in 2040, higher than Morocco's NDC target of 52 percent by 2030, and total generation reaches 83 TWh in 2040. Renewables share in electricity generation reaches 38 percent in 2030 and 71 percent in 2040 (Table 33).
- Total installed capacity would need to more than double from 10 GW today to 21 GW by 2030 (Table 33).
- Natural gas generation would be used mainly to meet demand peaks, while coal capacity would mostly contribute to baseload demand, with no further deployment of coal capacity. Coal imports would decline due to increased efficiencies of modern coal power plants.
- Flexibility options like utility-scale storage and larger interconnection capacities with neighbouring countries were not considered.

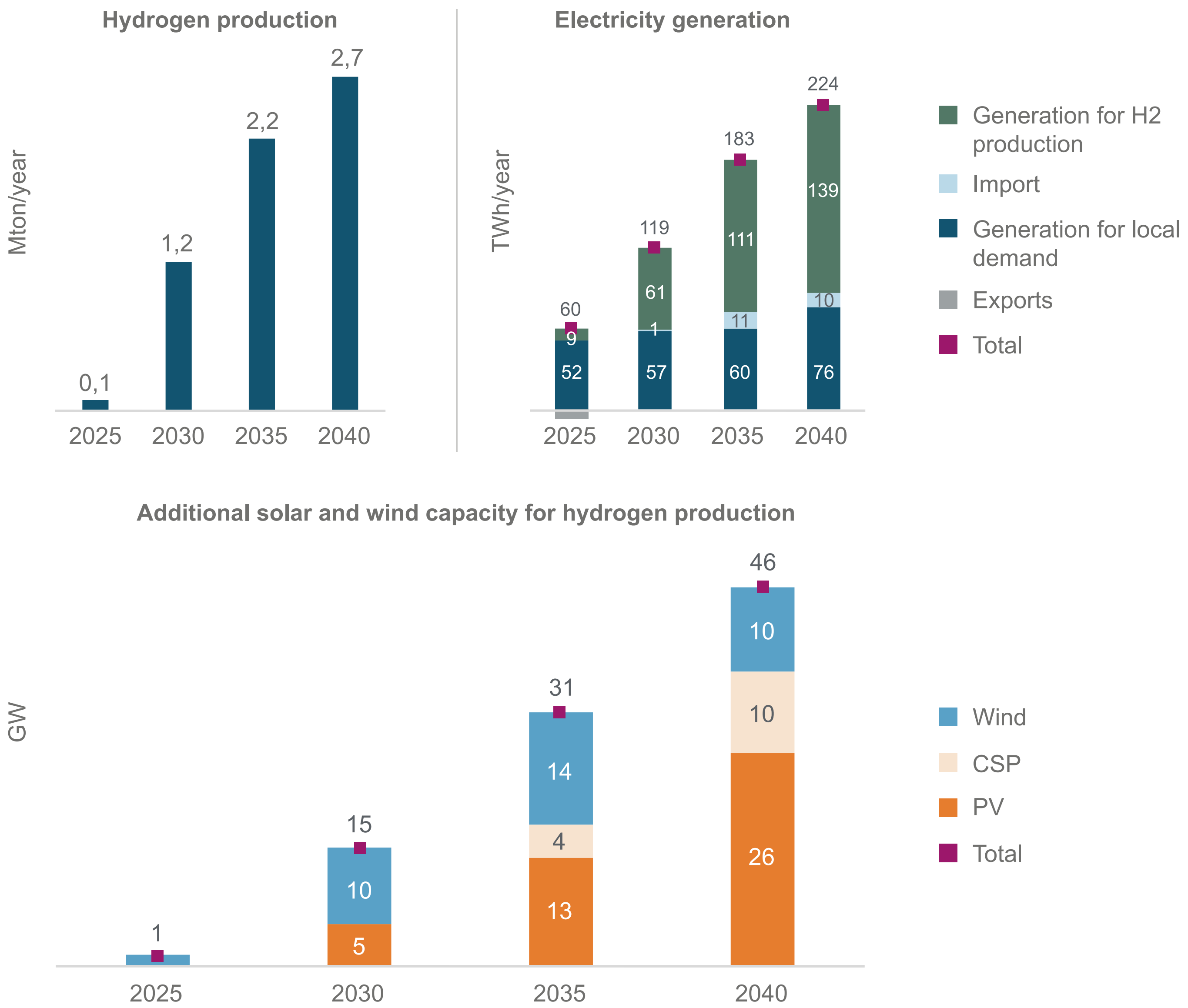


Figure 28 – Hydrogen production (top left), electricity generation (top right) and additional solar PV, CSP and wind capacity 2025-2040 (bottom)

In the Hydrogen Production scenario:

- Total installed capacity reaches 78.7 GW by 2040 and is dominated by solar PV (28.2 GW), wind (24 GW) and CSP (10.8 GW) (Figure 26). The renewables share of installed capacity reaches 75 percent in 2030 and 83 percent in 2040, also higher than Morocco's NDC target of 52 percent by 2030 and higher than the shares in the Reference scenario (Table 33). Total generation reaches 214 TWh in 2040, with 10 TWh of imports (Figure 27). Renewables share in electricity supplied to the grid climbs to 75 percent in 2030 and 88 percent in 2040.
- By 2030, total installed capacity would need to almost quadruple to 35 GW. That would include 15 GW of new RE capacity (10 GW of wind and 5 GW of solar PV) used to produce green hydrogen (Table 33).
- Morocco could produce 1.2 Mt of green hydrogen per year by 2030, about 4-5 percent of projected global demand (IRENA, 2020b). Europe would be the expected initial customer (Figure 28).
- Hydrogen exports would rise to 2.7 Mt in 2040, requiring a staggering 139 TWh of electricity, or 65 percent of the total generation of 214 TWh (Table 33).
- While most of the hydrogen would be exported, some could be processed locally into green methanol or green ammonia, which could be used to supply the fertiliser industry.

In both scenarios, GHG emissions decline from about 29 $MtCO_2e$ in 2025 to about 25 $MtCO_2e$ in 2030 and 21 $MtCO_2e$ by 2040, which is slightly lower than current levels (Table 33).

5.2.3 Investment needs

The substantial increases in new renewable energy capacity in both scenarios would require cumulative investments of USD 27 billion (2015 dollars) in the Reference scenario and USD 72 billion in the Hydrogen Production scenario between 2020 and 2040 (Table 34).

In addition, the Hydrogen Production scenario would require an estimated additional investment of USD 8-10 billion for 16 to 18 GW of electrolyser capacity by 2030 or USD 20-22 billion for 36-38 GW of electrolyser capacity by 2040 (Table 34).

Scenario	Thermal	Hydro and pump storage	Biomass	PV	CSP	Wind	Total power generation	Electrolyser for H_2
Reference	9.1	0.9	0.2	2.7	1	13.4	27.1	0
Hydrogen Production	9.1	1	0.2	14.8	21.7	24.9	71.7	20-22

Table 34 – Investment needs for power generation and electrolyser capacity 2020–2040 (in billion 2015 USD)

5.3 Systemic innovation needs and opportunities

Morocco is a leader in renewable energy in North Africa, with ambitious targets and farsighted policies that put the country at the forefront of the energy transition.[69] The country ranks fourth globally in electricity generation from thermal solar technologies, for example, behind Spain, the United States and South Africa (IRENA, 2020a).

Morocco is also a leader in new innovations in the power sector, as shown by the growing number of patents filed in the sector between 2000 and 2017 (Figure 29). The large majority of these cover aspects of solar power, such as ground-mounted or tracking solar systems. Indeed, 82 percent of the total number of patents filed have been in the power sector. The patents also include advances in such enabling technologies as thermal energy storage, hydrogen and other forms of energy storage (IRENA, 2020d).

This remarkable track record on patents both reflects the rapid pace of power sector innovation in Morocco and can help the country avoid or reduce its dependence on technology transfer as it continues to expand the development of renewable power. With continued innovation, there are opportunities for Morocco to reach 100 percent renewable energy by mid-century and to develop breakthrough technologies like renewable power-to-X, and especially renewable power-to-hydrogen. Figure 30 shows the specific innovations that have been identified as important in enabling Morocco to meet those goals in the coming decades.

