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IRENA

Planning and prospects for renewable power:

WEST AFRICA

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About IRENA

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

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The report draws upon discussions and inputs developed over two in-depth SPLAT-W training sessions held in Dakar, Senegal, in December 2015 and January 2016, as part of a six-month capacity development programme organised by IRENA and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), in collaboration with the International Atomic Energy Agency (IAEA) and the United Nations Framework Convention on Climate Change (UNFCCC). The sessions were attended by experts from planning offices in ministries, electric utilities and specialised agencies from Benin, Burkina Faso, Cabo Verde, Gambia, Guinea, Liberia, Niger, Senegal, Sierra Leone, and Togo. A full list of expert participants can be found at the back of this report.

IRENA is grateful to those experts for permitting the use of their national models in this regional analysis. The national models have been altered to some extent, so that the results presented here do not necessarily reflect the national experts' original analysis.

The report was developed under the guidance of Asami Miketa (IRENA) and drafted by Daniel Russo (IRENA) in close collaboration with Bruno Merven (Energy Research Centre, University of Cape Town, South Africa), who conducted major development work with IRENA on the System Planning Test model for Western Africa (SPLAT-W) and provided modelling support. Anjana Das (VITO) contributed to the development of an earlier version of the SPLAT-W model.

Valuable review and consultation were also provided by Hannes Bauer (ECREEE); Debabrata Chattopadhyay, Samuel Oguah and Fernando de Sisternes (World Bank); and IRENA colleagues Safiatou Alzouma, Nopenyo Dabla, Paul Komor, Thomas Nikolakakis, Sakari Oksanen and Tijana Radojicic.

For further information or to provide feedback: **info@irena.org**

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ABBREVIATIONS

CCGT	combined-cycle gas turbine
CLSG	Interconnection Côte d'Ivoire-Liberia-Sierra Leone-Guinea
CO_2	carbon dioxide
CSP	concentrated solar power
DDO	distillate diesel oil
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EREP	ECOWAS Renewable Energy Policy
GDP	gross domestic product
GIS	geographic information system
HFO	heavy fuel oil
IAEA	International Atomic Energy Agency
IIASA	International Institute of Applied System Analysis
IRENA	International Renewable Energy Agency
LCO	light crude oil
LCOE	levelised cost of electricity
LNG	liquefied natural gas
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
n/a	not applicable
NDC	Nationally Determined Contribution
NREAP	National Renewable Energy Action Plan
OCGT	open-cycle gas turbine
OMVG	The Gambia River Basin Development Organisation
OMVS	Senegal River Basin Development Organisation
O&M	operation and maintenance
PV	photovoltaic
RE	renewable energy model constraint includes large hydropower
RExH	renewable energy model constraint excludes large hydropower
ROR	run-of-river
SEforALL	Sustainable Energy for All
SPLAT-W	System Planning Test model for Western Africa
SWI	Shannon-Weiner Index
T&D	transmission and distribution
UNFCCC	United Nations Framework Convention on Climate Change
VRE	variable renewable energy
WAPP	West African Power Pool

UNITS OF MEASUREMENT

GJ	gigajoule
GW	gigawatt
GWh	gigawatt hour
h	hour
km	kilometre
$ktCO_2$	thousand tonnes of carbon dioxide
kV	kilovolt
kW	kilowatt
$MtCO_2$	million tonnes of carbon dioxide
MW	megawatt
MWh	megawatt hour
tCO_2	tonne of carbon dioxide
TWh	terawatt hour

EXECUTIVE SUMMARY

West Africa, like many other parts of the world, is grappling with daunting energy challenges. These include the urgent need to extend energy access and reshape energy matrices in line with the 2015 Paris Agreement, which calls for rapid decarbonisation to reduce the impact of climate change. The Sustainable Development Goals adopted by the United Nations to guide social development processes also call for a shift to new energy systems, based largely on renewables. Such global climate and sustainability imperatives have provided further impetus to the West African region's own drive to establish clear-sighted long-term energy plans.

In 2013, the International Renewable Energy Agency (IRENA) performed its first assessment of the prospects for renewable energy in the continental countries of the Economic Community of West African States (ECOWAS). That assessment, presented in the 2013 report *West African Power Pool: Planning and Prospects for Renewable Energy*, came on the heels of two major regional policy developments – the formal adoption of the 2011/12 West African Power Pool (WAPP) Master Plan, and the ECOWAS Renewable Energy Policy (EREP), which aims to increase the share of renewable energy in the region's overall electricity generation mix to 23 % in 2020 and 31 % in 2030 (ECREEE, 2013).[1]

IRENA's own power sector planning model for West African countries, called the System Planning Test model for Western Africa (SPLAT-W), was used to develop a "Renewable Promotion Scenario" in the 2013 *West African Power Pool* report. This scenario elaborated on the WAPP Master Plan to enhance the representation of renewable technology options, and showed their share in the region could increase from 22 % of electricity generation in a base year of 2010 to as much as 52 % in 2030, in a supportive environment.

Since that analysis, the energy landscape in West Africa has remained dynamic. Ambitious efforts have continued at both the national and regional level to further develop and harmonise policy targets and frameworks to take advantage of the region's vast renewable potential, enhance energy access and meet fast-growing demand.

In this report, three scenarios have been developed to better reflect the recent local and global context for renewable energy prospects in the region – a Reference Scenario, a Regional EREP Target Scenario, and a National Targets Scenario. The Reference Scenario describes renewable energy deployment in the absence of national or regional targets, based on a detailed project pipeline and range of other assumptions, with cost-competitiveness as the key driver for

1 *Including large hydropower, and 5 % in 2020 and 12 % in 2030 when excluding large hydropower. Unless otherwise noted, shares of renewable electricity generation quoted in this report include large hydropower.*

the deployment of various technologies. It builds on the Renewable Promotion Scenario from the 2013 version of this analysis, and is updated to reflect inputs from national experts, as well as the latest research from IRENA, particularly around resource availability and the cost of renewable energy technologies. The Regional EREP Target Scenario describes how the Reference Scenario changes with regional renewable targets set by the EREP, while the National Targets Scenario imposes national renewable targets based on specific input from national experts and/or Sustainable Energy for All (SEforALL) Action Agenda documents.

Using IRENA's SPLAT-W model to explore the three scenarios, this report presents the following main findings:[2]

- Despite a projected fourfold increase in regional demand, updated assumptions to reflect significantly lower fossil fuel price projections, and limited large hydropower potential relative to IRENA's 2013 analysis, the share of renewable power capacity increases in this report's Reference Scenario to exceed EREP capacity targets, reaching 65 % of peak load by 2030.

- While renewable power capacity deployment in the Reference Scenario exceeds expectations, renewable generation in the same scenario is 6 percentage points short of the 31 % EREP target, reflecting the complexity of renewable energy target setting using various metrics. This is mainly due to dry-year assumptions used for hydropower generation, and a lower average capacity factor in the non-hydro renewable mix than assumed in the EREP target-setting process.

- National renewable targets would deliver an even greater amount of renewable capacity relative to the Reference and Regional Target Scenarios, and in aggregate those targets do surpass the regional 2030 renewable generation target of 31 % five years earlier than expected, resulting in a 38 % share of renewable energy in total regional generation by 2030.

- Projected reductions in solar photovoltaic (PV) and wind technology costs make non-hydro renewables the primary driver of new capacity additions across all scenarios in the mid- to late-2020s, with solar PV, wind and biomass generating 23 % of total regional generation by 2030 in the National Targets Scenario.

- Depending on the scenario analysed, the amount of solar PV in the ECOWAS region ranges from 8 gigawatts (GW) to over 20 GW by 2030, implying an annual average deployment of 1.5 GW under a National Targets Scenario.

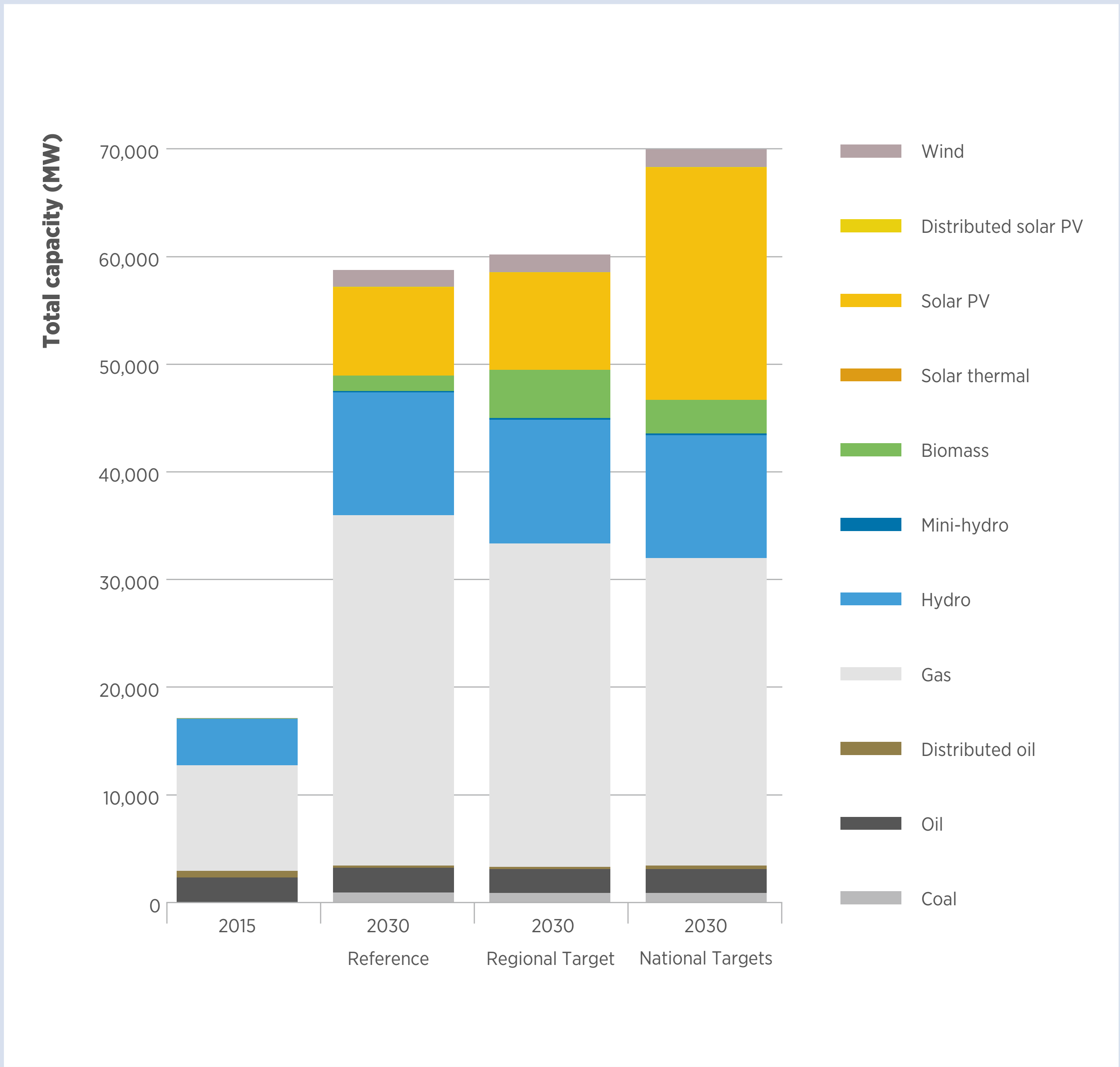
- The diversity, and therefore the resiliency, of the electricity supply mix in the vast majority of ECOWAS member countries significantly increases with the addition of various renewable sources to the capacity mix.

- The development of nearly all cross-border transmission infrastructure projects currently in the pipeline proves to be beneficial across all scenarios analysed.

- The increased capacity investment costs required to deliver national renewable targets are consistently offset by savings in fuel costs from displaced fossil fuel generation, resulting in overall system costs that are essentially equivalent to the Reference Scenario.

2 *The results in this report reflect discussions and inputs developed over two in-depth SPLAT-W training sessions held in Dakar, Senegal. These sessions were part of a six-month capacity development programme in 2015 and 2016 organised by IRENA and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), in collaboration with the International Atomic Energy Agency (IAEA) and the United Nations Framework Convention on Climate Change (UNFCCC). During the sessions, ten ECOWAS member country teams, made up of local experts from energy planning offices in ministries, electric utilities and specialised agencies, developed new model input data and created national renewable deployment scenarios using SPLAT-W country models. SPLAT-W models of five ECOWAS member countries that did not take part in the training programme were also updated as part of this report, based on IRENA research.*

Figure 1 Electricity capacity in Reference, Regional Target and National Targets Scenarios



Note: MW = megawatt.

As the scenarios in this report are meant to align more closely with national expert inputs during 2015 and 2016 IRENA capacity building sessions, as well as more current market conditions, they contain certain important updates to assumptions relative to the 2013 edition of this report. These include the limitation of large hydropower potential to projects identified by national experts, the omission of an import option from Central Africa, the inclusion of lower fossil fuel price projections, and significant renewable energy cost reductions.

Equally important, this report also reflects major enhancements to IRENA's SPLAT-W model itself. Rather than assigning generic capacity factors to variable renewable energy (VRE, *i.e.* wind and solar) the updated SPLAT-W model now includes individual wind and solar generation profiles for each ECOWAS member country, based on analysis of 30 years of hourly historical data. To further improve the representation of VRE, the temporal resolution of the SPLAT-W model has also been increased, and time slice calibration improved to better capture the potential alignment of VRE supply and variable demand, the time-linked operational constraints of a power system (*e.g.* flexibility), and other aspects.

With the updated SPLAT-W model, analysts can now perform a country-level analysis of hourly dispatch in representative days, taking into account each country's particular composition of demand, available resources and resource profiles, and connection within the regional transmission network. This enables a more refined analysis of VRE generation, the sources of system flexibility that can support that generation, and opportunities for complimentary trade that would benefit both resource-rich and resource-poor countries.

These enhancements further the SPLAT-W model's capability to design and explore medium- to long-term power system pathways, prioritise investment options and assess the economic implications of a given investment path.

While IRENA has used publicly available information – as well as inputs from national representatives – as the basis for the analysis presented here, further validation by local experts would always serve to enhance the robustness of model results. Moreover, 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. Local experts are advised to continue exploring different assumptions in order to develop and compare their own scenarios so as to analyse the benefits and challenges of accelerated deployment of renewables.

The results from this updated analysis are intended to support that effort, act as a starting point for further analysis and elaboration, and contribute to national and regional dialogue as ECOWAS member states prepare to meet ambitious renewable energy targets. The fact that the national-level renewable energy targets analysed here collectively surpass the current regional target also highlights the opportunity and benefit of establishing a regular data-informed target update process; such a process can act as a rallying point to build consensus among stakeholders, and align energy plans with broader climate goals reflected in regularly updated Nationally Determined Contributions (NDCs) under the Paris Agreement.

If, as revealed in this analysis, national energy plans and NDCs correspond to a higher level of renewable electricity than anticipated at the regional level, these increased ambitions will have to be reflected in an eventual update of the ECOWAS Renewable Energy Plan.

INTRODUCTION 1

1.1 BACKGROUND

The International Renewable Energy Agency (IRENA) aims to assist its Members in planning for a transition to energy systems that make maximum use of environmentally benign, fossil-free renewable technologies. This aim is particularly relevant in many African contexts, where substantial domestic renewable energy potential could be used to enhance modern energy access for growing populations, in an affordable and secure manner.

In 2011, IRENA's *Scenarios and Strategies for Africa* established the agency's role in promoting renewable energy to accelerate African infrastructure development (IRENA, 2011). Following that analysis, a more focused assessment of renewable energy prospects in the continental countries of the Economic Community of West African States (ECOWAS) was performed in IRENA's 2013 report *West African Power Pool: Planning and Prospects for Renewable Energy* (IRENA 2013).

The assessment in that report was based on IRENA's own power sector planning model for West African countries, called 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.[3]

The first version of the SPLAT-W model – used in IRENA's 2013 *West African Power Pool* report – took the 2011/12 WAPP Master Plan as a starting point to build the system database.[4] The model was then used to develop more elaborated scenarios, to explore the potential for renewable technology development under coordinated policies that would allow ECOWAS member countries to benefit from global cost reduction trends in renewable-based power generation.[5] The "Renewable Promotion Scenario" in IRENA's

3 *For greater detail on SPLAT-W, see Chapter 2, Overview of Methodology.*

4 *The 2011/12 WAPP Master Plan was formally adopted by ECOWAS member countries to provide an overall strategy and framework to prepare for and implement priority WAPP power sector projects (WAPP, 2011).*

5 *One Reference Scenario and three variations of that scenario – Renewable Promotion, No Central Africa Import, and Energy Security – were assessed in the 2013 edition of this report. The Reference Scenario in that report was compatible with the 2011/12 WAPP Master Plan reference scenario, but with important differences, including: the inclusion of mining demand and segregation of rural/urban/industrial demand; the inclusion of decentralised electricity supply options; updated renewable energy resource potential and technology costs; and a conservative "dry-year" hydro generation assumption. In the Renewable Promotion Scenario, cost reductions due to anticipated technology learning were taken into account for renewable energy technologies, fossil fuel prices were assumed to escalate relative to current values, and an option to import electricity from the Central African region was included. In the No Central Africa Import Scenario, the electricity import option from Central Africa was excluded, and in the Energy Security Scenario, import shares were limited to 25 % of total electricity demand for each country.*

2013 *West African Power Pool* report showed that the share of renewable technologies in the region could potentially increase from 22 % of electricity generation at the time (2010 base year) to as much as 52 % in 2030.