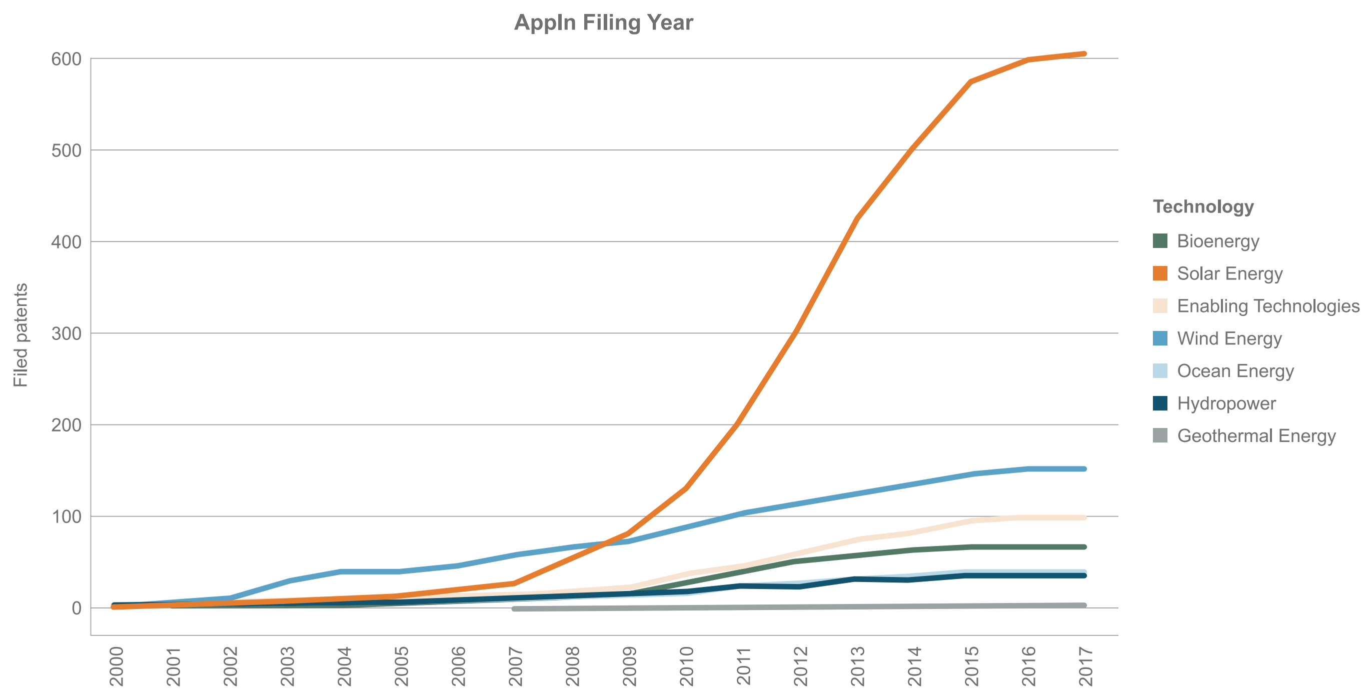


Figure 29 – Cumulative patents filed for the power sector by Morocco (2000-2017) Source: (IRENA, 2020d)

[69] Morocco has a dedicated "Green Energy Park" which has investigated – among other questions – the impact of intermittent solar energy on electrolysers and renewable power-to-X processes focused on solar PV and solar thermal energy since 2017; a Green and Smart Building Park since 2019; a Bioenergy-TIC and Storage Park; as well as a joint Morocco-Côte d'Ivoire Energy Park focusing on solar PV and solar thermal since 2018 (IEA, 2019b). More recently, Morocco announced the establishment of a dedicated power-to-X research platform together with partners from academia and industry (Siemens Energy, 2020).

New paradigm of the energy supply chain in Morocco

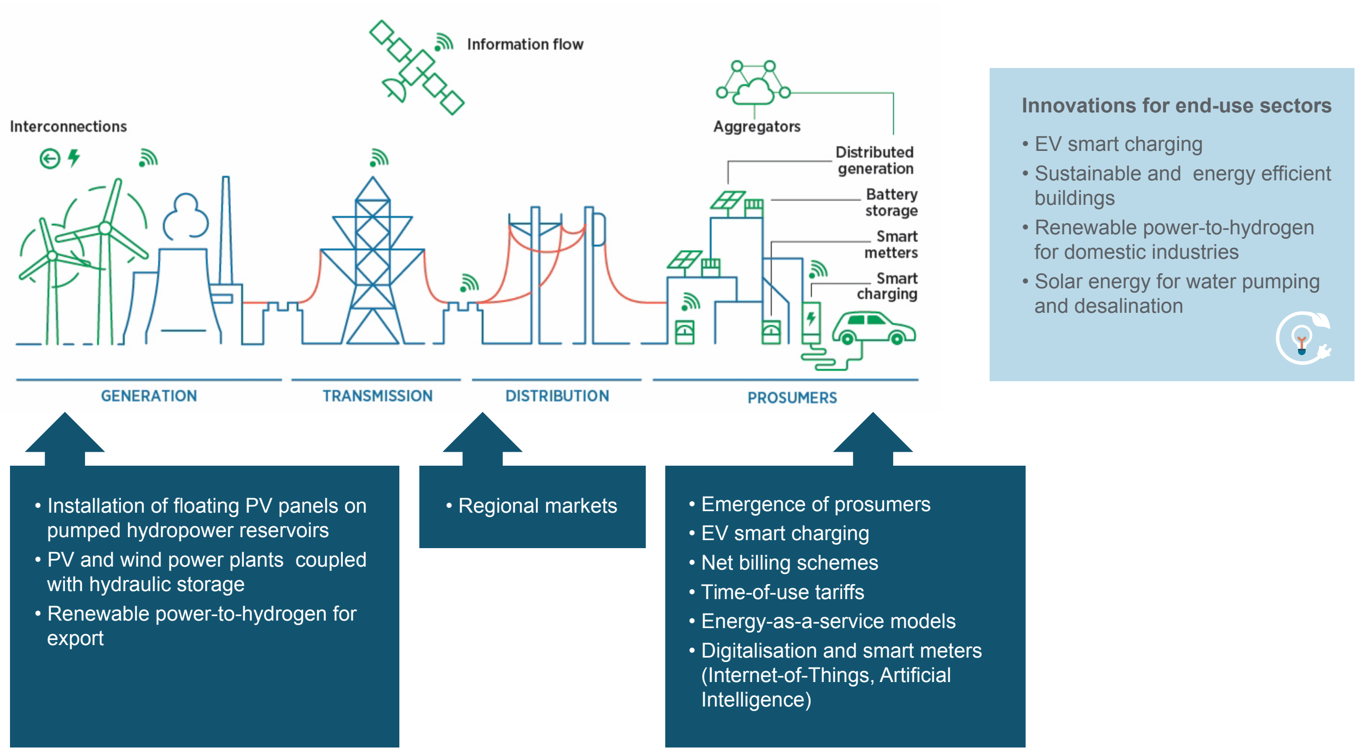


Figure 30 – Innovations to be considered for a future renewable power sector in Morocco

5.3.1 Innovation supporting a renewable power system

Innovations that allow greater utilisation of Morocco's abundant renewable resources, including solar CSP, PV, floating PV, onshore wind and hydropower technologies[70]

Morocco has a high average solar irradiation of 5.3 kWh/m2/day[71] and average wind speeds ranging from 6 to 10 m/s. The country has already taken advantage of these resources with projects like the NOOR-Ouarzazate solar project. With 510 MW of CSP and 72 MW of PV, it is the largest CSP facility in the world[72]. Morocco can now capitalise on the lessons learned from the Ouarzazate complex to accelerate implementation of the remaining project plans[73] and to initiate new projects.

One promising innovation is equipping planned pumped hydropower plants, such as the El Menzel (300 MW) and Ifahsa (300 MW) stations, with floating solar PV panels. The PV panels could share the grid connection, reducing the costs of installation (IRENA, 2020c), while the hydraulic storage can supply electricity during evening peak hours (Hydropower & Dams International, 2020).

Another innovative approach is producing hydrogen with surplus solar or wind energy, as in Africa's first hybrid renewable energy/hydrogen facility at Al Akhawayn University in Ifrane, which uses power generated by three wind turbines to produce electrolytic hydrogen when electricity demand is low.

Increasing regional electricity trade to enhance flexibility

Today, electricity trade with Algeria and Spain[74] adds power system flexibility. Further flexibility could come from establishing a regional power market and from harmonising market rules with EU regulations to enable Morocco's participation in the 25-country pan-European electricity market[75].

Innovations to better manage distributed energy resources and to allow consumers to become "prosumers"

Moroccan policies to liberalise the power sector and "unbundle" the state-owned vertically integrated utility, ONEE, are opening the door to new actors with innovative "energy-as-a-service" business models. These energy service providers (ESPs) can manage distributed resources, such as rooftop solar PV systems or plugged-in EV batteries, helping to unlock demand-side flexibility. Key enablers for such business models are digitalisation, smart meters and time-of-use tariffs[76].

[70] Hydropower has been in operation in Morocco for decades but there is little scope for additional large-scale hydropower projects. There is promise for the development of new pumped hydropower, the potential of which is estimated at 6 GW (IEA, 2019b).
[71] For comparison, the average solar irradiation in Germany is 2.7 kWh/m2/day.
[72] NOOR is the Moroccan Solar Energy Programme launched in 2010, implemented by the Moroccan Agency for Sustainable Energy (MASEN), comprising five solar technology complexes in Ouarzazate, Midelt, Laâyoune, Boujdour and Tata.
[73] Among the planned projects, the most advanced is NOOR Midelt (800 MW, 5h of storage, CSP and PV) which was auctioned and awarded in 2019 to a consortium of France's EDF, the Abu Dhabi Future Energy Company (Masdar) and Green of Africa. It will be funded by various public and public investors, including European national development banks (KfW, AFD), multilateral banks (AfDB, EIB) and the World Bank (ESI Africa, 2019).
[74] Morocco is interconnected with Spain via two subsea 400 kV interconnections and with Algeria via two 225 kV transmission lines. Further interconnections are planned with Mauritania and a study is being conducted to link it to Portugal (IEA, 2019b).
[75] In 2016, Morocco signed a joint declaration on the establishment of a Roadmap for Sustainable Electricity Trade Between Morocco and the European Internal Energy Market with Germany, Spain and Portugal (European Union, 2016), following which the Sustainable Electricity Trade roadmap was signed during COP22 in Marrakech to grant mutual access to the renewable electricity market. Other regional cooperation opportunities could arise within the Western African Power Pool (WAPP) once established (Morocco is not a member).
[76] Today, retail prices are regulated in Morocco and only 140 000 smart meters have been bought by ONEE (Les Eco Maroc, 2019b).