In July 2013, the Authority of ECOWAS Heads of State and Government expressed its commitment to provide access to sustainable energy services in West Africa by adopting a ground-breaking policy – the ECOWAS Renewable Energy Policy (EREP) – which aims to increase the share of renewable energy in the region's overall electricity generation mix to 23 % in 2020 and 31 % in 2030 (ECREEE, 2013).[6]

To operationalise this regional goal, each ECOWAS member country is mandated to develop a National Renewable Energy Action Plan (NREAP). NREAPs are built on a systematic assessment of future energy mixes, for which energy planning tools like IRENA's SPLAT-W need to be used.

With the aim of assisting ECOWAS member states to enhance their energy planning capacity, particularly within the context of NREAP development under the EREP, IRENA and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) have cooperated to develop templates for NREAP preparation and enhance the SPLAT-W model for further use in the region.

In December 2015 and January 2016, two in-depth SPLAT-W training sessions were held in Dakar, Senegal, as part of a six-month capacity development programme organised by IRENA and ECREEE in collaboration with the International Atomic Energy Agency (IAEA) and the United Nations Framework Convention on Climate Change (UNFCCC). During the sessions ten ECOWAS member country teams, made up of local experts from energy planning offices in ministries, electric utilities and specialised agencies, developed scenarios to explore cost-optimised integration of renewable energy into the power sector.[7]

The new input data and improved SPLAT-W scenarios emerging from the IRENA training sessions described above can be expected to provide valuable inputs as ECOWAS member states and ECREEE continue to enhance regionally harmonised NREAPs. This is happening in light of the EREP adopted in 2013 and other commitments, such as Action Agendas under the Sustainable Energy for All (SEforALL) initiative and Nationally Determined Contributions (NDCs) under the Paris Agreement.

1.2 THIS REPORT

This report serves to update the scenarios and analysis presented in IRENA's 2013 *West African Power Pool* report, taking into account new regional policy developments, inputs and outputs from national experts in the IRENA/ECREEE training sessions described above, and various improvements to IRENA's SPLAT-W model.[8]

6 *The target officially adopted by heads of state and government on 18 July 2013 was given under Article 2 of the supplementary act on the ECOWAS Renewable Energy Policy. The specific targets of the regional policy for grid-connected renewable energy are given as "increase the share of renewable energy in the overall electricity mix, including large hydro, to 35 % by 2020 and 48 % by 2030" and "increase the share of renewable energy in the overall energy mix, excluding large hydro, to 10 % by 2020 and 19 % by 2030. This will lead to the installation of 2,424 MW renewable energy generation capacity from wind, solar, bioenergy and small-scale hydro power by 2030, and to 7,606 MW by 2030". Although the metric for electricity/energy mix is not clearly articulated in the official document, the supplementary document "Baseline report for the ECOWAS Renewable Energy Policy" prepared by ECREEE shows these targets in terms of installed capacity of renewable energy as percentage of peak load. The report further presents these targets translated into shares of generation, according to which the target shares for non-hydro renewables is 12 % by 2030, and for total renewables including hydro as 31 %. This is the metric used throughout the analysis presented in this report. For the implications of adopting this metric, see Box 1, Renewable targets: Implications of metric choice.*

7 *The ten ECOWAS member countries represented at the SPLAT-W training and enhancement sessions were: Benin, Burkina Faso, Cabo Verde, Gambia, Guinea, Liberia, Niger, Senegal, Sierra Leone and Togo.*

8 *For more detail on the scenarios and analysis presented in IRENA's 2013 West Africa Power Pool report, see the previous section.*

A detailed elaboration of the inputs to this report is provided throughout Chapter 3, *Scenario Assumptions*.

The important updates made in this report include:

- The specification of regional renewable energy targets as defined in the EREP, published in 2013.
- The specification of national renewable energy targets as defined in SEforALL Action Agendas (if applicable), and/or by country teams present at the 2015–2016 regional training workshops held by IRENA on SPLAT-W.
- Updates to existing and projected power system parameters and site-specific projects, based on national expert input, IRENA research and the 2016–2019 WAPP Business Plan (WAPP, 2015).[9]
- Updates to the characterisation of some generic renewable energy technologies, based on recent work by IRENA around cost projections and recent projects in Africa.
- Refinement of variable renewable resource potential to reflect more granular geographic dispersion and assessment of exclusion zones.
- Improved SPLAT-W model representation of variable renewable energy (VRE) generation, to include individual wind and solar generation profiles for each ECOWAS member country, based on 30 years of hourly data, rather than generic capacity factor assumptions.
- Increased temporal resolution and improved time slice calibration in the SPLAT-W model, to better capture variable renewable generation and system dynamics.
- Updated bottom-up projections of demand for electricity, to incorporate commercial sector demand.
- Updated fuel price assumptions, to better reflect recent market conditions and industry outlooks.

The updated SPLAT-Wa model covers all continental ECOWAS member countries: Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. Cabo Verde is considered as a separate entity in the modelling, as it is not connected to the WAPP regional grid.

While IRENA has used publicly available information – as well as inputs from a number of national experts – to represent the current power supply infrastructure, further validation by local experts would always serve to enhance the model's robustness.[10] Moreover, the assessment is based on certain assumptions, including but not limited to fuel costs, infrastructure and policy developments, which energy planners in the region might regard differently. Local experts are advised to continue exploring different assumptions in order to develop and compare their own scenarios so as to analyse the benefits and challenges of accelerated deployment of renewables.

The results from this updated analysis are intended to support that effort and contribute to the national and regional dialogue to come, as ECOWAS member states prepare to meet ambitious renewable energy targets. They also serve to highlight the utility of SPLAT-W model as a free and well-maintained tool for IRENA Members to explore alternative national and regional power sector development scenarios.[11]

9 *This includes a limitation of large hydropower generation to align only with projects identified in country team inputs, and the removal of import potential from Central Africa.*

10 *The ten ECOWAS member country teams that attended the SPLAT-W training sessions did not develop the results presented in this report, which are a product of IRENA's modelling and analysis.*

11 *Several SPLAT model tutorials have been developed by IRENA and ECREEE, and are available upon request from the authors.*

OVERVIEW OF METHODOLOGY 2

The SPLAT-W model used in this report was developed using the modelling platform software called Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), a dynamic, bottom-up, multi-year energy system model applying linear and mixed-integer optimisation techniques. The modelling platform was originally developed at the International Institute of Applied System Analysis (IIASA), but has been further enhanced more recently by the IAEA. The modelling platform is a flexible framework within which the actual model is developed.

The MESSAGE modelling platform consists of a set of demand projections, a database of transmission infrastructure, power supply technologies characterised by economic and technical parameters, and information regarding existing capital stock and its remaining life span. From the point of existing power infrastructure in the region, the model calculates an evolution of technically feasible technology mixes that achieve a least-cost objective over the planning period (*i.e.* minimal total discounted system costs, including investment, operation and maintenance [O&M], fuel and any other user-defined costs), while meeting various system requirements (*e.g.* supply matching demand at a given time; sufficient resources and capacity in place to supply desired production) and user-defined constraints (*e.g.* reserve margin, speed of technology deployment, emission limits, policy targets).

The model inputs described above can be varied according to the user's preference, to explore different scenarios of system evolution under particular sets of assumptions. The model's "solution" includes, *inter alia*, investment in new technologies, production, fuel use and trade. Economic and environmental implications associated with the identified least-cost energy systems can be easily calculated with the model.

Using the MESSAGE platform described above, the IAEA developed a model and training materials to analyse power system evolutions over the coming 20 years in the ECOWAS region. IRENA's SPLAT-W model was adapted in 2012–2013 from that earlier work by the IAEA, and continues to be enhanced. The key characteristics of the most recent SPLAT-W model are:

- Countries modelled as separate nodes, interlinked by transmission lines. Each node, representing the power system of a single country, is characterised as shown in Figure 2.

- Bottom-up projections of demand for electricity split into four categories (heavy industry; commercial and small industry; urban residential; and rural residential) to allow for a better representation of different decentralised power supply options and improve the representation of the load curve. See Section 3.3 (*Electricity demand*) for more detail.

- Different levels of transmission and distribution (T&D) infrastructure required for the four modelled demand categories, each incurring specified levels of losses. See Section 3.4 (*Local transmission and distribution*) for more detail.

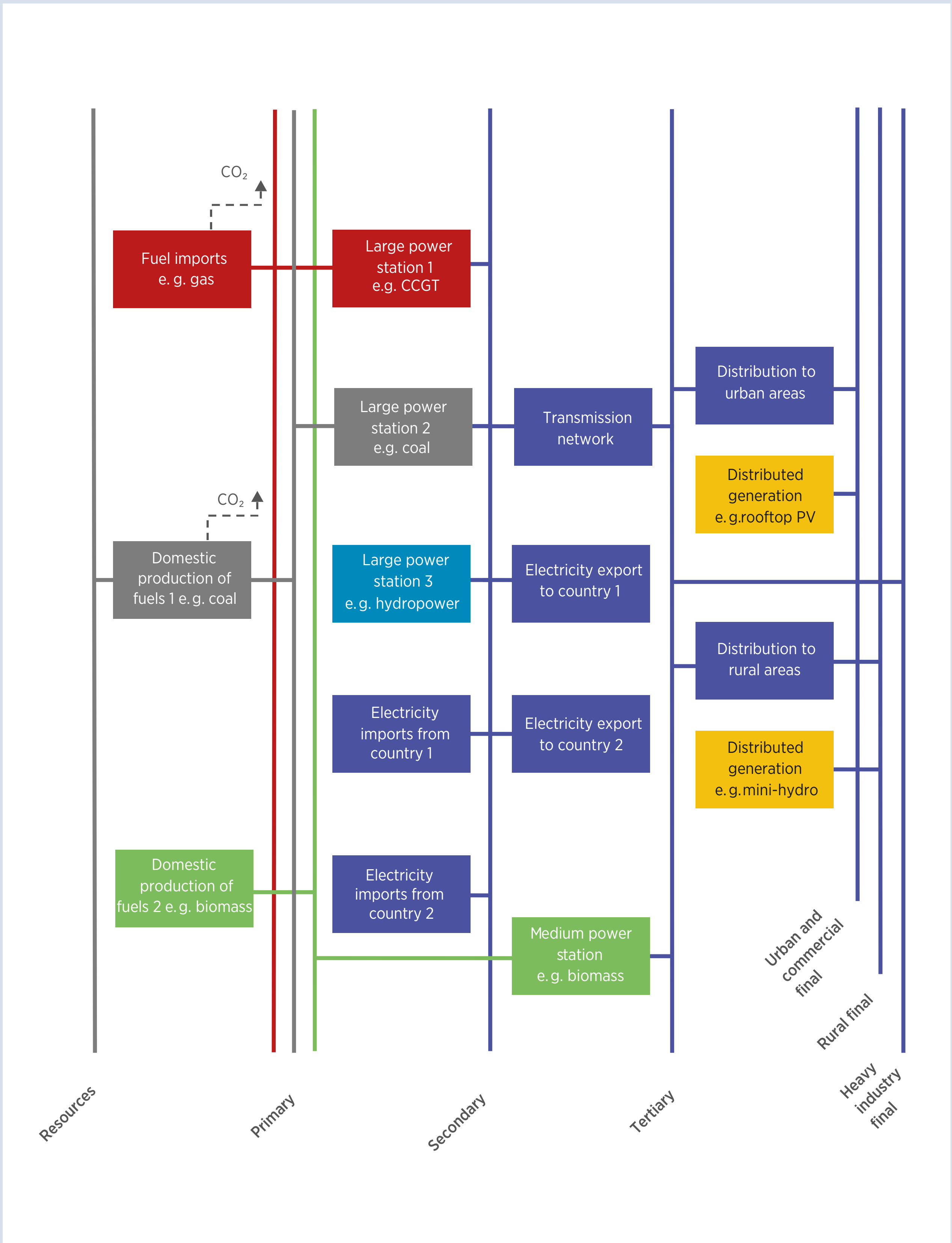
- Computation of a least-cost power supply system that meets the given demand while satisfying all user-defined constraints, with "least-cost" defined for the region as a whole, over the entire modelling period.

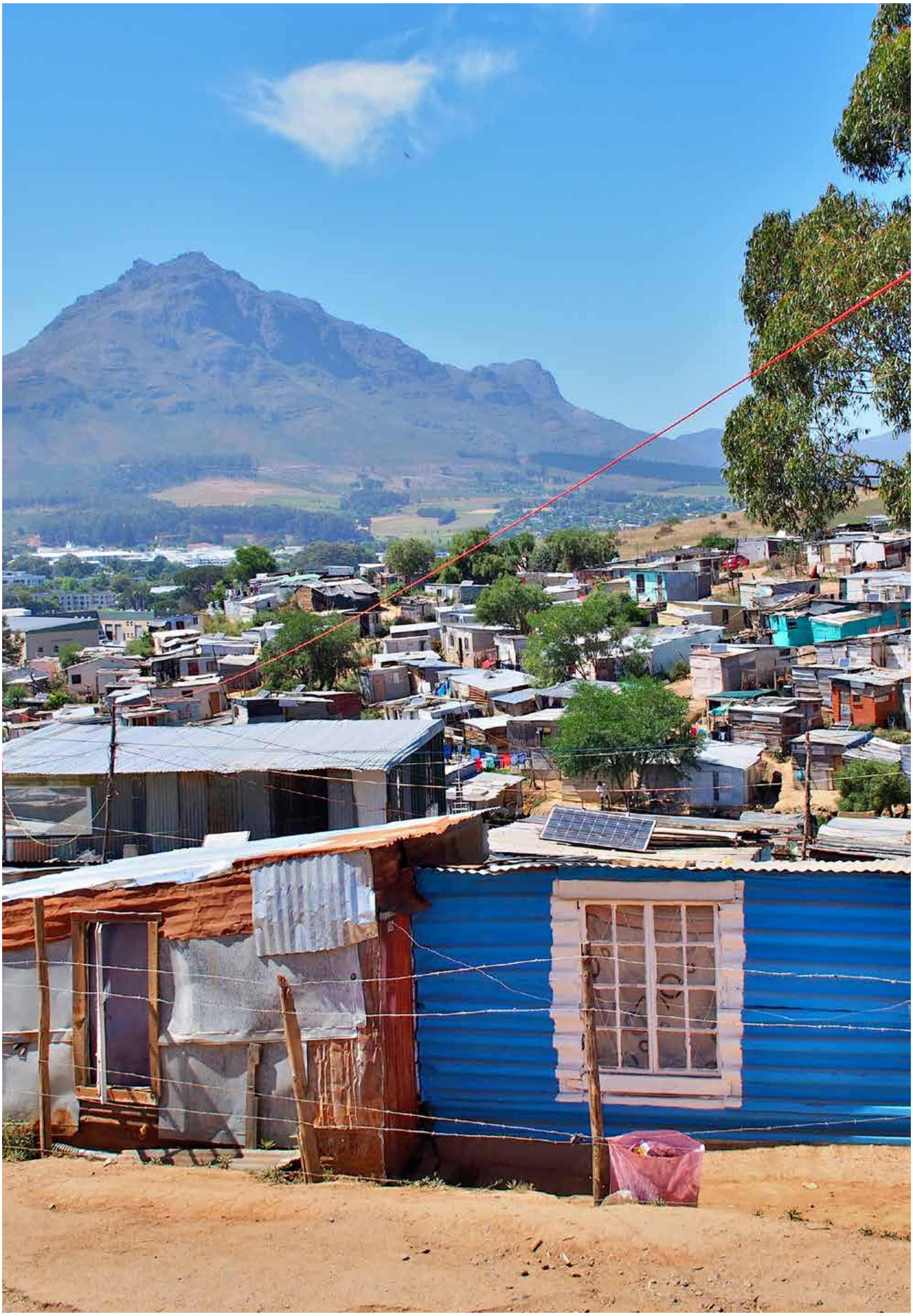
- Explicit modelling of four types of cross-border transmission and power generation options: existing capacity; projects to be commissioned; site-specific projects under consideration (candidate projects); and non-site specific (generic) projects. See Sections 3.7 (*Electricity generation options*) and 3.8 (*Cross-border trade*) for more detail.

- The reliability of supply addressed by assuring 10 % reserve margins, while variable renewable technologies are given levels of "firm" capacity based on the nature of the resource (*i. e.* not fully contributing to the reserve margin at times). See Section 3.9 (*Constraints related to system and unit operation*) for more detail.

- Significantly expanded and refined renewable energy supply options, reflecting the latest technology cost and capacity factor data, based on cost curves and hourly generation profiles in IRENA's most recent costing and resource assessment studies. See Sections 3.5 (*Renewable resource potential*) and 3.7 (*Electricity generation options*) for more detail.

Figure 2 Country power sector model structure





SCENARIO ASSUMPTIONS 3

3.1 GENERAL DEFINITION OF SCENARIOS

Three main scenarios were developed in this update report:

- Reference Scenario
- Regional EREP Target Scenario
- National Targets Scenario.

These are described in the sections below. For the two "Target" scenarios, targets are set for the SPLAT-W model's optimisation of capacity expansion, to meet specified minimum percentages of renewable energy supply in total generation by the years 2020 and 2030.

For the Regional EREP Target Scenario, these targets are imposed at the overall level, meaning that renewable generation capacity can be deployed in any country to contribute to the regional target, without national minimum requirements.

For the National Targets Scenario, targets are set only at country level, so that each country must at least meet its minimum specified percentage of renewable energy supply. Cross-border trade is treated equally across scenarios, limited to the extent of existing and planned transmission projects.

Reference Scenario

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 set out in the remainder of this chapter, with cost-competitiveness as the key driver for the deployment of various technologies. It builds on the Renewable Promotion Scenario from the 2013 version of this analysis, with wide-ranging updates to reflect expert national team inputs and IRENA's own research, as described in Chapter 1 *Introduction*.

Apart from updating renewable resource and cost information to align with the latest IRENA estimates, the most influential revisions include: updated electricity demand projections, removal of the option to develop non-site-specific hydropower resource potential (this includes ca. 7 gigawatts [GW] of generic large hydropower capacity developed in Nigeria in IRENA's previous study results), the exclusion of import potential from Central Africa, and a downward revision of fossil fuel price assumptions.

The scenario assumes a supportive institutional environment, in which policies and market developments allow for rapid reductions in renewable energy costs that are consistent with global observations and past trends.

Table 1 EREP grid-connected renewable energy targets

	2010	2020	2030
Capacity targets in MW	–	2,425	7,606
Peak load forecast ECOWAS in MW	–	25,128	39,131
EREP targets as percentage of peak load	**0 %**	**10 %**	**19 %**
Implied medium and large hydro in MW	–	6,370	11,177
EREP targets as percentage of peak load (incl. medium and large hydro)	**32 %**	**35 %**	**48 %**
Power generation targets in GWh	–	8,350	29,229
Load forecast ECOWAS in GWh	–	155,841	243,901
EREP targets as percentage of generation	**0 %**	**5 %**	**12 %**
Implied medium and large hydro in GWh	–	27,493	46,380
EREP targets as percentage of generation (incl. medium and large hydro)	**26 %**	**23 %**	**31 %**

Notes: GWh = gigawatt hour; MW = megawatt.

Source: ECREEE (2013), ECOWAS Renewable Energy Policy, www.ecreee.org/page/ecowas-renewable-energy-policy-erep.

Regional EREP Target Scenario

The Regional EREP Target Scenario imposes a region-wide minimum target on the Reference Scenario in line with EREP targets. As displayed in Table 1, the EREP aims to increase the share of grid-connected renewable energy in the region's overall electricity mix (defined as the share of renewable energy capacity as a percentage of peak load) to 35 % in 2020 and 48 % in 2030, which respectively include 25 % and 29 % of medium-sized/large hydropower (ECREEE, 2013). In this analysis, the generation-equivalent targets are used in the modelling of regional targets, with a linear trajectory between target years in the SPLAT-W model.

National Targets Scenario

Rather than a region-wide target, the National Targets Scenario sets minimum country-level targets for the percentage of renewable energy in total domestic generation, based on specific input from national experts attending IRENA's 2015–2016 regional SPLAT-W training workshops. In the absence of such inputs, targets are based on national SEforALL Action Agenda documents.

As seen in Table 2, five country targets exclude large hydropower (RExH). Note that although certain national action plans mention goals to deploy specific non-hydro renewable technologies, the targets imposed here are not technology-specific, *i. e.* they only set a minimum overall target for the percentage of renewable generation, which can be met by any renewable electricity generation option at least cost (outside of large hydropower for RExH targets). For an overview of renewable generation options included in this analysis, see Section 3.7 (*Electricity generation options*).

Table 2 National grid-connected renewable energy generation targets

Country	National target constraint	2020	2030	Source
Benin	RE	20 %	44 %	Benin SPLAT-W training team (2015)
Burkina Faso	RE	23 %	50 %	Burkina Faso SPLAT-W training team (2015)
Cabo Verde	RE	50 %	100 %	Cabo Verde SPLAT-W training team (2015)
Côte d'Ivoire	RExH	0 %	16 %	N'Goran (2015)
Gambia	RE	35 %	48 %	Gambia SPLAT-W training team (2015)
Ghana	RExH	10 %	20 %	Tettey (2015)
Guinea	RExH	25 %	30 %	Guinea SPLAT-W training team (2015)
Guinea-Bissau	RE	30 %	50 %	Raul (2015)
Liberia	RE	25 %	30 %	Liberia SPLAT-W training team (2015)
Mali	RExH	0 %	30 %	Touré (2015)
Niger	RE	40 %	57 %	Niger SPLAT-W training team (2015)
Nigeria	RE	20 %	30 %	Adebisi (2015)
Senegal	RExH	20 %	30 %	Niane (2015)
Sierra Leone	RE	30 %	50 %	Sierra Leone SPLAT-W training team (2015)
Togo	RE	17 %	30 %	Togo SPLAT-W training team (2015)

Note: RE = renewable energy model constraint includes large hydropower; RExH = renewable energy model constraint excludes large hydropower.

3.2 OVERALL ASSUMPTIONS

Overall assumptions across all scenarios are as follows:

- The real discount rate applied is 10 %, consistent with the assumption in the 2011/12 WAPP Master Plan.
- The monetary unit used throughout is the 2015 USD rate, and adjustments to reported data in USD from other years are made using the US gross domestic product (GDP) deflator from the World Bank (World Bank, 2017).
- The study horizon spans 2015 ("current" or "present") to 2030.
- A "dry-year" scenario is assumed for all hydropower sites through the modelling horizon, across all scenarios. See Section 3.5 (*Renewable resource potential*).

3.3 ELECTRICITY DEMAND

Electricity demand assumptions were previously based on secondary (*i.e.* at the utility level, before transmission) electricity demand projections given in the 2011/12 WAPP Master Plan and a simplified sectoral split. They have been updated in this report to reflect a more detailed bottom-up sectoral analysis, including progress related to electricity access and economic development, cross-referenced with inputs from national experts present at IRENA's 2015–2016 regional SPLAT-W training workshops.

Figure 3 presents the evolution of secondary electricity demand assumed in this analysis.[12] Relative to previous assumptions, demand in the early years of the model horizon has been revised downward, reflecting lower actual GDP growth than what was expected by the 2011/12 WAPP Master Plan. However, the growth rate of electricity demand is now higher, as total electricity demand is still expected to approach high long-term levels and reflects a fourfold increase between 2015 and 2030.

Each country's final electricity demand was divided into the following four end-use categories:

- Heavy industry (*e.g.* mining) – connected to generation at a high voltage and generally requires little transmission and distribution (T&D) infrastructure per unit of consumption;
- Commercial and small industry – connected via a moderate amount of T&D infrastructure per unit of consumption;
- Urban residential – connected via a moderate amount of T&D infrastructure per unit of consumption;
- Rural residential – requires the most extensive T&D infrastructure per unit of consumption.

Final electricity demand divided into these categories is given in Figure 4. Detailed country-by-country data can be found in Table 15 in Appendix A.

12 As in the previous edition of this report, demand across all scenarios includes demand from some mining projects. In Guinea, Guinea Bissau, Liberia and Sierra Leone, this mining demand is projected to be several times larger than all other electricity demand. Other mining projects in the West African region, such as gold mining in Burkina Faso, were not identified in the WAPP Master Plan and are not included in this analysis.

Figure 3 Secondary electricity demand projections, 2015–2030, by country (GWh)

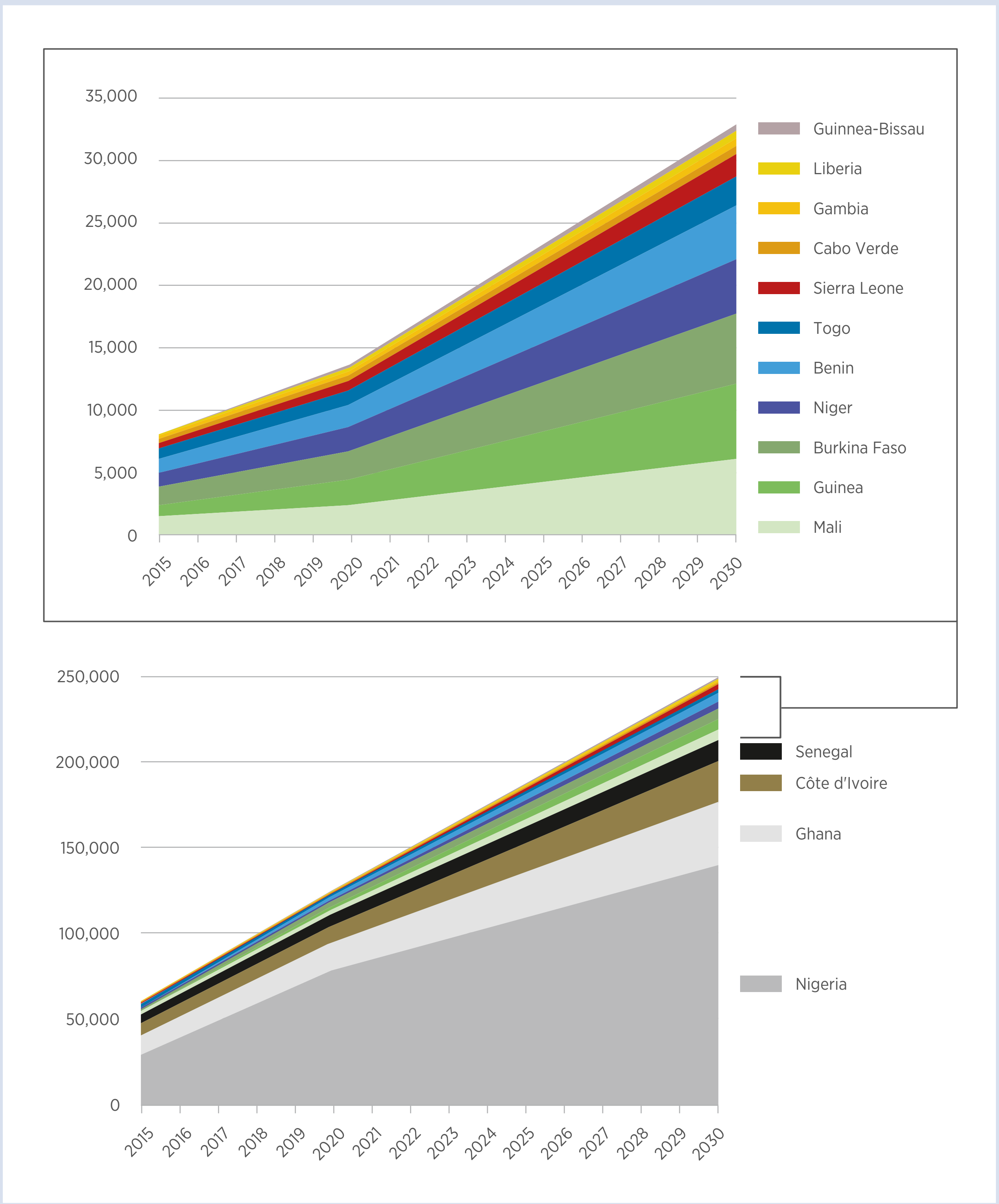
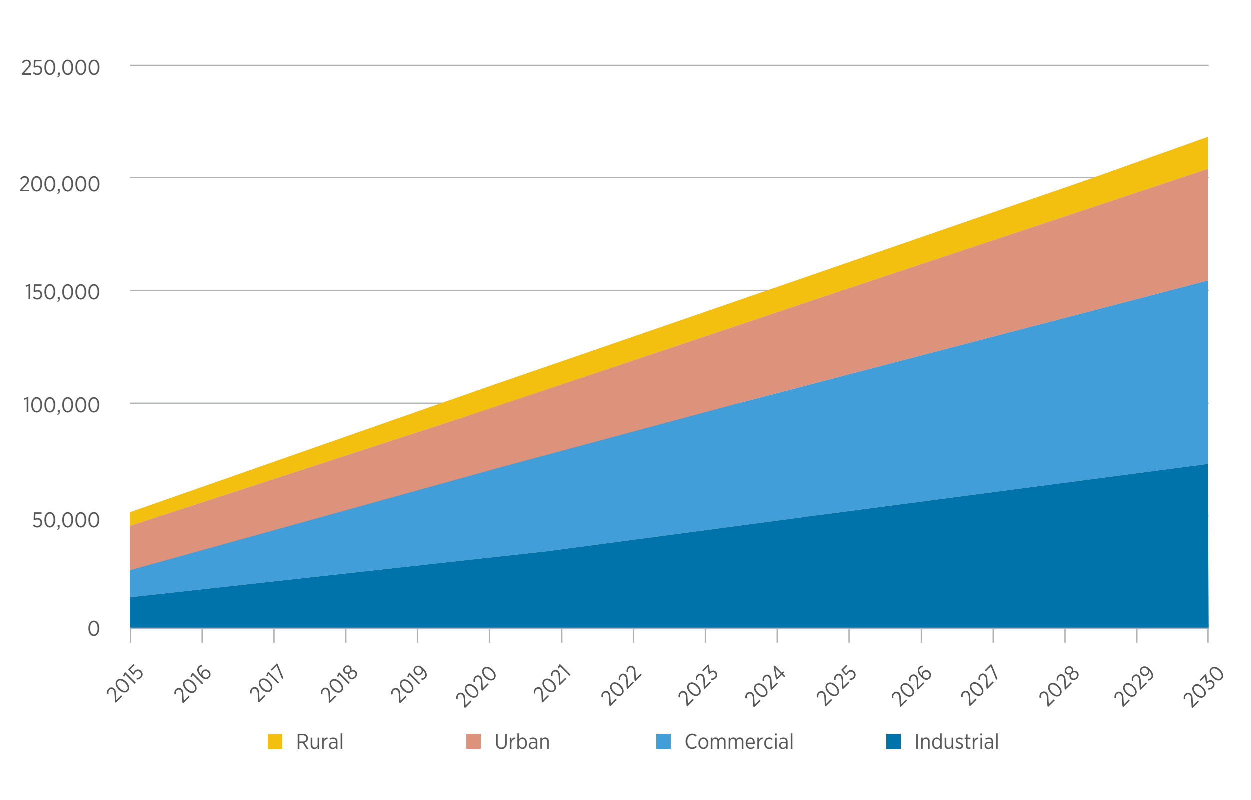


Figure 4 Final electricity demand projections, 2015–2030, by sector (GWh)