These technologies, along with additional retail market reforms, can also help turn more electricity consumers into producers as well, or "prosumers." Morocco's successful electrification programme and ONEE's Solar Home System (SHS) initiative have already put distributed energy resources, like solar PV, small hydro and wind turbines, into operation (ESI Africa, 2018). In addition, several electricity-intensive industrial consumers like mines and phosphate facilities generate some of their own electricity (IEA, 2019b). Generation by consumers could be further accelerated with the innovative policy of net billing, which allows consumers to be paid for power sent to the grid from distributed systems like rooftop PV. In the future, with more decentralised energy resources, digital technologies like artificial intelligence, big data or the Internet-of-things could spawn new business models.

5.3.2 Innovations for renewable-based electrification of end-use sectors

Transport

While Morocco has a programme to replace old, mostly diesel taxis with cleaner new vehicles (IEA, 2019b), it has not yet taken advantage of the opportunities to decarbonise transportation and increase power system flexibility with policies to encourage the adoption of electric vehicles and smart charging technologies.

The country does, however, have considerable potential to produce EVs both for export and for the local market. French carmakers Renault and the PSA group (which makes Citroën and Peugeot vehicles) already manufacture 500 000 cars per year in Morocco; both have plans to expand capacity in the country and to produce increasing numbers of EVs. In early 2020, in fact, Citroën began making an electric mini-car named Ami with a range of 70 km at its factory in Kenitra (Morocco World News, 2020).

Buildings

Morocco's Green and Smart Building Park (GSBP) initiative, launched by IRESEN in cooperation with academia and funded partially by the Korean Cooperation Agency KOICA, conducts R&D to enable "green" sustainable buildings with greater energy efficiencies and digital technologies to integrate more renewables in cities.

In addition, the Green Mosque Programme aims to improve energy efficiency and increase renewable energy use in 15 000 mosques and other public buildings. Morocco is also testing other technologies for use in the sector, such as solar and electric induction cooking stoves.

Industry

While Morocco has many thriving industry examples which could present opportunities for decarbonisation, it has the potential to be a global leader in green hydrogen production. The country is already a pioneer in renewable energy generation, especially large-scale CSP. It has a highly innovative and entrepreneurial culture. And its huge renewable resources are large enough to meet both the domestic demand for renewable electricity and the growing demand for green hydrogen in countries like Germany to decarbonise carbon-intensive industries (such as concrete and iron and steel)[77]. A new German-Moroccan green hydrogen cooperation agreement signed in June 2020 foresees that power-to-X processes like green hydrogen will be scaled up to 100 MW (Renewables Now, 2020; Siemens Energy, 2020).

Morocco is also well placed to become a key partner in other international discussions on certification schemes and international standards for green hydrogen production, drawing on lessons learned from past pilots. Those include ammonia production projects conducted with the GIZ-implemented German-Moroccan Energy Partnership (Adelphi et al., 2019).

In addition, the country could cost-effectively produce green hydrogen and other green products for domestic industries (Touili et al., 2018), such as mining and fertiliser production[78]. Green ammonia could replace imports of ammonia produced through the carbon-intensive Haber-Bosch process in fertiliser production. An estimated 3 GW of renewable generation would be needed to make 1 Mt of green ammonia, the amount of Morocco's current imports (Fraunhofer ISI, 2019).

Beyond green power-to-X innovations, Morocco is increasingly using solar energy for such end uses as water pumping and desalination, and is exploring using municipal and household waste to produce bioenergy (Afrik 21, 2019).[79]

5.4 Conclusions and areas for further considerations

Morocco's power system is currently dominated by coal and natural gas. However, the country has substantial high quality solar and wind resources that can be harnessed rapidly to decarbonise the power sector. IRENA's analysis identifies 442 zones of economically viable solar PV and wind, with the potential for an enormous 6 797 GW of solar PV capacity and 188 GW of wind capacity. Average weighted capacity factors are 25 percent for solar PV and 45 percent for wind.

In IRENA's feasible Reference scenario (which considers electricity demand growth similar to the historical average of 4 % per year), total power system capacity would grow threefold to 32.3 GW by 2040, dominated by wind at 13.7 GW. By 2030, almost 10 000 MW of new RE capacity would be added, including 6 500 MW of wind, 2 015 MW of solar PV, 350 MW of pump hydro and 660 MW of small hydro. This is considerably more than the total of 4 240 MW of new RE additions suggested in Morocco's 2019-2023 Investment Strategy.

[77] The German government expects up to 110 TWh in hydrogen demand by 2030, of which only 14 TWh can be expected to be served by domestic green hydrogen production (BMWi, 2020b), which indicates an import need for as much as 96 TWh, if all supply is to be renewable. For Germany, Morocco would be among the least-cost sources of green hydrogen, second only to Norway (Adelphi et al., 2019).
[78] Morocco has the world's largest phosphate reserves and the Moroccan public company OCP is the world's largest producer and exporter of phosphate (Touili et al., 2018).
[79] One operational bioenergy project is a 10 MW landfill biogas facility that uses municipal waste in Oujda, funded originally by the World Bank.

Natural gas would play only a small balancing role and no new coal capacity would be needed. The total investment would be USD 27 billion by 2040.

In a more ambitious Hydrogen Production scenario, Morocco would expand capacity eight-fold to 78.7 GW by 2040 in order to produce 2.7 Mt of green hydrogen per year and become a major hydrogen exporter to Europe and other markets that have ambitious targets for hard-to-decarbonise industries. That would require new additional capacity of solar PV (26 GW), wind (10 GW) and CSP (10 GW) by 2040 on top of the RE capacity additions in the Reference scenario (13.7 GW of wind, 2.3 GW of solar PV and 0.7 GW of CSP), along with 36-38 GW of electrolyser capacity (Figure 28). The total investment needed would be USD 72 billion until 2040 for power generation and USD 20-22 billion for electrolyser capacity.

Both scenarios would increase the share of renewable energy in the grid and achieve significant GHG emissions reductions in the power sector. Emissions would be 20 $MtCO_2e$ by 2040, lower than today's 22 $MtCO_2e$. Compared to Morocco's NDC's target of a 52 percent share of RE in installed capacity by 2030, the Reference scenario would reach 58 percent, and the Hydrogen Production scenario would reach 75 percent.

It is important to add that Morocco could jeopardise its own climate and renewable energy targets, as well as the additional potential identified by IRENA, by continuing coal capacity deployment or by increasing the role of natural gas. For example, LNG market expansion could flood the power sector with natural gas generation plants and undermine Morocco's opportunity to become a global leader in green hydrogen.

Morocco is leading the energy transition in North Africa in many ways, and has the opportunity to adopt additional innovations to achieve its goals and to accelerate the energy transition. Those measures include greater Integration into regional markets (both in Africa and Europe), taking advantage of synergies between rooftop solar PV panels and EVs, further unbundling electricity markets to enable new business models, and seizing the disruptive opportunity to become a major green hydrogen producer and exporter.

For example, the excellent renewable power-to-X partnership with Germany could be extended to all of the EU, given the new EU-wide hydrogen strategy established on 8 July 2020 that recognises the importance of green hydrogen for meeting Europe's "net zero" GHG target by mid-century. Morocco could also benefit from existing funding made available by European countries for the establishment of a global market for green hydrogen, such as the EUR 2 billon made available by Germany (Euractive 2020).

In addition, Morocco is already positioned as a car exporter to Europe, North Africa and, to a lesser extent, sub-Saharan African countries. With the increased expansion of manufacturing capacity and greater uptake of EVs, Morocco could become an EV leader.

The country should continue to invest in R&D and in pilot projects that demonstrate the techno-economic feasibility of renewable power-to-hydrogen technologies and EVs, with a goal of speedy commercialisation of these technologies using public-private partnerships.

As Morocco takes advantage of these opportunities, the need for a just and inclusive energy transition is especially urgent. It is encouraging, therefore, that Morocco is a pioneer in designing policies to achieve that goal.

Renewable energy auctions have been linked with industrial, labour market, education and financial policies aimed at avoiding individuals and communities being left behind. The Noor-Ouarzazate solar complex auctions were designed to contribute to the development of a domestic industry and to create economic opportunities for local communities, beyond generating electricity at competitive prices. The auctions encouraged local content and labour and remarkably, the local content commitments presented by developers were higher than the thresholds in each auction. As a result, 30-35 percent of the project's components and services were sourced locally in the first auction (Noor I) (ESMAP, 2018) and the four auctions brought employment to 6430 Moroccans (70 % of the total employed), with a third of the jobs sourced from the Ouarzazate region (IRENA, 2019g).