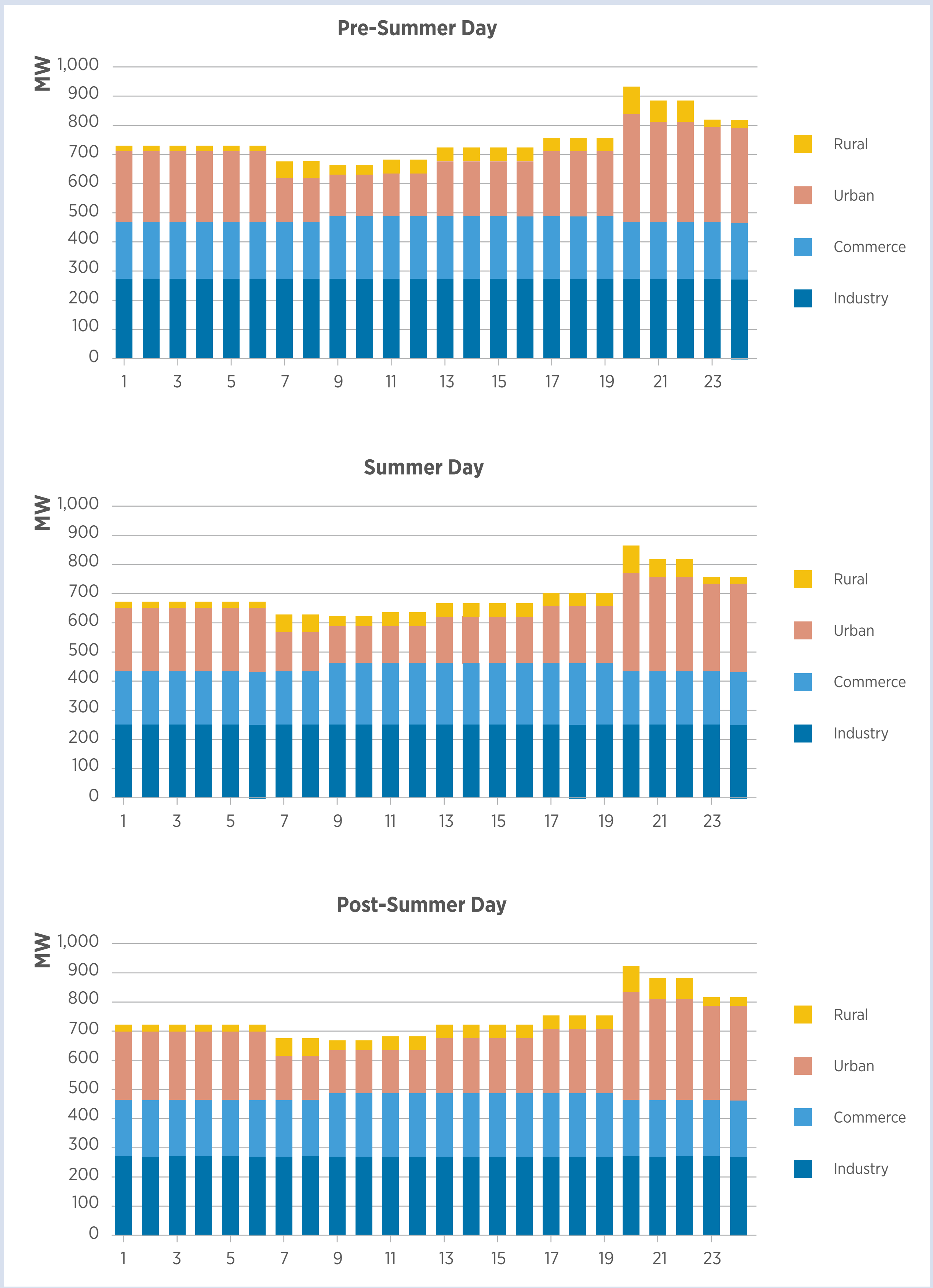
In order to capture the key features of electricity demand patterns, SPLAT-W model years are characterised by sector-specific load profiles for the various seasons and parts of the day. The model contains three seasons, namely pre-summer (January – April), summer (May – August), and post-summer (September – December). For each season, days are characterised by ten blocks of equal demand (including an 8pm "peak"), as presented in Figure 5 below, resulting in a total of 30 model "time slices". Since different countries have different shares of the four specified demand categories, the resulting load series are specific to each country.[13]

Figure 5 Daily time slice aggregation

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Block	1	1	1	1	1	1	2	2	3	3	4	4	5	5	6	6	7	7	7	8	9	9	10	10

13 *Load profile construction described here was performed in the following sequence. First, hourly annual electricity demand data provided by Côte d'Ivoire and Ghana was used to develop a representative overall load shape; within that overall shape, daily industrial sector demand was assumed to be spread flat, and commercial demand was assumed to have a midday increase, based on expert South African regional experience. Urban residential demand was then assumed to fill the balance remaining to form the predefined overall load shape. Given the small share of rural residential demand, the sector's demand was added on top as a final step, with daily load profile developed on the basis of recent research into prospective mini-grid demand profiles in sub-Saharan Africa (Hughes et al., 2017).*

Figure 6 Example of sector-specific load profiles: modelled Côte d'Ivoire demand, 2015



3.4 LOCAL TRANSMISSION AND DISTRIBUTION

T&D infrastructure requires investment to meet peak system demand. In SPLAT-W, the required investment in T&D infrastructure is modelled to exceed peak system demand by some margin, which in turn determines installed T&D capacity.[14] Costs and losses are defined for each demand category, reflecting the different levels of T&D infrastructure required. Off-grid technologies, requiring no T&D infrastructure, entail no costs and losses. Costs and losses for distribution through mini-grid solutions are not considered for the sake of simplification.

Assumptions around T&D costs and average losses are given in Table 3.[15] Costs are kept constant over time and assumed to be the lowest for heavy industry, moderate for urban and commercial demand, and highest for the rural demand category.

The assumptions on T&D losses are specific to each country, and fully detailed in Table 25 in Appendix D. For industry, losses are assumed to be 7 % in 2015 across all countries, and are reduced to 5 % by 2030. For the urban and commercial demand categories, they are assumed to range between 16 % and 22.5 % in 2015 depending on the country, falling to 13 % by 2030 in all countries.

Like costs, losses are highest for the rural demand category, and fall from 22.5–30 % in 2015 depending on the country, to 20 % by 2030 in all countries. The average T&D losses discussed here are used to calculate the levelised cost of electricity (LCOE) discussed in Section 3.7 (*Electricity generation options*).

Table 3 Assumptions for T&D infrastructure costs and losses

	Cost (USD/kW)	Losses (%)		
		2015	2020	2030
Heavy industry	160	7	7	5
Urban residential/commercial	320	16–22.5	15	13
Rural residential	460	22.5–30	25	25

Notes: The costs of the distribution technologies are modelled as investment cost based on the load factor of each of the demand categories and not as a variable cost; kW = kilowatt.

Source: IRENA analysis, incorporating data from WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy, www.ecowapp.org/en/documentation.

14 *Note that this is a simplified approach – the model does not represent specific domestic transmission or distribution lines, but rather assigns a generic investment cost for both transmission and distribution infrastructure to each unit of demand. Total investment in domestic T&D infrastructure is therefore a function of a country's sectoral demand and specified T&D losses.*

15 *Cost and loss assumptions by sector based on benchmarks from 2011/12 WAPP Master Plan, data provided by national experts present at IRENA's 2015–2016 regional SPLAT-W training workshops, and expert opinion from South African regional experience. Sectoral loss differences are developed to preserve mean overall value in source (2011/12 WAPP Master Plan). Losses displayed in tables are in terms of percentage of generation, and include non-technical losses.*

3.5 RENEWABLE RESOURCE POTENTIAL

Large hydropower

Large hydropower potential is summarised in Table 4. Detailed parameters for existing and planned hydropower projects are given in Table 17 and Table 19 in Appendix B. Unlike the 2013 edition of this report, in which generic large hydropower projects were allowed to be built in the SPLAT-W model, hydropower potential in this study is limited to the sites identified in the WAPP Master Plan (2011), with updates from national experts present at IRENA's 2015–2016 regional SPLAT-W training workshops. Like in the 2013 edition of this report, however, a "dry-year" scenario is still assumed for all hydropower sites in all years within the modelling horizon, across all scenarios.[16] 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.[17] In terms of modelling outcomes, both of these assumptions – the limitation of new generic large hydropower projects, and conservative dry-year power generation – have significant influence on national and regional energy system evolution.

Table 4 Existing and identified hydropower projects

	Existing hydropower	Identified hydropower projects
Country	Capacity	Capacity
	MW	MW
Benin	0	436
Burkina Faso	23	110
Cabo Verde	0	0
Côte d'Ivoire	585	1,179
Gambia	0	0
Ghana	1,580	307
Guinea	367	5,148
Guinea-Bissau	0	20
Liberia	5	967
Mali	249	240
Niger	0	359
Nigeria	1,900	3,750
Senegal	68	0
Sierra Leone	56	749
Togo	67	108
Total	**4,899**	**13,371**

Source: IRENA analysis, incorporating data from WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy, www.ecowapp.org/en/documentation.

16 *Plant-level dry-year capacity factors are based on WAPP (2011) and national team inputs during IRENA's 2015–2016 SPLAT-W training sessions. For detailed values see Appendix B.*

17 *A more comprehensive stochastic approach (as used in WAPP 2011) was not possible due to current limitations of the MESSAGE modelling platform.*

Other renewable energy potential

Estimates for the technical potential of non-large-hydropower renewable resources are shown in Table 5. Estimates of regional potential for solar photovoltaic (PV) and wind are based on analysis carried out in IRENA (2016a). Instead of categorising land in a binary way, as either "available" or "unavailable" for development, the analysis in that report takes an opportunity-based approach to measure resource potential, by ranking the quality of areas for development according to scores assigned to a range of relevant factors.[18]

Concentrated solar power (CSP) potential is based on unpublished updates of IRENA (2014a), which applies exclusion criteria (*e.g.* geographic, technical, ecological, legislative) to theoretical renewable energy potential derived from high-resolution solar irradiation and wind speed datasets (Helioclim-3 data for solar, provided by Mines ParisTech, and 9 kilometre [km] resolution wind data provided by Vortex).[19]

Small or mini-hydropower (<10 MW) data are based on estimates from the United Nations Industrial Development Organization and the International Center on Small Hydro Power (UNIDO and ICSHP, 2016). Biomass data have been updated based on analysis in both IRENA (2014a) and (2014b), and represent conservative technical resource potential for co-generation.

Table 5 Estimates of technical potential for other renewable energy

	Small hydro	Solar CSP	Solar PV	Biomass	Wind
	MW	MW	MW	MW	MW
Benin	187	0	3,532	761	322
Burkina Faso	38	0	82,556	1,075	9,881
Côte d'Ivoire	41	213	28,919	3,260	2,548
Gambia	12	953	428	60	44
Ghana	1,245	229	20,295	4,449	2,014
Guinea	198	2,774	37,569	1,732	2,114
Guinea-Bissau	0	2,583	1,043	205	101
Liberia	66	41	2,871	1,375	192
Mali	117	103,658	298,812	447	7,962
Niger	0	171,136	442,931	266	54,156
Nigeria	735	36,683	492,471	7,291	44,024
Senegal	0	5,424	37,233	466	4,531
Sierra Leone	330	111	1,885	587	131
Togo	144	0	2,686	378	73

Note: TWh = terawatt hour.

Source: IRENA analysis, incorporating data from UNIDO and ICSHP (2016), World Small Hydropower Development Report 2016, www.smallhydroworld.org/menu-pages/reports/2016/.

18 *Six factors were included in the analysis: renewable energy resource intensity, distance to the grid, population density, topography, land cover, and protected areas. Underlying datasets include wind speed (1 km resolution, from DTU Global Wind Atlas) and solar irradiation (global horizontal irradiance) (1 km resolution, HelioClim-3 data from MINES ParisTech). For further detail on methodology and underlying data, see IRENA (2016a).*

19 *As in the previous edition of this report, the solar and wind potential shown here may underestimate actual potential in some areas, due to conservative assumptions regarding the use of land areas. Even so, they are still vast enough that no country would be expected to reach its resource constraints by 2030.*

3.6 FUEL AVAILABILITY AND PRICES

Assumptions on fuel availability in the ECOWAS region are summarised in Table 6.

Three types of gas are assumed to be available for supply: locally produced gas (in Côte d'Ivoire, Ghana and Nigeria); Nigerian gas, supplied through the Western African Gas Pipeline (in Benin, Ghana and Togo, with eventual extension to Côte d'Ivoire);[20] and imported liquefied natural gas (LNG) (in other coastal countries).[21]

For petroleum products, three types of fuel are distinguished: heavy fuel oil (HFO), distillate diesel oil (DDO) and light crude oil (LCO). Different prices are assumed for petroleum products delivered to coastal countries as opposed to inland countries.

For coal, only Nigeria and Niger are assumed to have resources for local production. All coastal countries other than Nigeria have the option of coal imports, which are assumed to be available. Inland countries other than Niger are assumed to have no domestic coal resource or coal transport infrastructure, and costs to these countries are assumed to be prohibitively expensive.

For biomass, two fuel types are distinguished: moderately priced biomass and more expensive biomass in countries where biomass resource is relatively scarce. Countries where the agricultural industry could potentially make biomass available to the power sector were allocated to the moderate category, while resources in Cabo Verde and the three inland countries of Burkina Faso, Mali and Niger are assumed to be scarce, based on analysis presented in Section 3.5 (*Renewable resource potential*).

The price evolution assumed for the fuel categories described above is summarised in Table 7 and Figure 7 below. While fuel prices in the previous edition of this report were based on those in the 2011/12 WAPP Master Plan, which were derived from an assumed benchmark oil price of USD 100 per barrel, price evolution in this update is largely based on the IEA New Policies Scenario in its 2016 *World Energy Outlook* (2016).[22] Although the fossil fuel price trajectory is still assumed to be increasing, the base-year price level of fossil fuels in this update is noticeably lower, reflecting the recent global commodity price slump. As fuel prices are critical determinants of future technology choice, price sensitivity analyses are recommended as part of any further expansion of the modelling undertaken in this report.

20 Assumed that the option for Côte d'Ivoire to access regional pipeline supply occurs in 2025 at the earliest.

21 Annual limits are placed on gas availability via domestic production and pipeline supply, based on national documents detailing typical production and pipeline flow values. While this analysis does not set cumulative production limits across the modelling horizon to reflect proven commercial reserve estimates, the results presented here have been cross-checked and reflect plausible levels of gas infrastructure development and utilisation over the modelling horizon. Supply of LNG is not tied to specific projects or regasification terminals, but rather assumed to be available given the existing use of floating storage regasification terminals in the region – the timeline of this availability is an area for further improvement by local experts.

22 High-level benchmarks (e. g. crude oil and LNG price) are first taken from the IEA New Policy Scenario, with more granular oil/diesel and natural gas categories derived from the price ratios between those categories in the WAPP Master Plan. Given the correspondence of South African and Australian thermal coal prices, Coastal China was used as a benchmark for the imported coal price, corrected for freight rate differential to reflect transport from South Africa to West Africa. The domestic coal price in Niger and Nigeria continues to be set at a lower level in this update, based on Idrissa (2004). The price of biomass, produced domestically, is assumed to remain constant over the planning horizon, and remains based on the projections in the 2011/12 WAPP Master Plan.

Table 6 Assumptions on fuel availability

	Coal	Gas	Oil	Biomass
Benin	Import	Pipeline/LNG	Coastal	Moderate
Burkina Faso	n/a	n/a	Inland	Scarce
Cabo Verde	Import	LNG	Coastal	Scarce
Côte d'Ivoire	Import	Domestic/pipeline/LNG	Coastal	Moderate
Gambia	Import	LNG	Coastal	Moderate
Ghana	Import	Domestic/pipeline/LNG	Coastal	Moderate
Guinea	Import	LNG	Coastal	Moderate
Guinea-Bissau	Import	LNG	Coastal	Moderate
Liberia	Import	LNG	Coastal	Moderate
Mali	n/a	n/a	Inland	Scarce
Niger	Domestic	n/a	Inland	Scarce
Nigeria	Domestic	Domestic	Coastal	Moderate
Senegal	Import	LNG	Coastal	Moderate
Sierra Leone	Import	LNG	Coastal	Moderate
Togo	Import	Pipeline	Coastal	Moderate

Note: n/a = not applicable.

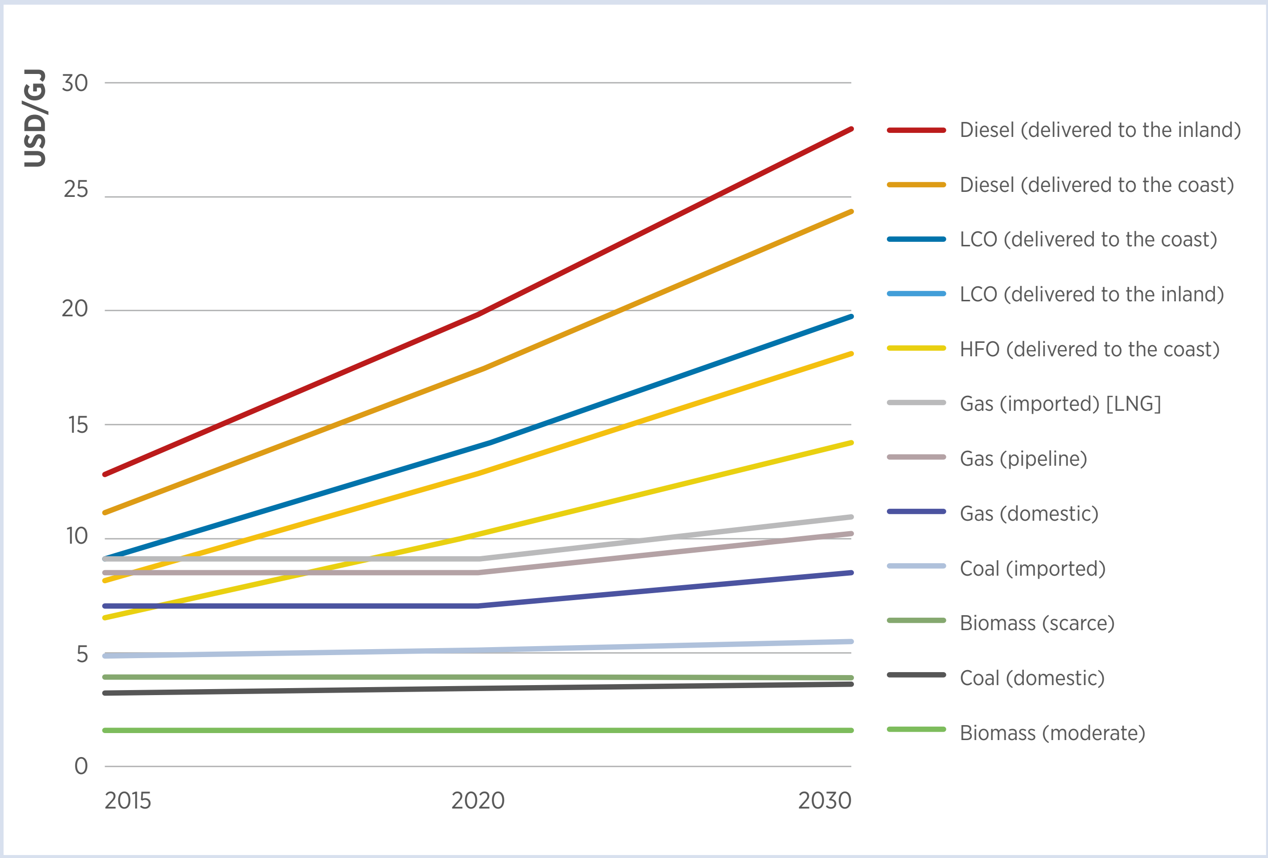
Table 7 Fuel price projections

USD/GJ	2015	2020	2030
HFO (delivered to the coast)	6.6	10.2	14.3
HFO (delivered inland)	8.3	12.9	18.1
Diesel (delivered to the coast)	11.2	17.3	24.3
Diesel (delivered inland)	12.9	19.9	28.0
LCO (delivered to the coast)	9.1	14.1	19.8
Gas (domestic)	7.1	7.1	8.5
Gas (pipeline)	8.6	8.6	10.3
Gas (imported) [LNG]	9.2	8.7	11.0
Coal (domestic)	3.3	3.4	3.6
Coal (imported)	4.9	5.1	5.5
Biomass (moderate)	1.6	1.6	1.6
Biomass (scarce)	3.9	3.9	3.9

Note: GJ = gigajoule.

Source: IRENA analysis, incorporating data from IEA (2016), World Energy Outlook 2016, http://dx.doi.org/10.1787/weo-2016-en*; WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy,* www.ecowapp.org/en/documentation*; and Idrissa (2004), "Projet de création d'une société de traitement et de commercialisation du charbon minéral à des fins domestiques (SNTCD)",* www.cilss.bf/predas/Activites%20par%20Pays/NE/34Projet%20de%20creation%20societe%20charbon%20mineral.pdf*.*

Figure 7 Fuel price projections



3.7 ELECTRICITY GENERATION OPTIONS

The core of IRENA's SPLAT model is its power system database, which consists of existing generation and international transmission capacity in the ECOWAS region, as well as a range of future technology options.

Existing generating capacity

Existing power generation in the ECOWAS region, based on the 2011/12 WAPP Master Plan in the previous edition of this report, has been updated by IRENA and national experts present at IRENA's 2015–2016 regional SPLAT-W training workshops.[23]

A summary of existing generation capacity is presented in Table 8 below. As of 2015, installed power generation capacity in the ECOWAS region stood at roughly 20 GW, of which Nigeria accounted more than a half.[24] Detailed parameters surrounding existing capacity by country are given in Appendix B.

23 IRENA has conducted the update of data for four countries not in attendance at the 2015–2016 regional SPLAT-W training workshops – Côte d'Ivoire, Ghana, Guinea-Bissau and Nigeria.

24 A significant portion of this installed capacity in Nigeria (nearly 40 %) is known to be unavailable for various techncal reasons.

Table 8 Existing power generation capacity as of 2015 (MW)

	Oil	Gas	Coal	Hydro	Biomass	Solar	Wind	Total
Benin	77	100	0	0	0	0	0	**177**
Burkina Faso	256	0	0	23	0	0	0	**279**
Cabo Verde	165	0	0	0	0	5	9	**179**
Côte d'Ivoire	0	1,628	0	585	0	0	0	**2,213**
Gambia	84	0	0	0	0	0	0	**84**
Ghana	690	310	0	1,580	0	3	0	**2,583**
Guinea	252	0	0	367	0	0	0	**619**
Guinea-Bissau	19	0	0	0	0	0	0	**19**
Liberia	23	0	0	5	0	0	0	**27**
Mali	300	0	0	249	0	10	0	**560**
Niger	92	20	32	0	0	0	0	**144**
Nigeria	0	10,302	0	1,900	0	0	0	**12,202**
Senegal	605	49	0	68	0	0	0	**721**
Sierra Leone	21	0	0	56	8	0	0	**85**
Togo	49	120	0	67	0	0	0	**235**
Total	**2,631**	**12,529**	**32**	**4,899**	**8**	**18**	**9**	**20,126**

Future generating capacity options

Two types of future power generation options are available in the model: site-specific projects and generic technology options.

Site-specific projects – originally based on the project listings in the 2011/12 WAPP Master Plan – have been updated based on national expert input during IRENA's 2015–2016 regional SPLAT workshops, IRENA research and the 2016–2019 WAPP Business Plan. Projects are specified by unit size, capacity factor, efficiency, O&M costs, investment costs, etc.

Some site-specific projects are already "committed" and are thus included as part of the future energy mix. Other projects are in a separate "under consideration" category and may or may not be included in the optimal solution computed by the model under a set of assumptions for the respective scenarios. A summary of site-specific project capacity is presented in Table 9 below, with more detailed tables provided in Appendix B. Committed projects are commissioned at fixed dates, while projects under consideration are regarded as investment options from 2016 to the end of the study horizon.

Table 9 Capacity of planned and committed (second row) projects (MW)

	Oil	Gas	Coal	Hydro	Biomass	Solar	Wind	Total
Benin	0	810	0	436	20	135	10	1,411
	0	570	0	436	0	40	0	1,046
Burkina Faso	346	0	0	110	0	147	0	603
	8	0	0	38	0	147	0	192
Cabo Verde	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
Côte d'Ivoire	0	450	0	1,179	0	0	0	1,629
	0	0	0	0	0	0	0	0
Gambia	44	0	0	0	0	3	1	48
	44	0	0	0	0	3	1	48
Ghana	525	445	0	307	0	20	225	1,522
	425	430	0	0	0	20	225	1,100
Guinea	131	0	0	5,148	0	92	0	5,370
	125	0	0	1,332	0	0	0	1,457
Guinea-Bissau	0	0	0	20	0	0	0	20
	0	0	0	0	0	0	0	0
Liberia	28	0	0	967	8	0	0	1,003
	28	0	0	66	0	0	0	94
Mali	166	0	0	240	33	30	0	470
	0	0	0	140	0	0	0	140
Niger	97	8	625	359	0	7	30	1,125
	0	0	0	130	0	7	0	137
Nigeria	0	6,300	0	3,750	0	0	0	10,050
	0	0	0	0	0	0	0	0
Senegal	122	0	425	0	0	130	150	827
	122	0	125	0	0	0	150	397
Sierra Leone	57	0	0	749	8	11	0	824
	57	0	0	0	8	11	0	76
Togo	0	200	0	108	0	45	25	378
	0	0	0	0	0	0	0	0
Total	**1,516**	**8,213**	**1,050**	**13,371**	**69**	**620**	**441**	**25,279**
	809	**1,000**	**125**	**2,141**	**8**	**228**	**376**	**4,686**

Source: IRENA analysis, incorporating data from WAPP (2015), 2016–2019 WAPP Business Plan, www.ecowapp.org/en/documentation.

In the SPLAT-W model, electricity demand that cannot be met by existing technologies and committed projects requires the further development of site-specific projects that are under consideration but not yet committed, and/or generic power generation technologies.

Generic power generation technologies are modelled without a specific reference to any unit size, although limits on annual deployment are enforced. Certain technologies are assumed to provide electricity only via the grid (*i. e.* connected to upstream transmission), while others are assumed to provide on-site electricity.

For thermal technologies, the following are included as generic options:

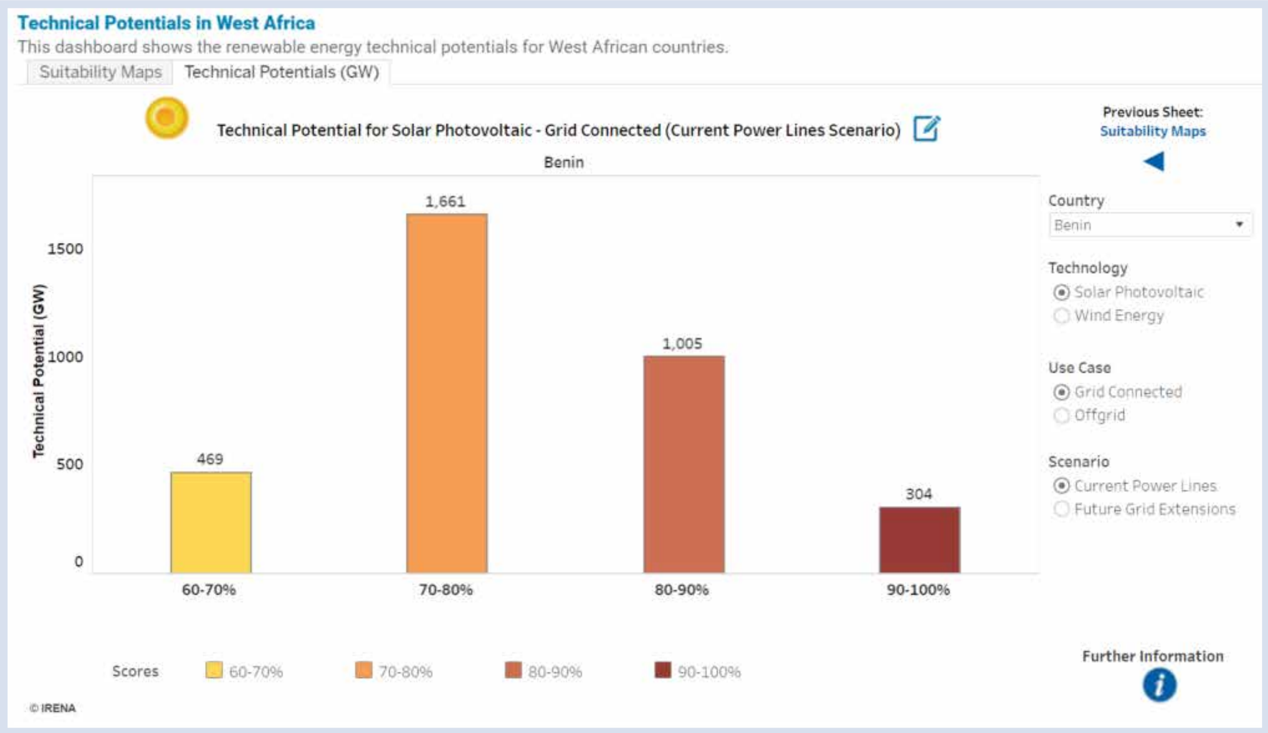
- **Diesel/gasoline 1 kW system** to supply urban and rural demand.
- **Diesel 100 kW system** to supply industrial demand.
- **Diesel centralised** connected to upstream transmission.
- **Heavy fuel oil** connected to upstream transmission.
- **Open-cycle gas turbine (OCGT)** connected to upstream transmission.
- **Combined-cycle gas turbine (CCGT)** connected to upstream transmission.
- **Supercritical coal** connected to upstream transmission.

For renewable energy technologies, the following are included as generic options:

- **Small or mini-hydropower (<10 MW)** to supply rural demand.
- **Onshore wind** connected to upstream transmission.
- **Biomass** mainly in the form of co-generation to be consumed on site, with surplus exported to the grid (upstream of transmission).
- **Utility-scale solar PV** or PV farms managed by the utility and connected to upstream transmission.
- **Distributed or rooftop solar PV** to supply either urban residential, commercial and small industry demand, or rural residential and commercial demand.
- **Distributed or rooftop solar PV with 2 hours of storage** in the form of a battery, for extended use beyond daylight hours.
- **CSP** in the form of medium- to large-scale CSP connected to upstream transmission.
- **CSP with storage** in the form of medium- to large-scale CSP with thermal storage, able to supply electricity during the daytime and in the evening.

Detailed technical parameters for these generic technologies (*e. g.* load factor, O&M costs, efficiency, construction duration, lifetime) are summarised in Table 20 in Appendix C. As discussed in Section 3.5 (*Renewable resource potential*), only site-specific projects are included as future generation options for large hydropower.

Figure 8 Country-level detail on technical potential (MW) by suitability category: Example of solar PV in Benin



Source: IRENA (2016a), Investment Opportunities in West Africa: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Figure taken from IRENA's REsource Knowledge Gateway (resourceirena.irena.org/gateway).

Variable renewable power generation

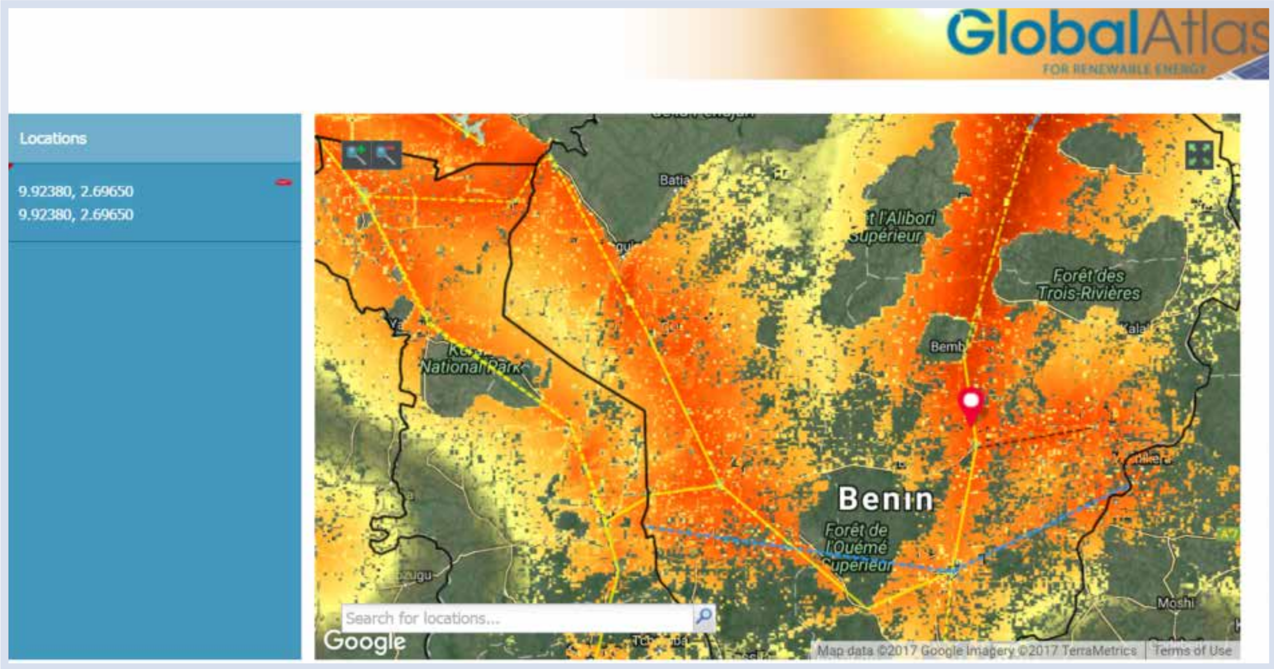
Model treatment of VRE generation (*i.e.* onshore wind and solar PV) has been improved as part of the update to this report. Rather than assigning a generic capacity factor to all wind and solar PV installations, the SPLAT-W model has been updated to reflect individual generation profiles for each ECOWAS member country, at a more refined time resolution.

To develop country-specific generation profiles, broadly representative wind and solar resource locations were first chosen based on IRENA's 2016 report *Investment Opportunities in West Africa: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind* (2016a).

That report provides pre-feasibility assessment of solar and wind opportunities, resulting in a high-resolution (1 km) suitability map of the ECOWAS region that accounts for a range of exclusion criteria.[25] The map was used to select locations in each country's most prevalent suitability category (*e.g.* 80–90% suitable), situated on relatively flat land, and near existing transmission infrastructure. An example of the representative solar PV location selection in Benin can be seen in Figure 8 and Figure 9.

25 This resource map, along with a range of other GIS data visualisations, can be found on IRENA's online Global Atlas platform: www.irena.org/globalatlas.