Long-term deployment plans, social protection policies such as unemployment insurance, and education and skills training can promote job continuity and ensure that workers in declining industries like coal can find good and meaningful new jobs. For the Noor complex, L'Agence Marocaine pour l'Energie Durable (MASEN) partnered with the Agence Nationale de Promotion de l'Emploi et des Compétences (ANAPEC) to facilitate local recruitment by training the young workforce in the region to become electrical and mechanical technicians, solar field operators and mirror cleaning operators, among other occupations (Stitou, 2019).

Other social protection measures can spread the socio-economic benefits of renewable energy projects more evenly. As compensation for land lost to the development of the Noor complex, the community received investments in basic amenities and social services, such as drainage and irrigation channels, drinking water facilities, community centres, mobile health caravans, a dormitory for female students, and sport and camp programmes for children. These investments were made instead of handing out cash compensation for the land, which would have benefited male landowners only (ESMAP, 2018).

In addition, the Noor complex has offered employment opportunities, including highly skilled positions – like topographer and welder – but also traditional activities and technical roles to women in Morocco, whose participation in the labour force is among the lowest in the world (ESMAP, 2018). Still, increasing the participation of women in the energy sector remains a challenge; even at the Noor complex, women make up only four percent of the workforce.

Challenges in finding jobs include adverse gender norms in rural areas and inadequate qualifications. Programmes like the Noor auctions that have socio-economic objectives beyond procuring electricity at the lowest price need political support to continue promoting a just and inclusive transition (IRENA, 2019g).

6 Rwanda country analysis

Key messages

Rwanda has ambitious plans to achieve universal access to electricity and increase the share of renewable power, and has been successful in bringing solar home systems to rural areas. However, the country has opportunities that support much greater ambitions. IRENA's analysis shows that 543 MW of on-grid solar PV could be cost-effectively deployed by 2040, and a number of small off-grid systems could be added in rural areas, increasing the share of renewable energy to above 60 percent. That new solar capacity would help enable Rwanda to meet its goals for both increased access and reduced GHG emissions. The country also could benefit from increasing trade with neighbouring countries and importing up to 40 percent of its energy. To follow the pathway in the analysis, however, Rwanda would need to increase the focus on solar PV in its energy planning, and promote inclusive and accessible financial instruments.

6.1 Status quo of the power sector in Rwanda

6.1.1 A brief introduction to the overall energy landscape

According to UN statistics, total primary energy supply (TPES) in the Republic of Rwanda was 99 PJ in 2017, dominated by biomass energy (85 %) followed by imported oil (13 %) and electricity (1.5 %) (Table 35). Total imports (mostly oil) make up 14 percent of the energy supply (UNSTATS, 2020).

	Oil	Natural gas	Primary biofuels and waste	Electricity	Total
TPES	13	0.7	84	1.3	**99**
Production	0	0.7	84	1	**86**
Net imports	14	0	0	0.3	**14**
Others	-1	0	0	0	**-1**

Source: (UNSD, 2020)

Table 35 – TPES in 2017 in PJ

A quarter of oil and all of the natural gas in the primary energy supply are used for power generation.

In 2017, the total final energy consumption (TFEC) was 80 PJ (UNSD, 2020). The TFEC essentially reflects the supply mix with predominantly biomass (63 %) and charcoal (23 %), followed by oil (13 %) and electricity (3 %) (Table 36).

Most of the final energy demand is in the residential sector (81 %), followed by transport (9 %) and industry (9 %) (UNSD, 2020). The dominance of the residential sector is the result of the sector's high dependence on biomass for cooking and heating (firewood in rural households and charcoal in urban households) (MININFRA, 2018).

Electricity consumption has steadily grown at an average rate of 6.1 percent per year since 1990, to the current level of 580 GWh (2.1 PJ) in 2017. The residential sector consumes 57 percent of the total electricity and the industry sector uses 25 percent (UNSD, 2020).

Currently, per capita electricity consumption is 50 kWh per person per year (UNSD, 2020; World Bank, 2019e). Overall penetration of electricity use in TFEC is as low as three percent. The commerce and public service sector is estimated to have a high penetration rate of electricity.

In 2016, total GHG emissions were about 5.8 $MtCO_2e$ (World Bank, 2020b).

6.1.2 Electricity generation and use

The total on-grid generation capacity has grown steadily from less than 50 MW in the early 2000s to 245 MW in 2017 (Figure 31) (IRENA, 2020f). Hydropower dominates, at 40 percent of total capacity, and 10 MW of off-grid solar capacity was added in 2018. Overall, renewables represent 52 percent of capacity (Table 37).

	Oil	Primary biofuels and waste	Charcoal	Electricity	Total (PJ)
Total TFEC	10	50	18	2	**80**
Manufacturing, const., mining	0.4	6	0	0.5	**7**
Transport	7	0	0	0	**7**
Commerce and public services	0	0	0	0.4	**0.4**
Households	0.7	45	18	1	**65**
Other energy use	1	0	0	0	**1**
	13 %	63 %	23 %	3 %	**100 %**

Table 36 – TFEC in 2017 in PJ

Source: (UNSD, 2020)

The total amount of electricity generated in 2017 was 767 GWh. Hydropower generated 303 GWh (40 %) while solar PV generated 72 GWh (9 %).

The cost-effectiveness of hydropower makes it one of Rwanda's least-cost generation options in the long run and the country has committed to build an additional 119 MW of hydropower by 2026. However, in the absence of sufficient water storage, seasonal changes in river flow can limit hydropower generation. That could cause electricity shortages during peak demand evening hours when solar electricity is off-line (MININFRA, 2018).

Rwanda has built three diesel generators[80] since 2004, with the latest in 2017,[81] so diesel is likely to continue as a key fuel of electricity generation in the medium to long term. The country also built a peat plant in 2016, and has committed to bringing 72 MW of peat and 50 MW of methane generation capacity online between 2019 and 2025 (Rwanda Energy Group, 2019). In addition, Rwanda has found high concentrations of methane in Lake Kivu, but exploitation of such resources is still under discussion. Shared with DRC, that methane could be used to generate 700 MW power for 55 years (MININFRA, 2020).

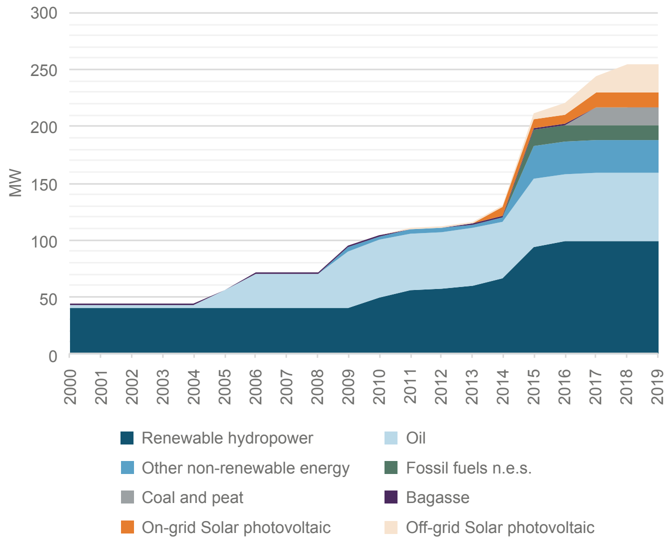


Figure 31 – Installed generation capacity, 2000-2019 Source: (IRENA, 2020e)

	2017		Latest data	
	Generation (GWh)	Capacity (MW)	Generation (GWh) 2018	Capacity (MW) 2019
On-grid	**709**	**230**	**817**	**230**
Coal and peat	-	15	-	15
Oil	77	60	151	60
Fossil fuels n.e.s.	15	14	15	14
Other non-renewable energy	297	29	302	29
Hydropower	303	99	331	99
On-grid Solar photovoltaic	15	12	16	12
Bagasse	2	1	2	1
Off-grid	**22**	**15**	**38**	**25**
Off-grid Solar photovoltaic	22	15	38	25

Table 37 – Rwanda's installed electricity generation capacity (MW) and generation (GWh) Source: (IRENA, 2020f)

As of 2019, Rwanda's electricity system has cross-border interconnections with a capacity of 2 MW with Uganda and 3.5 MW with DRC (Rwanda Energy Group, 2019). These interconnections play important roles in balancing supply and demand.

6.1.3 Electricity access

In 2018, 35 percent of the population in Rwanda had access to electricity, an increase from eight percent in 2003, as shown in Table 38 (World Bank, 2019d). The official statistics from the government show that 55 percent of households have access to electricity (Republic of Rwanda, 2020a).

The huge leap in access was accomplished through the deployment of off-grid solutions, which now provide electricity to 15 percent of households and seven percent of the total population. This level of electricity access with off-grid technologies is the highest in Africa and the third highest in the world, after Nepal and Mongolia.

In Rwanda, off-grid electricity is being produced mainly by solar home systems of >50 W (Tier 2+) and 11-50 W (Tier 1). In 2018, over 10 percent of the population was using solar lighting systems (below Tier 1) (IEA et al., 2020). The use of mini-biogas and solar mini-grids is small in comparison.

Indicator	2003	2017	2018
Access to electricity (% of total population)	8 %	34 %	35 %
Access to electricity (% of urban population)	41 %	85 %	89 %
Access to electricity (% of rural population)	1 %	24 %	23 %

Table 38 – Electricity access statistics Source: (World Bank, 2019d)

[80] The plants are Jabana 1, Jabana 2 and So Energy, totalling 59 GW.
[81] The lifetime of a diesel generator is typically one to two decades, depending on use.

6.1.4 National planning scenarios, NDC, and key emissions/renewable energy targets

Government plans

The Rwanda Energy Policy (REP) is Rwanda's key planning document. Published in 2015 by the Ministry of Infrastructure (MININFRA, 2015), it presents the main long-term policies for achieving a sufficient, reliable, safe, sustainable and more affordable power supply for all households and economic sectors. It emphasises the importance of diversifying the generation mix and increasing the share of renewable-based power. It also sees cross-border transmission investments as being important to enable regional cooperation that can improve the security of supply.

The Rwanda Energy Policy is reinforced by the latest Energy Sector Strategic Plan (ESSP), published in 2018 by the Ministry of Infrastructure. The plan acknowledges the need for increased generation capacity to ensure that growing demand is met in a cost-competitive fashion, and offers an action plan that measures short-term progress (between 2018/19 and 2023/24) toward the long-term goals and objectives in the Rwanda Energy Policy. It sets power system targets, such as a reserve margin of 15 percent, less than 92 hours of outage per year, and transmission and distribution losses under 15 percent. It also sets goals of ensuring electricity access to 100 percent of households and productive users, and achieving a modest 52 percent renewable share in electricity generation by 2024. In addition, it refers to a target from Sustainable Energy for All of raising the renewable share of generation to 60 percent by 2030. Capacity additions are expected to be led by hydropower plants of all sizes (small, large and regional plants) followed by methane and biomass projects (MININFRA, 2018).

Rwanda has already reduced its emissions intensity below the 2025 target set by the 2015 ESSP of 0.378 tCO_2/MWh, down from a baseline of 0.504 tCO_2/MWh (Rwanda Energy Group, 2019).

The ESSP also builds on the Electricity Access Roll-out Program (2013), the Rural Electrification Strategy (RES) (2016) and the National Electrification Plan to lay out a strategy for raising access to electricity from 35 percent in 2018 to 100 percent by 2024 (MININFRA, 2018; World Bank, 2019d). The Government recognises that while electrification through grid connection is desirable, it is neither efficient nor quick, especially since the majority of households without access to electricity are in rural areas (USAID, 2020). The plan, therefore, is to achieve 100 percent access through off-grid electrification[82] – such as solar home systems and mini-grids for 48 percent of the population, and grid extension for the other 52 percent. Grid expansion, however, will continue in rural areas to further support rural economic development and improve the sustainability of electrification efforts (MININFRA, 2018).

More specifically, the ESSP established four programmes as part of the rural electrification strategy:

– The government is supporting low-income households in obtaining solar home systems (SHSs).

– It is also reducing risk for the private sector by subsidising purchases of solar home systems. Funds from the Scaling up Renewable Energy Program (a USD 50 million fund) and a USD 15 million loan from the Abu Dhabi Fund for Development will contribute to the purchase and installation of 500 000 SHSs for lighting and for charging mobile phones and radios. The project uses a flexible mobile payment platform, and is expected to benefit 2.5 million people in rural communities and create more than 2 000 local jobs.

– The government is working to identify sites and establish attractive financial frameworks for the private sector to develop mini-grids.

– The fourth programme will continue to extend the grid through the Electricity Access Roll-out Program (2013), especially to electricity-intensive users.

These programmes have spawned the growth of an off-grid industry with more than 20 companies supplying and servicing SHSs.

Rwanda also has a Least Cost Power Development Plan (LCPDP), published in 2019 by the Rwanda Energy Group – a government-owned company responsible for the development and operation of national energy infrastructure (Rwanda Energy Group, 2019). The LCPDP aims to reduce the tariff in Rwanda for electricity, which was 22 percent more expensive than any other tariff in the East Africa Community[83] block (Bimenyimana, Asemota and Li, 2018). It also aims to maximise the use of renewable energy within the country's energy mix.

In both of the LCPDP's two scenarios, electricity production reaches 4 TWh by 2040 with similar generation mixes: 2.4 TWh from hydropower and 1.5 TWh from methane-fuelled generation. The scenario pathways differ, however, in the degree of utilisation of cross-border trade in the medium term. The use of non-hydro renewables is not prominently reflected in this plan, but the ESSP renewable generation target of 60 percent in 2030 would already be reflected in the base year 2019.

The dominance of hydro in Rwanda's electricity production may make the electricity system vulnerable to the growing impacts of climate change, such as changes in precipitation patterns and more uncertain seasonal river flows. To ensure the security and reliability of the energy supply, Rwanda can further implement regional grid integration as a contingency option. Overall, the contribution from solar technology in the LCPDP, both in terms of capacity and electricity production, is projected to decrease, largely due to the mismatch between solar availability and electricity demand. Pumped hydro storage is therefore preferred. The LCPDP thus offers a very different pathway than other Rwandan energy plans, which include large amounts of solar (mainly mini-grids) to achieve rural electrification goals.

[82] Examples include stand-alone solar PV systems, solar lamp kits, biogas digesters and micro-grids powered by small hydro, efficient diesel or solar-wind, and solar-diesel hybrid systems (MININFRA, 2018)
[83] The EAC is made up of Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda.

	Capacity				Generation			
	2019		2040		2019		2040	
	MW	%	MW	%	GWh	%	GWh	%
Hydro	107	49	169	34	558	70	2410	61
Solar PV	12	6	12	2	17	2	7	<1
Methane	26	12	186	37	193	24	1521	39
Peat	15	7	15	3	33	4	10	<1
Thermal	**58**	**27**	**58**	**12**	**0**	**0**	**0**	**0**
Natural gas	0	0	59	12	0	0	0	0

Table 39 – Electricity generation in the LCDPD scenario in 2019 and 2030

Source: (Rwanda Energy Group, 2019)

On the regional level, the Eastern African Power Pool (EAPP) Master Plan published in 2014 analysed the regional electricity system covering 12 countries. The plan looks to 2040 and includes 21 scenarios. In addition to the "Main scenario", which acts as a base case, other scenarios explore a high renewable future, different demand trajectories, transmission capacity expansion plans, hydro resource availabilities and costs, the implementation of a carbon tax, various export levels, nuclear generation, gas prices, interest rates and reserve margin requirements (EAPP, 2014).

According to the EAPP Master Plan, Rwanda's sent-out demand (final electricity consumption plus T&D losses) would grow nearly 8.5 percent per year between 2013 and 2040 to reach 4.9 TWh (equivalent 3.9 TWh of final consumption assuming T&D losses of 20 percent). However, the demand projection used in the plan overestimated demand growth between 2014 and 2020. For example, the final electricity demand for 2020 was estimated to be 1.5 TWh, whereas actual demand is less than half of that.

The Nationally Determined Contribution

As in many other sub-Saharan African countries, Rwanda's current GHG emissions are negligible. However, potential future emissions from deforestation, agriculture, energy use and land use would create a large enough carbon footprint for Rwanda to devise a mitigation response. The Green Growth and Climate Resilience Strategy (GGCRS) provided the basis for the development of the response described in the NDC.

The updated NDC under the Paris Agreement includes a plan to install 68 MW of solar mini-grids in rural areas by 2030 as part of the Rural Electrification Strategy, which would displace traditional biomass, diesel and kerosene for household energy consumption (Republic of Rwanda, 2020b).

In the NDC base year of 2015, the energy sector contributed 32.1 percent to the country's total GHG emissions of 5.3 $MtCO_2e$. By 2030, total emissions under a business-as-usual (BAU) scenario are projected to be 12.1 $MtCO_2e$. Of that, 4.8 $MtCO_2e$ would come from the energy sector.

Rwanda has an ambitious conditional contribution target of reducing GHG emissions by 38 percent relative to the BAU scenario. This would result in total reductions of up to 4.6 $MtCO_2e$ in 2030, including 1.5 $MtCO_2e$ of emissions reductions from the energy sector (Republic of Rwanda, 2020b).

Area	Targets
Emissions	– Reduction of 1.9 $MtCO_2e$ GHG emissions relative to BAU in 2030 (16 %). Further reduction of 2.7 $MtCO_2e$ GHG emissions relative to BAU (22 %) if support and funding are provided (Republic of Rwanda, 2020b).
Renewables	– Reach a 52 % share of renewable energy in the electricity generation mix by 2024 (MININFRA, 2018). – Reach a 60 % share of renewable energy in the electricity generation mix by 2030 (MININFRA, 2018). – Strive to achieve 100 % renewable energy between 2030 and 2050 (Climate Vulnerable Forum, 2016b). – Install 68 MW of solar mini-grids by 2030 (Republic of Rwanda, 2020b).
Others	– Universal access to electricity by 2024 with about 52 % to have access through grid connection and the remainder through innovative off-grid technologies (MININFRA, 2018; Republic of Rwanda, 2020a). – Universal access among productive users by 2022 (MININFRA, 2018; Republic of Rwanda, 2020a).