Figure 9 Selection of representative resource locations using suitability maps on IRENA's Global Atlas: Example of solar PV in Benin



Source: IRENA (2016a), Investment Opportunities in West Africa: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects. Map taken from: http://irena.masdar.ac.ae/?map=2742. *Map data: IRENA, Google and TerraMetrics.*

For each representative country location, hourly annual solar irradiation and wind speed datasets from the past 30 years were provided by Vortex, based on NASA's MERRA dataset. This was done as part of IRENA's Solar and Wind Site Appraisal Programme.

To preserve the variability inherent in the wind and solar time series, hourly annual country data from one representative historical year were used, rather than a 30-year average. The choice of representative year was based on proximity of the year's annual average capacity factor to the 30-year average. Only years from a subset of regional dry years were considered, to correspond with this analysis' dry-year hydropower generation assumption across all scenarios.

For final input into the SPLAT-W model, the resulting hourly generation profiles for wind and solar PV in each country in the ECOWAS region were then calibrated into 30 annual time slices (3 seasons, 10 daily time blocks) to correspond with the model's updated load profile categorisation. While long-term generation expansion models such as SPLAT-W are not designed to assess the full impact of VRE deployment, the increased temporal model resolution and improved time slice calibration described above can be critical to better model the economic impact of VRE, by capturing the potential alignment of VRE supply and variable demand, and the time-linked operational constraints of a power system (*e.g.*, flexibility), among other aspects.[26]

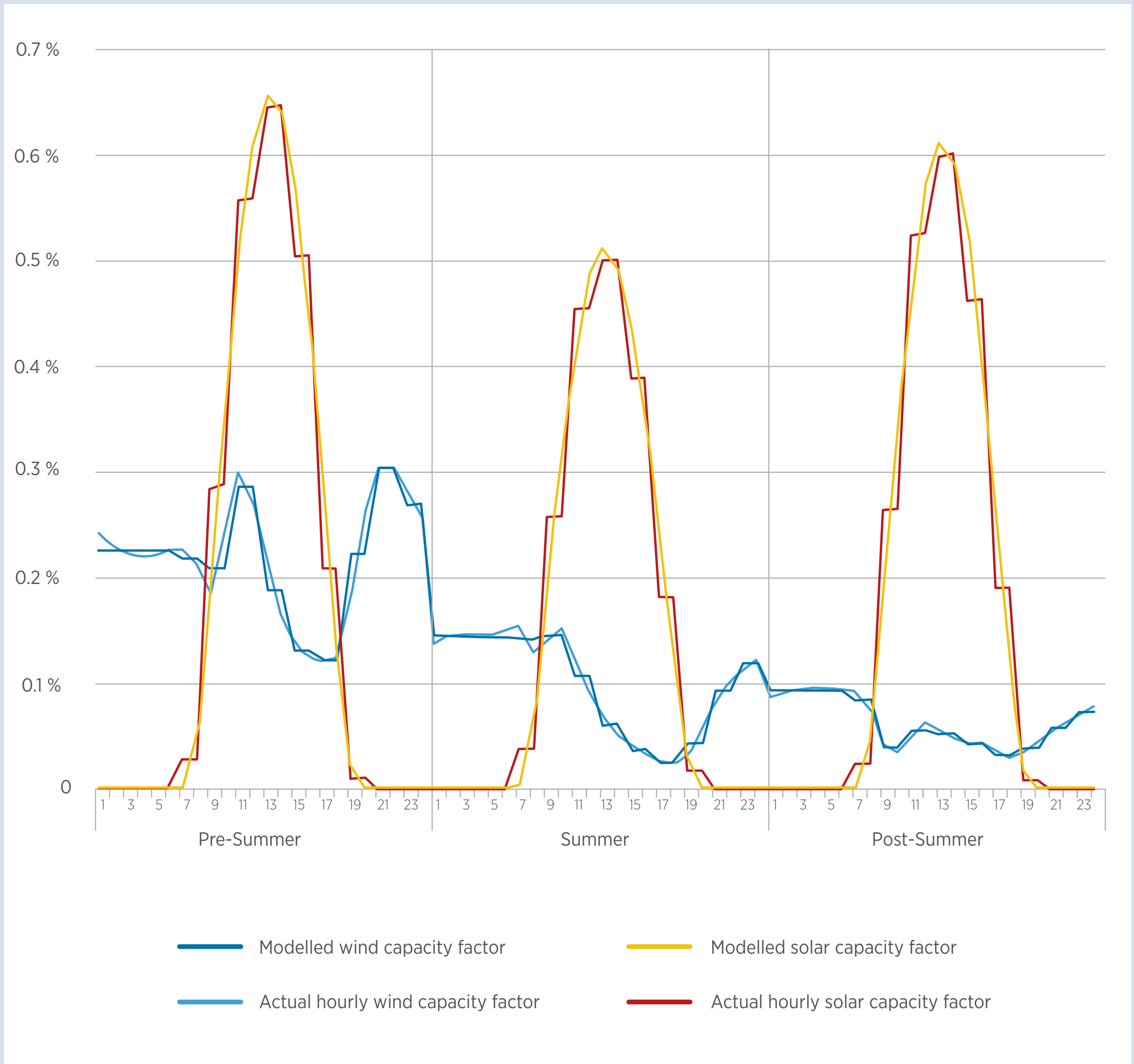
The average annual country-specific solar and wind capacity factors employed in this study are presented in Table 10. An example of actual hourly wind and solar generation profiles for Benin (in light blue and light orange), and the SPLAT-W model's time slice approximation for those profiles (in dark blue and dark orange) is given in Figure 10.

Table 10 Solar PV and wind capacity factor by country

	Solar PV	Wind
Benin	18.8 %	12.6 %
Burkina Faso	20.5 %	19.1 %
Cabo Verde	20.4 %	27.6 %
Côte d'Ivoire	19.2 %	12.7 %
Gambia	20.0 %	10.9 %
Ghana	19.5 %	16.5 %
Guinea	20.2 %	14.4 %
Guinea-Bissau	19.7 %	15.3 %
Liberia	17.6 %	5.3 %
Mali	20.5 %	21.7 %
Niger	21.9 %	38.2 %
Nigeria	19.2 %	15.7 %
Senegal	20.4 %	27.6 %
Sierra Leone	18.1 %	7.9 %
Togo	19.3 %	15.0 %

26 In addition to increased or improved temporal resolution, future analyses would do well to also expand upon the geospatial resolution of VRE options. An example of one methodology and data available for better geospatial representation can be found in IRENA's Renewable Energy Zones for the Africa Clean Energy Corridor report (IRENA and LBNL, 2015).

Figure 10 Example of SPLAT-W hourly solar PV and wind generation profiles: Benin

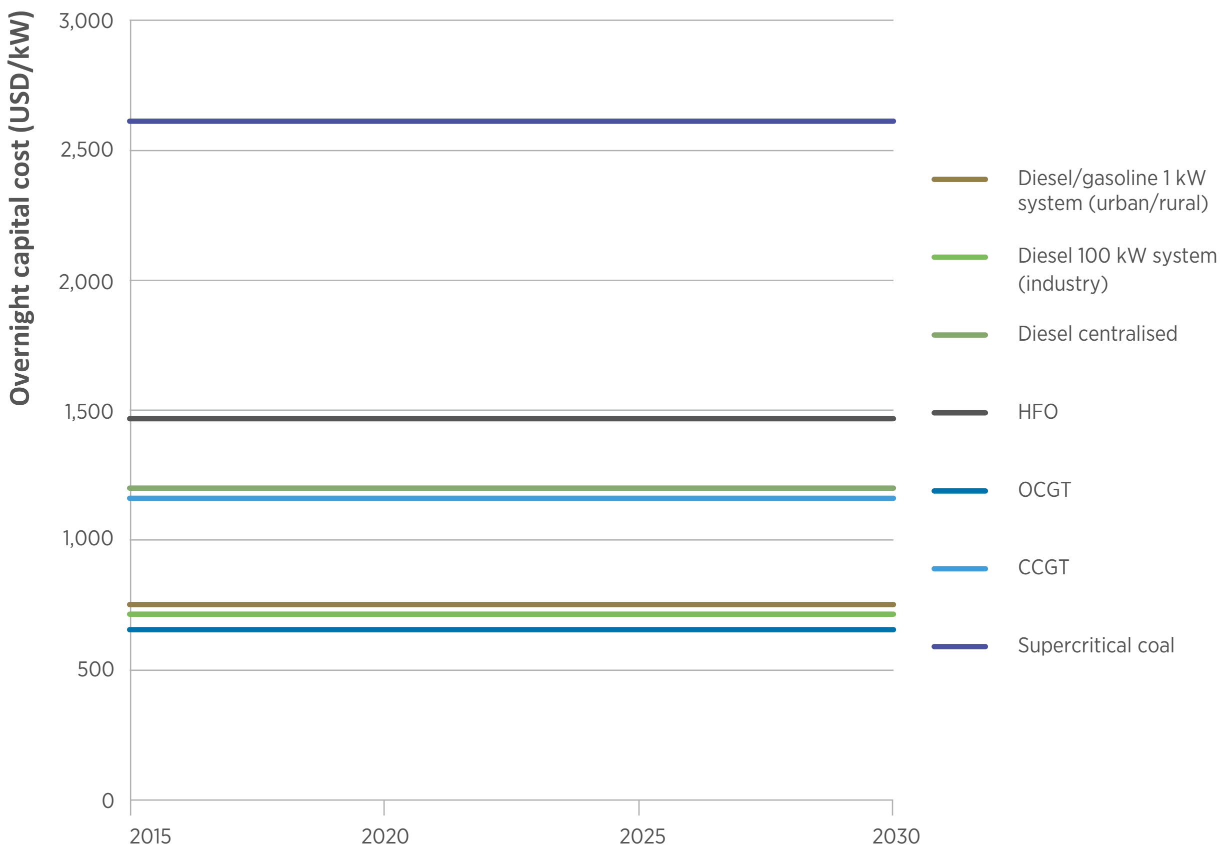


Cost of future power generation options

Figure 11 shows the overnight investment cost assumptions for generic non-renewable thermal generation technologies. As in the previous edition of this report, these assumptions are mainly based on the 2011/12 WAPP Master Plan, with the exception of distributed diesel generators, where parameters are sourced from the World Bank (2007).

No cost reduction is assumed for non-renewable technologies in the scenarios explored in this report.

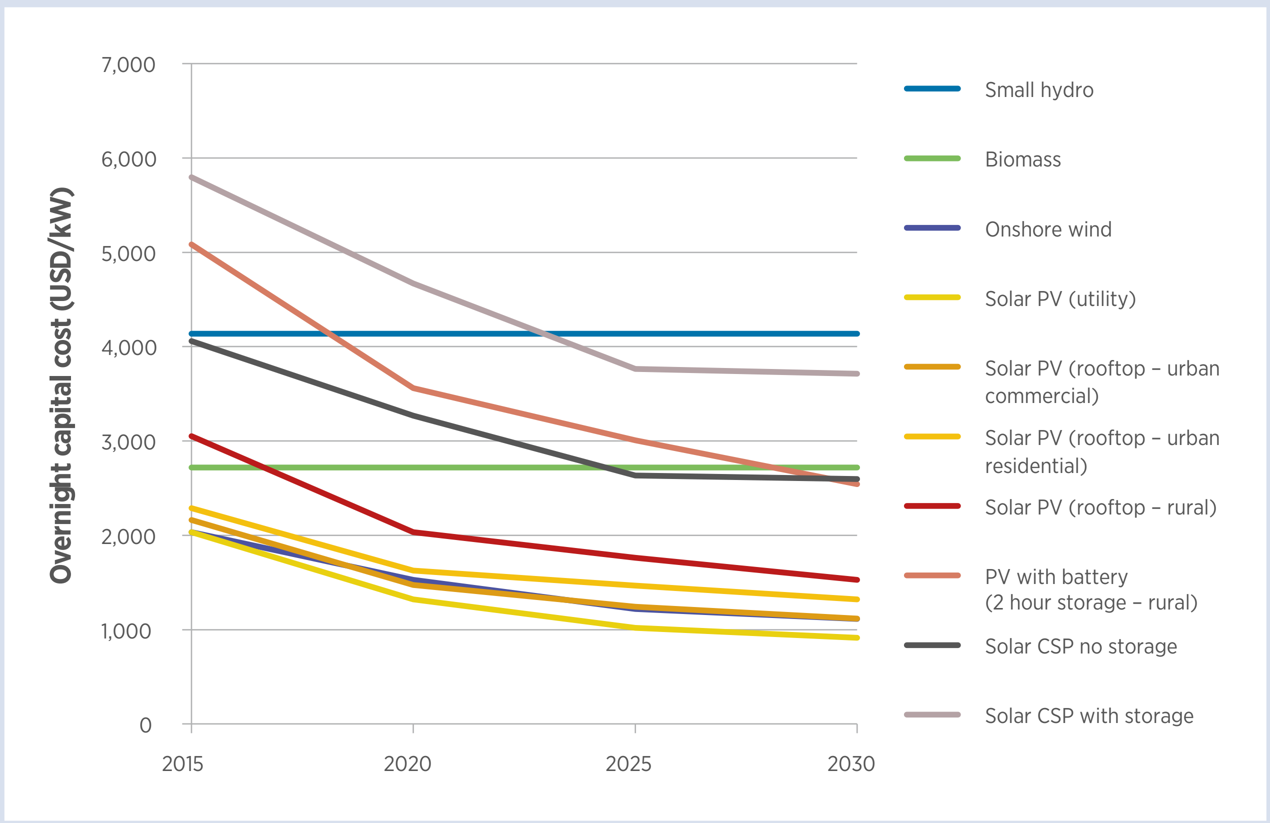
Figure 11 Overnight investment cost assumptions for generic non-renewable technologies



Source: IRENA analysis, incorporating data from WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy, www.ecowapp.org/en/documentation*; World Bank (2007), Technical and Economic Assessment of Off-Grid, Mini-Grid and Grid Electrification Technologies (English),* http://documents.worldbank.org/curated/en/634581468333897517/Technical-and-economic-assessment-of-off-grid-mini-grid-and-grid-electrification-technologies.

Figure 12 shows the overnight investment cost assumptions for generic renewable generation technologies. Investment costs of certain renewable technologies have fallen drastically in recent years, and all scenarios explored in this report reflect a continuation of that trend to some extent. The assumed cost reductions for solar PV have been updated in this report to reflect the latest research by IRENA on project costs in Africa (2016b), and the remaining renewable cost assumptions are based on the most recent updates to IRENA's internal costing database.

Figure 12 Overnight investment cost assumptions for generic renewable technologies



The LCOE of generic future power generation options, although not a model input, is presented for reference in Table 11, based on the above assumptions around current and projected investment costs, fuel costs, O&M costs, capacity factor, generation capacity and expected years of operation. T&D costs and losses in delivery for the three specified consumer groups in the SPLAT model (as detailed previously in Table 3) are included in the LCOE calculation for electricity delivered through the grid.[27]

As generation profiles of generic wind and solar PV technologies are country-specific, the LCOE for these technologies is similarly country-specific – for reference the LCOE values for wind and solar PV technologies in Senegal are presented in Table 11. For LCOE values of wind and solar PV technologies by country, see Appendix C.

Notably, technology choice in the SPLAT model is not based solely on the factors behind LCOE: system requirements in terms of both reliability

27 E. g.: LCOE for the industrial customer = LCOE of generation / (1-loss) + T&D costs of industry.

and the correlation of supply and demand profiles are also taken into account during optimisation. Additionally, the LCOE results shown here assume a load factor equal to the availability factor of the technologies (for availability factors by technology see Appendix B and Appendix C). Given differences in investment and fuel costs, the ranking of different technologies would change at different load factors. For example, gas plants at an 80 % load factor may be less competitive than coal on a levelised basis, but more competitive at a 40 % load factor. Diesel or OCGT would be competitive at very low load factors and may well play a role in meeting peak loads, which occur for short durations.

The MESSAGE platform on which the SPLAT model is built accounts for such aspects in its optimisation, and results may therefore differ from what could be expected from a simple LCOE analysis.

As noted earlier, generic technology options and costs are not applicable to large hydropower in the SPLAT-W model, as only site-specific projects are included as future generation options. Figure 13 shows the LCOE range for the large hydropower projects that are included in the latest model update as future options. Costs are highly site-dependent and can vary considerably from one plant to the next.

Table 11 LCOE assumptions for generic power technologies

LCOE (USD/MWh)	Generation		Industry		Urban		Rural	
	2015	2030	2015	2030	2015	2030	2015	2030
Diesel/gasoline 1 kW system (urban/rural)	311	607	n/a	n/a	311	607	311	607
Diesel 100 kW system (industry)	131	266	131	266	n/a	n/a	n/a	n/a
Diesel centralised	138	273	148	288	171	313	188	360
HFO	98	178	105	187	121	203	133	234
OCGT (imported gas/LNG)	123	144	132	152	157	165	172	190
OCGT (pipeline gas)	116	136	124	143	143	156	157	179
OCGT (domestic gas)	91	106	98	112	108	122	128	140
CCGT (imported gas/LNG)	92	105	98	111	117	120	129	138
CCGT (pipeline gas)	87	100	94	105	108	114	119	131
CCGT (domestic gas)	72	81	77	86	85	93	101	107
Supercritical coal (imported)	97	103	105	108	124	117	137	135
Supercritical coal (domestic)	83	86	89	91	98	99	109	114
Biomass	95	95	102	100	117	109	129	125
Small hydropower	134	134	n/a	n/a	n/a	n/a	134	134

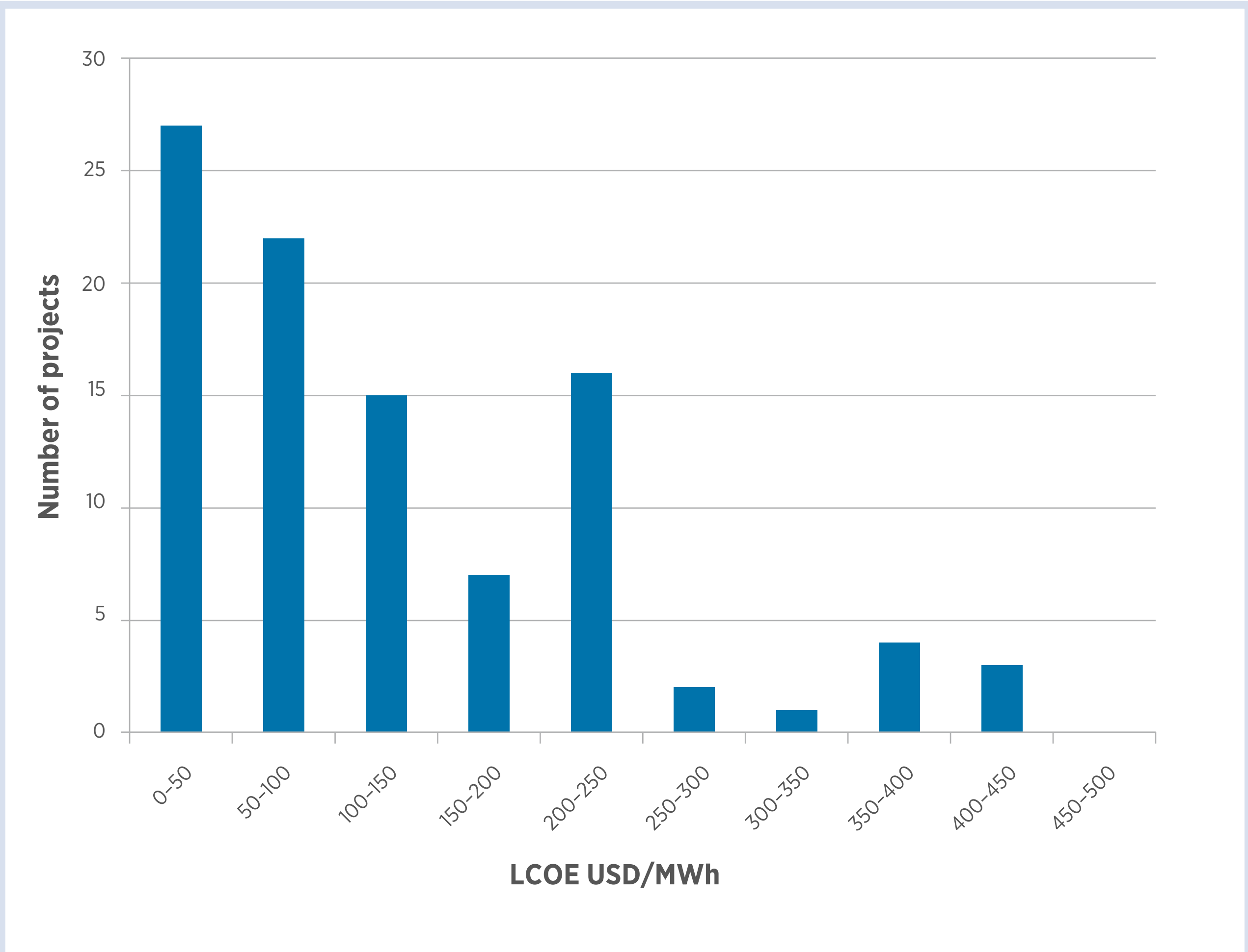
Note: MWh = megawatt hour.

Table 12 LCOE assumptions for generic variable power technologies: example of Senegal

LCOE (USD/MWh)	Generation		Industry		Urban		Rural	
	2015	2030	2015	2030	2015	2030	2015	2030
Solar PV (rooftop – commercial)	203	109	203	109	203	109	203	109
Solar PV (rooftop – rural)	420	218	n/a	n/a	n/a	n/a	420	218
Solar PV (rooftop – urban)	213	126	n/a	n/a	213	126	n/a	n/a
Solar PV with 2 h storage (rooftop – rural)	864	455	n/a	n/a	n/a	n/a	864	455
Solar PV with 2 h storage (rooftop – urban)	228	132	n/a	n/a	228	132	n/a	n/a
Solar PV (utility)	143	68	153	72	177	78	194	89
CSP no storage	327	209	351	220	406	239	444	275
CSP with storage	332	212	357	224	412	243	451	280
Wind far from grid	154	94	166	99	192	108	210	124
Wind near grid	136	77	147	81	170	88	185	101

Note: MWh = megawatt hour; n/a = not applicable; h = hour.

Figure 13 LCOE: Distribution of 97 site-specific large hydropower projects



3.8 CROSS-BORDER TRADE

Trade between countries is limited by existing infrastructure and planned transmission projects. Any hypothetical projects that are not currently identified are not included as options. Existing transmission infrastructure and planned projects for transmission are based on the WAPP Master Plan and are summarised in Table 13 and in Table 14, with further details in Appendix D. The earliest year that new cross-border transmission lines can be built has been updated in this report, based on input from national experts, the 2016–19 WAPP Business Plan, and IRENA research. These updated assumptions largely reflect delays to projects that were expected to be completed over the past several years.

Importantly, unlike the 2013 edition of this report, the option to import electricity from the Central African region is no longer included in the scenarios analysed here, as it is not included as a key expectation in the 2011/12 WAPP Master Plan or recent regional discussions.

Table 13 Existing cross-border transmission infrastructure summary

Country 1	Country 2	Line capacity (MW)
Ghana	Côte d'Ivoire	327
Ghana	Togo	438
Senegal	Mali	100
Côte d'Ivoire	Burkina Faso	327
Nigeria	Benin	686
Togo	Benin	345
Nigeria	Niger	169

Source: IRENA analysis, incorporating data from WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy, www.ecowapp.org/en/documentation.

Table 14 New cross-border transmission projects

Project name	Capacity of line (MW)	Earliest year
Committed projects		
Dorsale 330 kV (Ghana, Togo/Benin, Côte d'Ivoire)	~650	2017–2019
CLSG (Côte d'Ivoire, Liberia, Sierra Leone)	~330	2018
OMVG (Senegal, Guinea, Gambia, Guinea Bissau)	~315	2019
Hub Intrazonal (Ghana, Burkina Faso, Mali, Côte d'Ivoire, Guinea)	~320	2017–2020
Planned projects		
Corridor Nord (Nigeria, Niger, Togo/Benin, Burkina Faso)	~650	2020
Dorsale Mediane (Nigeria, Togo/Benin, Ghana)	~650	2020
OMVS (Mali, Senegal)	~330	2020

Notes: CLSG = Interconnection Côte d'Ivoire-Liberia-Sierra Leone-Guinea; kV = kilovolt; OMVG = The Gambia River Basin Development Organisation; OMVS = Senegal River Basin Development Organisation.

Source: IRENA analysis, incorporating data from WAPP (2011), Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy, www.ecowapp.org/en/documentation*; WAPP (2015), 2016–2019 WAPP Business Plan,* www.ecowapp.org/en/documentation.

3.9 CONSTRAINTS RELATED TO SYSTEM AND UNIT OPERATION

In the SPLAT-W model, key system constraints are introduced to ensure the system is reliably operated, and that variable renewable generation – *i.e.* wind and solar power – is represented more accurately.

Reserve margin

To ensure power system reliability, excess operational capacity needs to be installed over and above peak demand requirements. This is referred to as a reserve margin and is defined as the difference between operable capacity and the peak demand for a particular year, as a percentage of peak demand. In all scenarios, a minimum reserve margin constraint of 10 % has been imposed on every country.[28] Only "firm" capacity, which is guaranteed to be available to meet demand, is considered to contribute to this requirement.

The "capacity credit", or the share of capacity that is considered firm, is set to 1.0 for dispatchable technologies such as thermal and large hydropower with dams.[29] For variable renewable generation technologies, however, the capacity credit values that can be applied in such a modelling exercise typically depend on a statistical analysis of the correlation between a country's variable resource and its demand profile.

The capacity credit of these technologies wis generally lower than their capacity factor, as no single site can be relied upon to generate power at any given time, considering the natural variability of wind and solar conditions. As reflected in the following section, the capacity credit of solar PV and wind is treated conservatively in this report, given that no country-level analysis has been performed.

The reserve margin constraint is defined as follows:

$$\sum_{i=1}^{n} \alpha(i) C_P(i) \geq (1 + RM)D$$

Where:

- α*(i)* is the capacity credit given to plant/technology *(i)* or share of capacity that is accounted as "firm" (fraction)
- $C_p(i)$ is the capacity of power plant/technology *(i)* in MW (centralised only)
- *D* is the peak demand on the centralised grid system in MW
- *RM* is the reserve margin (fraction).

28 While reserve margin is defined in the model, progress toward this target for countries currently below the 10 % level is practically constrained by the combination of existing capacity and available future capacity options in a given year. This essentially results in a gradual approach to 10 % reserve margins in certain contexts.

29 Note that capacity credit values assigned to conventional generation can depend on the methodology behind the value calculation. Values less than 1.0 are reasonably applied to account for plant availability in certain approaches.

Constraints on variable renewables

Given that the model has an aggregate representation of the load, the variability of wind and solar PV is accounted for in an aggregate and conservative manner:

- **Flexibility of dispatch**: Both wind and solar PV are not given any flexibility in the way they can be dispatched to meet demand.

- **Capacity credit**: Centralised solar PV plants are given a 5 % capacity credit, and wind capacity is not considered to contribute to the reserve margin.[30]

In addition to conservative assumptions regarding the contribution of wind and solar PV to the reserve margin (*i.e.* their capacity credit), upper limits on the share of centrally dispatched generation (upstream of transmission) coming from these sources have also been set for all countries in this analysis – 25 % for wind and 50 % for solar PV on an annual basis, and 70 % for both sources combined on an instantaneous (*i.e.* hourly) basis.

These generic constraints have been assumed to ensure reliable systems are projected, in the absence of country-specific analyses of capacity credit values and/or operational constraints related to system flexibility. Performing such country-specific analyses would help to refine the constraints applied here, by capturing dynamics such as the potential increase in firm capacity of wind and solar PV due to the geographical spread of resources, which may reduce meteorological variability through diversification of site-specific generation profiles.

Load-following capability of power plants

There are some technical limitations as to how fast certain thermal plants – such as coal or biomass – can ramp up or down production. To represent this limitation, all coal plants in the model were de-rated by (1-availability). For example, a 100 MW coal plant with an availability of 85 % can only produce up to 85 MW at any given point in time. Biomass power plants were de-rated by the availability factor (50 %).

Run-of-river (ROR) hydropower plants as well as mini-hydropower options are modelled as non-dispatchable, with capacity de-rated by (1-availability). While seasonal generation profiles of ROR sites may warrant further investigation in more detailed analyses, they have not been incorporated in this report. Hydropower plants with dams are modelled as dispatchable to reflect the more flexible operation that a dam allows.

30 Detailed country-specific analyses of variable renewable production are recommended to improve upon these simplified assumptions. Note that solar PV could alternatively be modelled without a capacity credit, though sensitivity analysis run in parallel to this analysis found that the value assigned is not unduly favourable, with regional solar PV capacity deployment only marginally affected (e.g. decrease of <3 % by 2030 in the National Targets Scenario) if the technology is not considered to contribute to the reserve margin.

MODELLING RESULTS

4

4.1 REFERENCE SCENARIO

As discussed in Section 3.1 (*General definition of scenarios*), the Reference Scenario in this study represents a wide-ranging update to the work presented in the 2013 edition of this report. The Reference Scenario here has been updated to reflect, *inter alia*, national expert input during IRENA's 2015–2016 regional SPLAT training (particularly regarding generation and transmission capacity development), updated information around fuel costs and renewable technology costs, and enhancements in the representation of renewable energy generation in IRENA's SPLAT-W model. For a full list of such updates, see Section 1.2 (*This report*).

Figure 14 presents the electricity generation mix in the updated Reference Scenario. As was the case in the 2013 edition of this report, the results regarding the prevalence of hydro and gas generation are broadly consistent with the reference scenario of the 2011/12 WAPP Master Plan. However, differences between the SPLAT-W results and the WAPP Master Plan continue to appear in the emergence of non-hydro renewables, and a lower share of hydropower due to a "dry-year" assumption imposed over the modelling period.