Table 40 – Summary of key national emissions/renewable energy targets

6.1.5 Overview of policy instruments, regulations and measures supporting national plans and driving renewable energy deployment in the power sector[84]

The table below provides an overview of the key policy instruments, regulations and measures that have supported the renewable energy targets and priorities discussed above.

Name	Launch	Details
Feed-in-tariff	2012	– Hydropower plants between 50 kW and 10 MW received tariffs that ranged from USD 0.166/kWh to USD 0.67/kWh (Republic of Rwanda, 2012). – Projects outside that size range could still be eligible if they were close to the grid, could exploit economies of scale and did not adversely affect the system's stability. – Under rural electrification regulation (Republic of Rwanda, 2015), hydro Small Power Producers (usually under 5 MW) that are eligible for the FiT are also eligible for a simplified generation license if they can sell electricity to a Small Power Distribution company or the Transmission System Operator (TSO) (Republic of Rwanda, 2015).

Table 41 – Summary of relevant renewable energy policy instruments, regulations and measures in Rwanda's power sector

[84] Based on IRENA's repository of knowledge on policies and measures.

6.2 Prospects for renewable power towards 2040

IRENA has analysed Rwanda's power system as part of a regional study on the Eastern and Southern Power Pools. The analysis was conducted under the framework of the Africa Clean Energy Corridor (ACEC), where IRENA assesses the prospects of different technology options, trade among EAPP and SAPP countries and emissions of carbon dioxide, along with system costs, benefits and opportunities. The conclusions from this regional study, alongside the study's methodologies and assumptions, can be found in IRENA's upcoming report on planning and prospects for renewable power in Eastern and Southern Africa (IRENA, forthcoming). The analysis on Rwanda in this section is an extract from IRENA's assessment of the two power pools; it gauges the economic potential for higher renewable energy uptake in the country in relation to the regional power system.

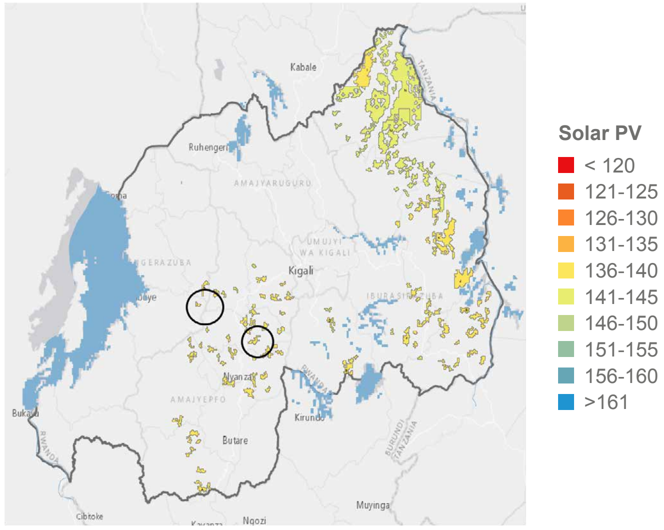


Figure 32 – Solar PV zones with total levelised cost of electricity (USD/MWh)
Note: Boundaries and names shown on this map do not imply any endorsement or acceptance by its Authors.

6.2.1 Methodology and assumptions

Solar and wind resource potential and zoning analysis: IRENA assessed the renewable energy potential in Southern and Eastern Africa through a geospatial analysis (IRENA and LBNL, 2015a). In areas where good resources concentrate, IRENA analysed a subset of available resources as project-sized "zones", with associated land areas, resource quality and cost estimates. Out of the 15 zones totalling 330 MW, two were modelled in the SPLAT-ACEC, based on their prospective generation profiles and distances to load centres. These two zones have capacity factors of 23 and 24 percent, respectively. In comparison, no solar CSP and wind zones have been identified. The solar PV zones and the locations of the two modelled utility-scale zones for Rwanda (4.1 GW) are mapped in Figure 32.

SPLAT-ACEC model: IRENA used its in-house SPLAT-ACEC model to analyse the power systems for Rwanda and other countries in the ACEC. The model uses a cost-minimisation algorithm to identify the cheapest electricity supply mix and transmission infrastructure for meeting an estimated demand.

Assumption	Description	Sources
Electricity demand projections (TWh)	4.9 TWh in 2040	EAPP masterplan (EAPP, 2014).
Load profile	Details in IRENA's forthcoming planning report on Eastern and Southern Africa (IRENA, forthcoming)	Proxied with IRENA's load profile for Uganda.
Renewables potential (MW)[85] **Solar PV** **Wind** **Hydropower** **Biomass** **Geothermal**	 330 0 226 211 0	Solar PV and wind: zoning analysis (IRENA and LBNL, 2015a). Hydropower and geothermal: EAPP Master Plan (EAPP, 2014). Biomass: IRENA biomass studies (IRENA, 2014b; 2014a).
Existing and planned generation projects (MW) **Existing and committed** **Candidate**	 950 47	EAPP Master Plan (EAPP, 2014), renewables calibrated to 2019 PLATTS and IRENA data (IRENA, 2020f; Platts, 2019).
Existing and planned cross-border transmission lines (MW) **Existing Rwanda – Uganda** **Candidate DRC – Rwanda** **Candidate Rwanda – Burundi** **Candidate Rwanda – Tanzania**	 363 988 181 610	EAPP Master Plan (EAPP, 2014), World Bank-funded and Aurecon-led SAPP-EAPP Interconnector Impact study (Aurecon, 2018).
Fuel costs projections (2017 USD/GJ) **Coal** **Diesel** **HFO** **Natural Gas**	(2015 → 2040) 3.1 → 3.7 10.7 → 21.8 7.3 → 14.9 2.6 → 3.9	SAPP Master Plan (SAPP, 2017a).
CAPEX projections to 2040	Details in IRENA's forthcoming planning report on Eastern and Southern Africa (IRENA, forthcoming)	Solar PV and wind: IRENA cost data, zoning analysis (IRENA and LBNL, 2015a). Other technologies: EAPP master plan (EAPP, 2014). Transmission: World Bank-funded and Aurecon-led SAPP-EAPP Interconnector Impact study (Aurecon, 2018).

Table 42 – Summary of IRENA's assumptions in the SPLAT-ACEC model

[85] This is not an upper limit for the total potential in the country. There is potential beyond these capacities, which represent possible projects that have been identified and have locational information. More costly generic options are also modelled, so it is possible for there to be more capacity of a technology than that presented here. The numbers here represent the following: solar PV and wind capacity identified in zones; hydropower shows planned and existing hydropower projects; geothermal shows planned and existing geothermal projects.

For Rwanda, assumptions were formulated with the country's power sector data. Key assumptions and their sources are summarised in Table 42.

6.2.2 IRENA electricity capacity expansion scenarios

For the analysis of Rwanda and other Eastern and Southern African countries from a regional perspective, two scenarios for the power sector were constructed through a capacity expansion analysis for reaching the cost-optimal generation mix in 2040, using the SPLAT-ACEC model:

- **The High RE Scenario** describes the evolution of the regional power supply mix to 2040. It uses assumptions from the SAPP master plan, but has a more ambitious deployment of renewables. It does not stipulate any specific renewable energy penetration targets or CO_2 emissions reduction targets, and limits cross-border interconnector expansion to currently identified projects. In the scenario, the share of renewable energy in the regional generation mix reaches 63 percent by 2040.
- **The Regional Target Scenario** has a target of raising the combined share of solar PV and onshore wind in the regional electricity system of EAPP and SAPP countries to 50 percent by 2040, higher than the VRE share of 36 percent in the High RE scenario. The scenario investigates the level of regional trade and investment needed to meet this more ambitious deployment of VREs. In the scenario, RE penetration (including hydro) reaches 70 percent by 2040.

The results are summarised in Table 43 and Figure 33.

Figure 33 – Generation, imports and capacity in the High RE and Regional Target scenarios

		High RE		Regional target	
		2030	2040	2030	2040
Capacity (MW)	Solar PV – utility	28	543	151	757
	Large hydropower	121	121	121	121
	Diesel	67	50	67	50
	Natural gas (methane)	202 (152)	200 (152)	202 (152)	200 (152)
	Oil products	20	0	20	0
	Coal	145	130	145	130
	Total	**583**	**1 044**	**706**	**1 258**
Generation and imports (GWh)	Solar PV – utility	58	1 049	312	1 404
	Large hydropower	699	699	699	699
	Diesel	29	22	29	22
	Natural gas (methane)	88 (66)	162 (130)	88 (66)	130 (100)
	Oil products	9	0	9	0
	Coal	1 080	968	1 080	685
	Electricity trade	1 244	2 032	990	2 221
	Total	**3 207**	**4 932**	**3 207**	**5 161**

Table 43 – Capacity and generation mix in the High RE and the Regional target scenarios

Key insights from the results include the following:

- The final generation mix in both scenarios has high shares of renewable energy penetration: 64 percent in the High RE scenario (with a total of 1 748 GWh) and 70 percent in the Regional Target scenario (with 2 103 GWh). Under the Regional Target scenario[86], total capacity would reach 1.3 GW in 2040 and 27 percent of domestic generation would be from solar PV.
- In Rwanda, the High RE scenario would increase utility-scale solar PV capacity to 543 MW by 2040, making it the largest renewable source in Rwanda's capacity mix (at 58 % of total capacity). About 110 MW of solar PV would be built outside of the two identified PV zones. Hydropower does not increase in capacity.
- Imports from neighbouring countries could also become a growing source of supply, providing 39-43 percent of domestic demand in 2040 (2.0 TWh in the High RE scenario and 2.2 TWh in the Regional Target scenario). In addition, generation from natural gas (methane) would increase, though capacity would remain the same.
- Under the High RE scenario, carbon intensity declines from 0.504 tCO_2/MWh to 0.43 tCO_2/MWh by 2040, and 93 percent of total emissions (1.27 Mt) would be from coal. GHG emissions would peak in 2032, at 1.42 Mt. In addition to the climate benefits from reduced CO_2 emissions, renewables deployment in Rwanda would reduce pollution, create jobs and increase financial savings.
- The majority of the emissions would be from coal. The future role of coal in the power sector is therefore essential to consider in the discussion of mechanisms and policy instruments to reduce carbon emissions, particularly in future scenarios aligned with the ambitions of the Paris Agreement. In addition, more ambitious targets could be met with innovative solutions – such as solar PV plus storage – that have improved in performance and declined in cost since the time of this analysis.

Comparing IRENA's High RE case to the EAPP masterplan as well as the LCPDP, IRENA's cost-driven analysis shows that a markedly higher renewables penetration in domestic supply (64 %) is possible by 2040 than shown in those plans. The masterplan, for example, foresees 60 percent of generation from fossil fuels in 2040, even in its renewable scenario. A key reason for the difference is that the masterplan grossly underestimates the economic potential of solar PV, so the only renewable generation option in the plan is hydropower.

IRENA's scenarios also have a more diverse outlook than does the LCPDP. Under the LCPDP, hydropower (both large and small) continues to dominate the capacity mix as the main renewable option, while under IRENA's High RE scenario, solar PV grows and diversifies the system by 2040. Total generation capacity in 2040 is 1 044 MW in IRENA's High RE scenario, while it is just above 800 MW in the LCPDP scenario. IRENA's scenarios use demand projections from the masterplan and estimate a significantly higher demand than does the LCPDP (4.9 TWh vs. 4 TWh).

[86] The Regional Target scenario has a 50 % penetration target of VRE (solar PV and onshore wind) regionally, to be reached by 2040. Since this is a regional constraint, not all countries would need to reach 50 %.

6.2.3 Investment needs

The High RE scenario would require USD 628 million (in 2015 USD) for building new capacity between 2020 and 2040, almost all of it for solar PV (USD 441 million) in the early and late 2030s. Figure 34 shows both the yearly investment costs for generation technologies and the cumulative investment.

To achieve the six percent increase in RE penetration in the Regional Target scenario, an additional USD 174 million would be required to build 214 MW more solar PV by 2040.[87] The build-out of solar would also start sooner.

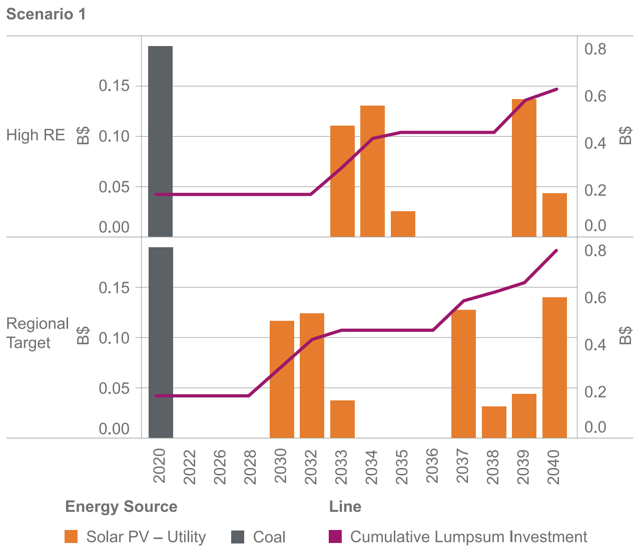


Figure 34 – Yearly system cost and cumulative lumpsum investment cost between 2020 and 2040

Including O&M and fuel costs, the annualised system cost would increase from USD 173 million per year to USD 279 million per year from 2020 to 2040,[88] with a total system cost[89] from 2020 to 2040 of about USD 4.6 billion. In 2040, the largest share of the system cost would be the annualised capital investment[90] (USD 189 million), followed by fuel (USD 65 million) and O&M costs (USD 25 million). With the higher share of renewables in the Regional Target scenario, total system cost would be only slightly higher, at USD 4.8 billion.

As cross-border trading volume increases to 5.1 TWh by 2040 in the High RE scenario, 893 MW of new cross-border transmission capacity would be needed, requiring investments of USD 161 million. In the Regional Target scenario, trading volume is lower (at 2.9 TWh in 2040), so 345 MW less capacity would be needed and the investment required would be USD 61 million lower (Table 44).

Cross-border transmission	High RE	Regional target
Rwanda-DRC	114	36
Rwanda-Tanzania	47	47
Rwanda-Burundi	-	11

Table 44 – Investment costs (USD million) of cross-border transmission between Rwanda and neighbouring countries

New paradigm of the energy supply chain in Rwanda

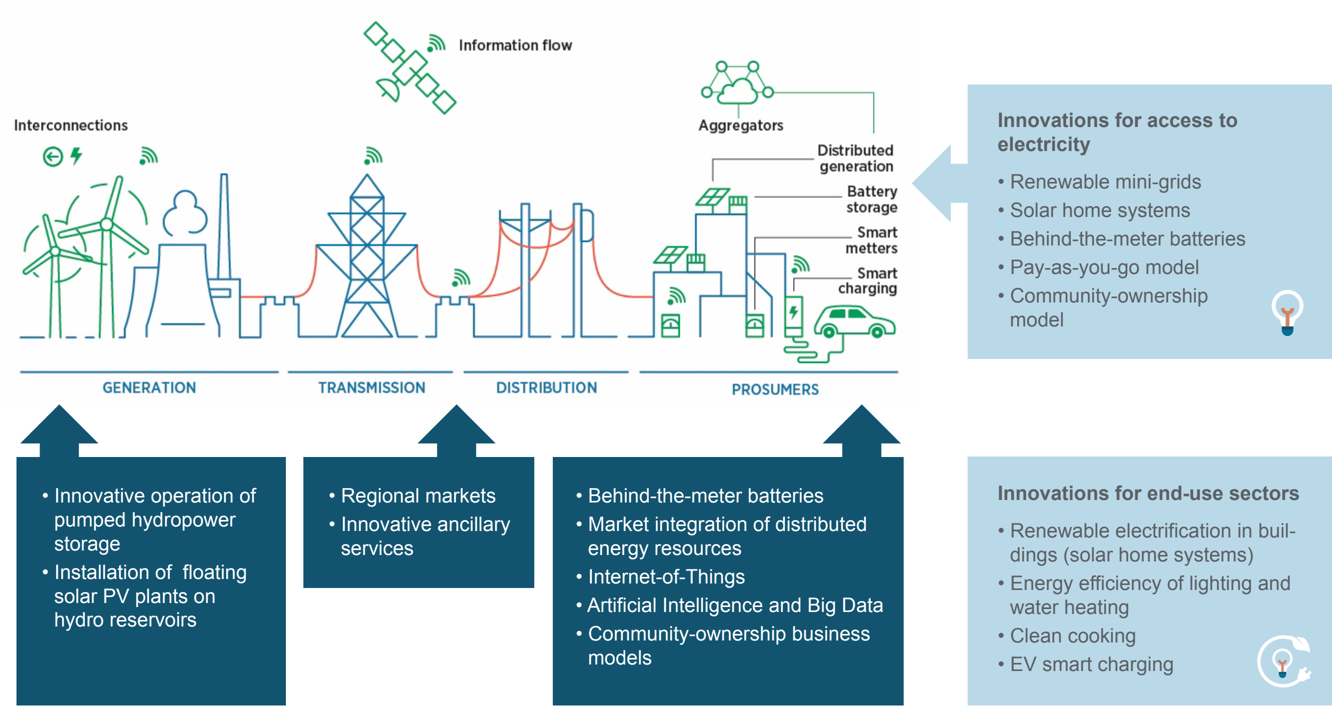


Figure 35 – Innovations to be considered for a future renewable power sector in Rwanda

[87] Inevitably, the stability of the grid would be a key consideration in a system with high solar penetration. Although the analysis here implicitly considers system cost, the meaningful modelling of storage systems and balancing mechanisms would require more time slices and granularity than in a long-term planning model such as SPLAT.
[88] Using a discount rate of 10 %.
[89] It should be noted that these system costs do not capture all potential investment needs in such a large-scale transition. The following chapter will also discuss emerging innovations which could have a significant influence on investment needs and overall system costs.
[90] It may be noted that the annualised investment cost is significantly higher than the average of total investment costs. This is due to the high discount factor applied (10 %). In addition, the annualised investment cost accounts for the entire modelling horizon including the period 2015-2019, the results of which are not presented in this section.

6.3 Systemic innovation needs and opportunities

IRENA's analysis shows that increasing the share of renewable energy in Rwanda to more than 60 percent by 2040 (to 70 % in the Regional Target scenario) is both attainable and cost optimal. However, it will require a major shift in generation planning from hydropower to solar PV, which will also help bring electricity to the 65 percent of the population that currently lacks access (Republic of Rwanda, 2020a). Key innovations for meeting both objectives are summarised in Figure 35.

6.3.1 Innovation supporting a renewable power system

Expanding access to electricity

The rapid expansion of solar PV micro- and mini-grids and other off-grid solar can quickly increase electricity access, especially in rural areas where 83 percent of the population lives and where access now is only 23 percent (World Bank, 2020e). These solar power plants can also be connected with battery storage and solar home systems and enhanced with enabling digital technologies such as smart meters and sensors. Innovative business models like pay-as-you-go billing, peer-to-peer electricity trading and community ownership can accelerate the adoption of these solar systems. Achieving this expansion, however, will require changing the current long-term planning focus away from centralised generation and grid expansion, and also changing regulations to encourage private investment and allow new actors in a power sector now dominated by the state-owned Rwanda Energy Group (REG).

Harnessing synergies between hydro and solar PV power generating technologies

With a power supply that is mainly reliant on hydropower, Rwanda could increase the flexibility of the system by operating the hydropower plants more flexibly and allow the integration of large amounts of variable renewable generation. In addition, adding pumped hydro storage to existing and planned hydropower plants[91] would further increase system flexibility. Solar power would be used to fill reservoirs during the day and then hydropower generation would increase to meet the evening peak demand.

Another innovation that could be explored in Rwanda is installing floating PV on hydro reservoirs, thereby reducing connection costs and improving efficiencies for both solar and hydro generation.

Benefiting from deeper integration of the regional market EAPP

Rwanda is interconnected with Uganda through the 220 kV Mirama–Shango line and is also part of the regional market, the Eastern Africa Power Pool (EAPP).

So far, power trading within the EAPP is taking place only between Ethiopia and Sudan. But several new interconnections[92] are under construction, which if added to existing ones would help Rwanda benefit from greater regional trading. For example, solar generation in Rwanda can complement hydropower generation in the DRC, lowering costs and making better use of capacity in both countries (Rwanda Energy Group, 2019). Harmonising trading rules with countries participating in the EAPP and establishing a more integrated regional market can help increase trading (IRENA, 2019f).

Empowerment of grid-connected prosumers through decentralised energy resources

Rwanda's distribution grid is below standard and suffers from reliability issues. However, grid-connected decentralised energy resources (DERs) like rooftop solar PV can help improve the stability of the national power system by providing innovative ancillary services, such as flexibility reserves, to the main network.[93] They also would allow a new role for end-use consumers as electricity producers (or prosumers).

6.3.2 Innovations for renewable-based electrification of end-use sectors

Buildings

The buildings sector consumes by far the largest share (82 %) of the total energy in Rwanda, generated predominately from traditional biomass (85 %). As a result, efforts for renewable-based electrification for end-use sectors will have the greatest impact if concentrated in the sector, both in rural and urban areas.

A key part of that effort is providing universal access to electricity, especially though solar home systems, rooftop solar and solar mini-grids. The ESSP has a target of 1 500 000 additional households with electricity access using solar off-grid solutions by 2030, at a rate of 250 000 connections per year (Republic of Rwanda, 2020b).

Rwanda is also working to increase the energy efficiency of lighting and water heating through various programs such as the distribution of LED lamps and compact fluorescent lights (CFL) in residential, commercial and institutional buildings; the “SolaRwanda” Solar Water Heaters (SWH) project; and the replacement of high-pressure sodium lamps with LEDs in street lights (Republic of Rwanda, 2020b).

In a country where only 0.9 percent of the population has access to clean cooking options, another important step is switching to cleaner technologies, such as electric stoves, biomass pellets with gasifier stoves, or the use of agricultural waste from local farms (IEA et al., 2020).

[91] Given the relatively pronounced topography of Rwanda compared to other countries analysed in the present study, the scope for pumped hydropower should be explored as a key innovation.
[92] Interconnection projects include Rwanda-DRC (180 km), Rwanda-Burundi (64 km) (Bimenyimana et al., 2018) and Rwanda-Tanzania (IRENA, forthcoming).
[93] Installed capacity of new power plants is currently limited to 10 % of Rwanda's peak demand, which is largely concentrated around the capital Kigali, to avoid high spinning reserves and grid instability (Rwanda Energy Group, 2019).

Transport

Energy use in the transport sector is small, at only eight percent of the total energy consumed in 2016. But it is rising, with vehicle registrations tripling between 2006 and 2015 to almost 162 000 vehicles. Over half of those were motorcycles, 34 percent were passenger cars and 15 percent were vehicles like buses and trucks (Republic of Rwanda, 2020b). To avoid GHG emissions, pollution and greater dependence on fossil fuel imports as the sector continues to grow, Rwanda could begin an "e-mobility" transition to electric vehicles, including two- and three-wheelers. Enabling technologies like smart charging and innovative business models for charging would allow an EV fleet to be integrated into the power system without being a burden for REG's operations.

Rwanda has the advantage of being the first country in Africa where Volkswagen is manufacturing electric cars. At the end of 2019, the company brought four e-Golfs and a charging station to the capital, with the objective of creating a fleet of 200 EVs for ride hailing using an app called "MoveApp" developed by a local IT start-up, Awesomity Lab (Volkswagen, 2019).

Industry

Rwanda's industry sector revolves mainly around construction, manufacturing, mining and quarrying. Among the innovations available to increase the use of renewable energy in this sector are reliable and high quality on-site renewable power generation for mining and quarrying, using on-farm biodigesters and solar pumping for irrigation in agriculture, and small-scale power generation using agricultural residues (such as bagasse or rice husks) or biomass briquettes (from compacted waste residues or charcoal dust). Rice husks also could be used as fuel for cement clinker production (Republic of Rwanda, 2020b).

6.4 Conclusion and areas for further consideration

Rwanda has ambitious plans to achieve universal access to electricity by 2024, from just 35 percent in 2018. As the country rapidly increases its electricity generation capacity to meet this goal, it has an invaluable opportunity to also significantly increase the share of renewable generation. That would bring a number of important benefits, such as avoiding GHG emissions and pollution, and avoiding stranded fossil fuel assets.

In fact, IRENA's High RE scenario shows that raising the share of renewable electricity to 64 percent of the total by 2040 is the cost-optimal pathway for Rwanda. To follow that pathway, however, Rwanda would need to switch its main focus for future generation from hydropower to solar PV. IRENA's analysis shows that 543 MW of utility-scale solar PV can be cost-effectively deployed by 2040. In addition, there is considerable potential to use decentralised systems like mini-grids and solar home systems, both on and off the grid, along with investments in grid expansion and digital technologies.

Rwanda could capitalise on the progress made so far by accelerating the deployment of solar water heaters, clean cooking stoves and solar home systems, especially for households in rural areas. New business models, such as community ownership and pay-as-you-go billing, are also needed.

The country can cost-effectively increase the amount of renewable energy it uses and further reduce emissions by increasing imports of renewable electricity, such as hydropower from the DRC. The analysis shows that 40 percent of domestic demand can be met through imports. Higher levels of trade, made possible by strengthening and expanding interconnector expansions to neighbouring countries such as the DRC and Tanzania as well as by harmonising trade rules, also function as an important balancing mechanism, especially with high shares of variable renewable sources.

As Rwanda moves ahead to increase electricity access and renewable generation, it is crucial that the resulting transition is as just and inclusive as possible. Key measures include:

- Policies and regulations to reduce the risks of conflicts between the various on- and off-grid electrification modes. For mini-grids, dedicated regulations are needed to address the risks associated with main grid arrival, licensing and tariff setting.

- Dedicated funding facilities that enable financing for both suppliers and end-users. For instance, while mini-grid developers require access to local debt facilities, end-users require innovative financing and business models to cover connection costs, leasing or owning stand-alone systems and buying appliances. That financing must be inclusive and accessible for all. In one example, Rwanda has secured dedicated funds from international funds such the Climate Investment Funds (CIF) and the Abu Dhabi Fund for Development.

- Tying energy supply to productive end-uses, such agriculture and local manufacturing, and public services like water, healthcare and education. This will improve livelihoods and maximise the socio-economic benefits of energy access.

- Ensuring that Rwanda's strategies for increasing access and renewable generation leave no one behind and advance other Sustainable Development Goals (SDGs), including gender, health and education.

In general, the goal of a just and inclusive transition is broadly sharing positive outcomes, such as new employment opportunities, while limiting negative effects like job losses in disappearing sectors. For Rwanda, that may require measures like targeted job training, since a different set of skills is needed to shift from a power system dominated by hydropower to a system with much higher levels of solar power and variable generation.

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn
Phone +49 61 96 79-0
Fax +49 61 96 79-11 15
info@giz.de
www.giz.de

IRENA
Masdar City
P.O. Box 236, Abu Dhabi
United Arab Emirates
Phone +97 124179000
info@irena.org
www.irena.org
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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn
Phone +49 61 96 79-0
info@giz.de
www.giz.de

IRENA
Masdar City
P.O. Box 236, Abu Dhabi
United Arab Emirates
Phone +97 124179000
info@irena.org
www.irena.org