Figure 14 Electricity production shares in the Reference Scenario

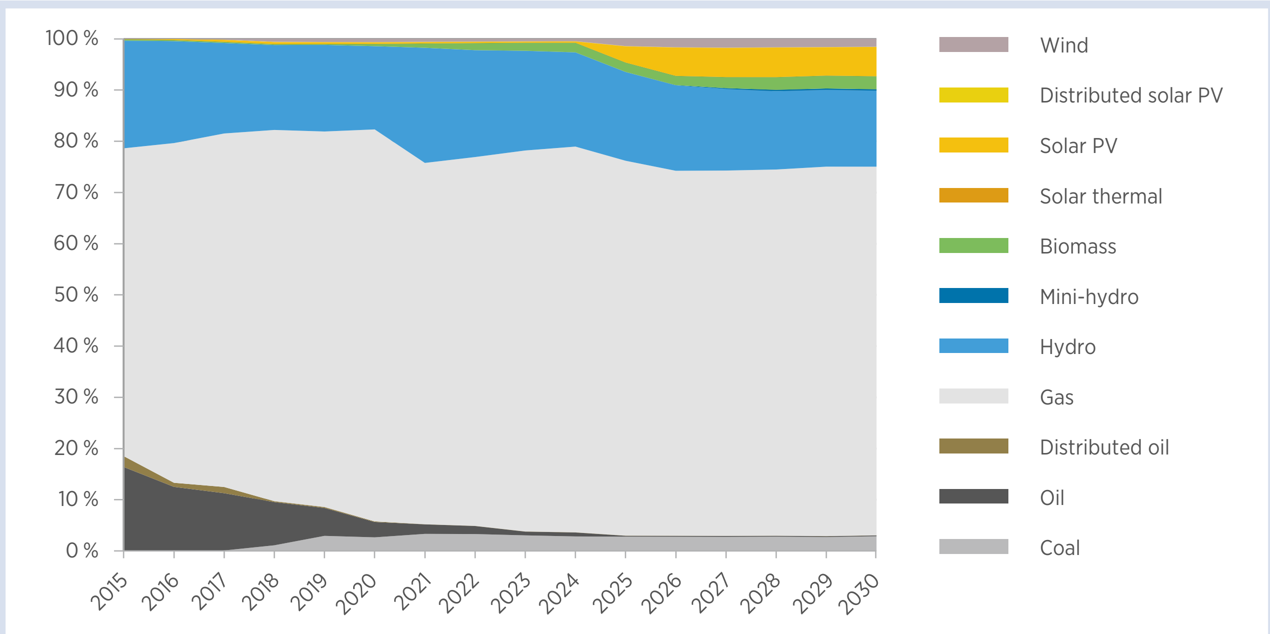
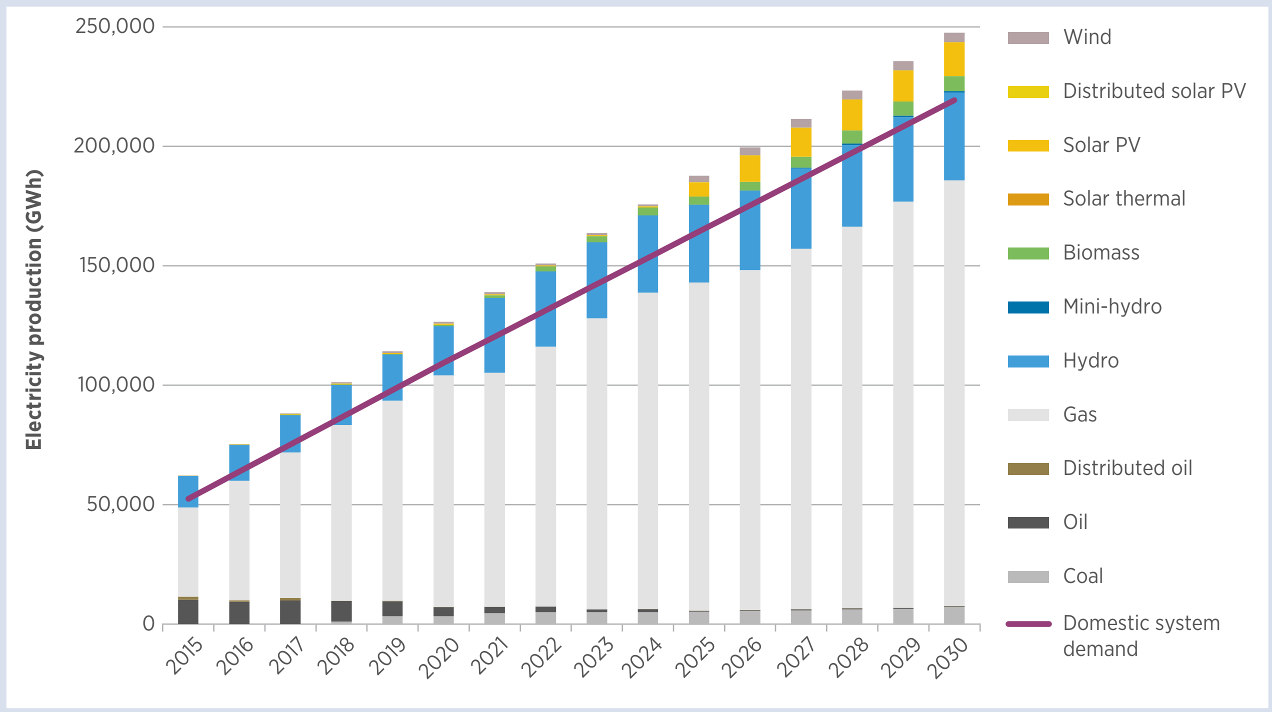
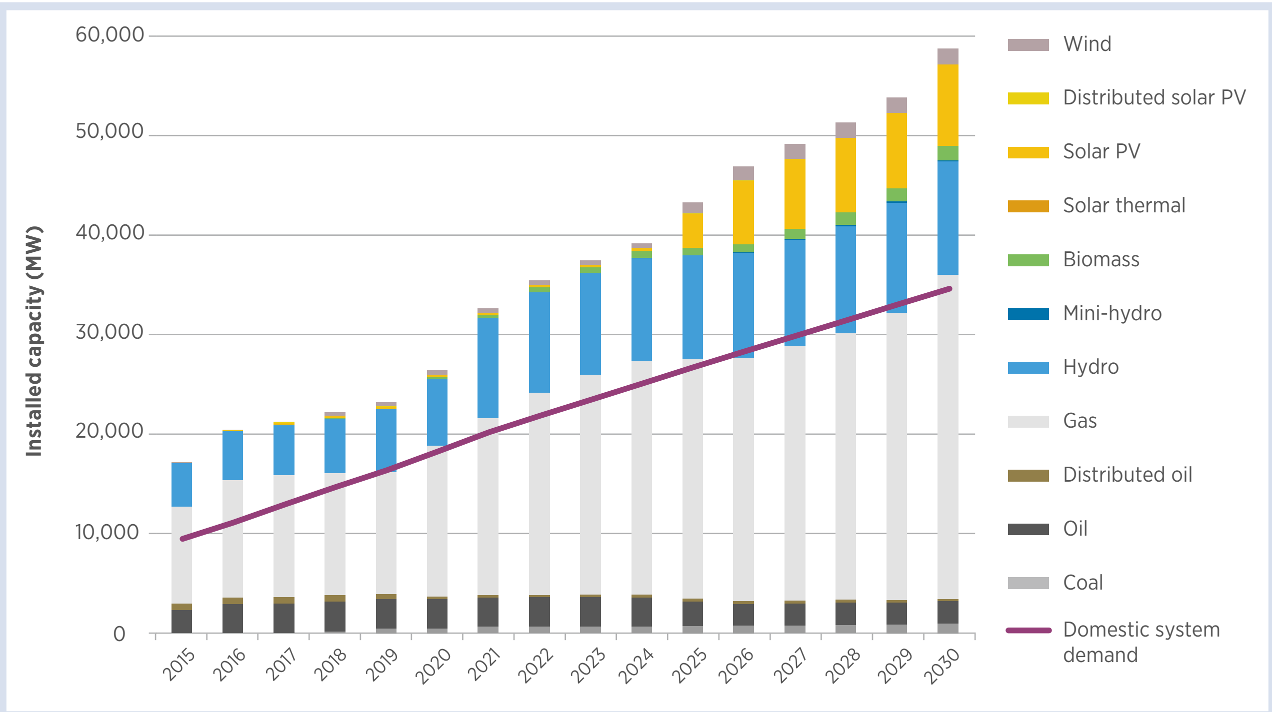


Figure 15 Electricity production in the Reference Scenario



Note: Difference between production and domestic system demand reflects system losses.

Figure 16 Electricity capacity in the Reference Scenario



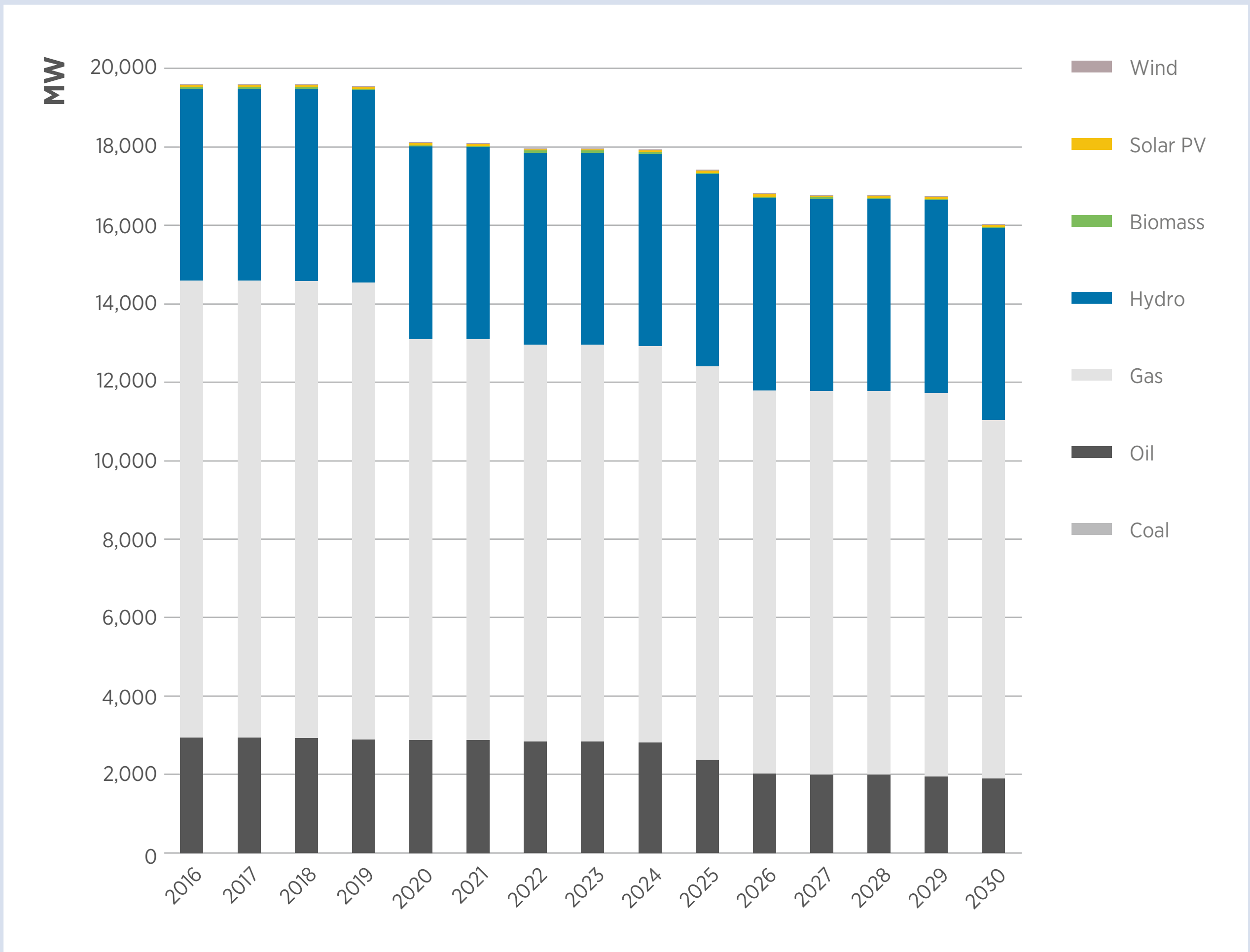
Note: Difference between installed capacity and system peak is based on system firm capacity and the modelled reserve margin.

As discussed in Section 3.3 (*Electricity demand*), and reflected in Figure 15 and Figure 16, electricity demand in ECOWAS member countries is expected to increase nearly fourfold between 2015 and 2030, mainly driven by growth in Nigeria, Ghana and Côte d'Ivoire (together accounting for roughly 80 % of regional demand, both currently and in 2030). At the same time, as seen in Figure 17, around 3.5 GW of currently installed capacity is scheduled to retire across the region, mainly consisting of oil and gas generation in the early and mid-2020s.

To fill the supply-demand gap, the capacity of the region's most widely used generation technologies – gas and hydropower – roughly triples in the Reference Scenario by 2030 (to 32 GW and 11.5 GW, respectively).

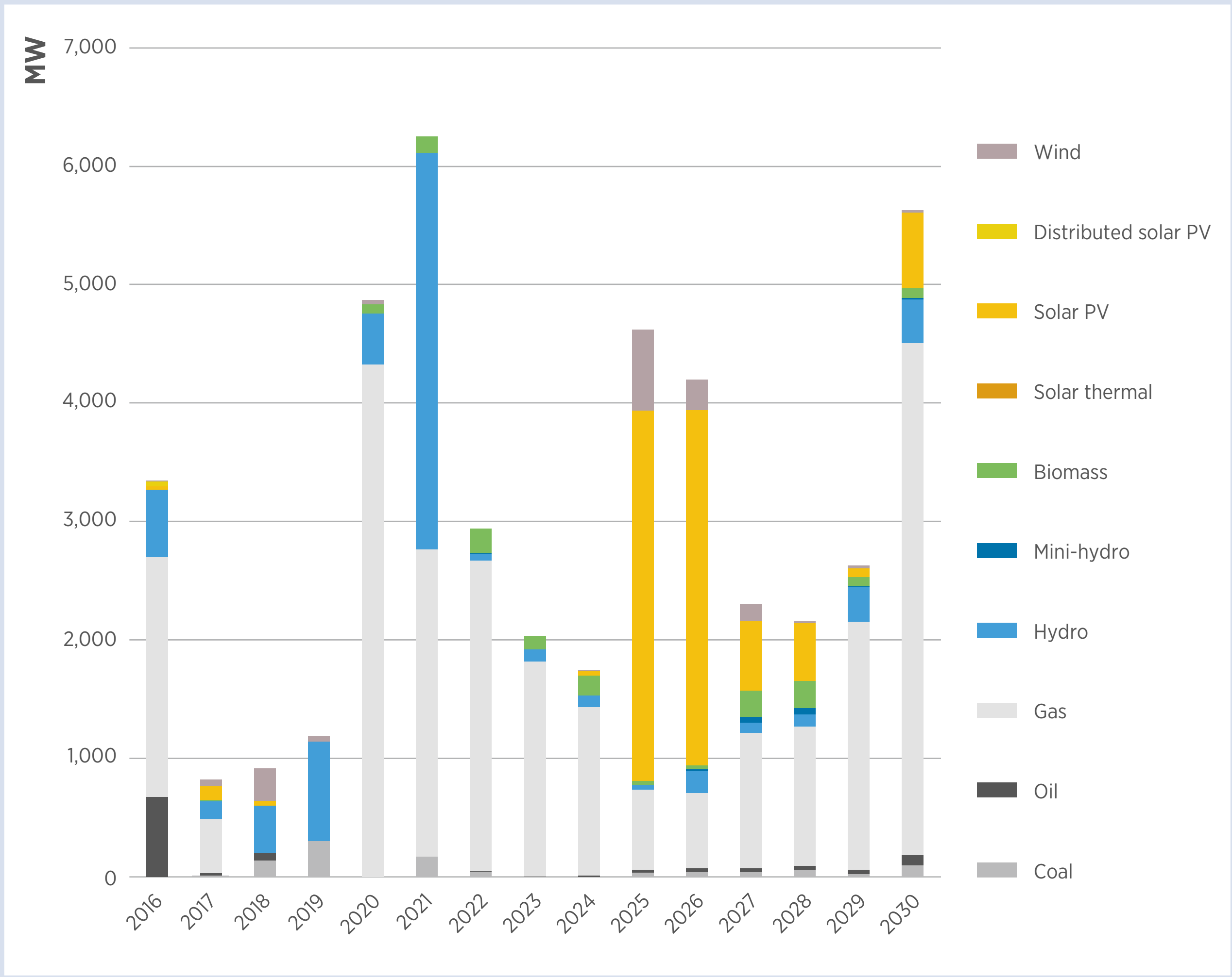
The share of hydropower in overall generation decreases over the same period (from 22 % of generation in 2015 to 15 % in 2030), however, as increasingly competitive solar PV, wind and biomass capacity is also deployed to meet demand growth and replace retired capacity in the mid-2020s.[31] Regional electricity production observes a general trend of new renewable and gas generation displacing generation from existing oil-fuelled capacity, even though less utilised oil-fuelled capacity remains online to fulfil reserve margin requirements and meet certain instances of peak demand.

Figure 17 Evolution of existing capacity mix



31 This represents a significant difference to the 2013 edition of this report, in which the options to build generic large hydropower capacity and import hydropower production from Central Africa were available, leading to a 41 % share of large hydropower in regional electricity supply by 2030 under the Renewable Promotion Scenario explored in that study.

Figure 18 New capacity additions under the Reference Scenario



Interestingly, in the updated Reference Scenario, solar PV and wind make up roughly 10 % of total grid-connected electricity production in the region by 2030, compared to essentially 0 % in the 2013 edition of this report. This competitiveness reflects the impressive cost reductions observed in wind and solar PV technology in recent years.

This is perhaps even more notable given that projections of oil and gas fuel costs in 2030 have also fallen in the updated Reference Scenario, by 20–30 % relative to 2013 (in real terms).

Box 1 **Renewable energy targets: Implications of metric choice**

Renewable energy targets – and the extent to which they are achieved – can be quite different depending on the metric used. This is important to keep in mind when reviewing the results of the scenarios presented in this analysis. As noted in Sections 1.1 (Background) and 3.1 (General definition of scenarios), the region's EREP contains targets for grid-connected renewables both in capacity terms (as a percentage of peak load) and in generation terms.

In the Reference Scenario presented here, the 2030 results for the renewable share of generation – the metric used in the modelling of regional targets in this analysis – fall short of the EREP target of 31 % by six percentage points (with large hydro producing 15 % vs an envisaged 19 %, and other renewables producing 10 % vs an envisaged 12 %). However, the renewable share of capacity (percentage of peak load) in 2030 under the same Reference Scenario not only meets but exceeds the official EREP target of 48 % by 17 percentage points (with large hydro at 33 % and 11,386 MW vs an envisaged 29 % and 11,177 MW, and other renewables at 32 % and 11,165 MW vs an envisaged 19 % and 7,606 MW).

This discrepancy points to the importance of underlying assumptions behind renewable energy targets, such as technology mix and capacity factors of future technologies in the system. While there is more hydro capacity in the Reference Scenario than envisaged in the EREP, the dry-year assumption used in this analysis means the actual generation from that capacity – its capacity factor – is less than anticipated. A similar dynamic is at play for non-hydro renewables in the Reference Scenario – although the results here show nearly 4 GW more capacity than the EREP targets, they do not include the CSP technology anticipated in the EREP, which has a higher capacity factor than both solar PV and wind. As a result, generation from the non-hydro renewable technology mix is lower than anticipated in the target-setting methodology.

These results underline the fact that caution should be exercised if considering renewable energy targets in both capacity and generation terms. Ensuring consistency is often difficult, given the uncertainty around future technology mix and system dynamics. IRENA's *Renewable Energy Target Setting* report (2015) provides an overview of the advantages and disadvantages surrounding both types of target design.

4.2 RENEWABLE TARGET SCENARIOS

Capacity and generation

Figure 19 and Figure 20 display a comparison of the capacity and generation mixes in the Reference Scenario with those in the two alternative scenarios explored in this report, in which regional and national renewable energy targets are met. Although the Reference Scenario sees a significant share of renewable generation by 2030, at 25 % of total grid-connected generation, additional capacity deployment is required in the Regional EREP Target Scenario to meet the EREP target of 31 %.

Based on the regional optimisation performed by the SPLAT-W model, greater renewable deployment is mainly achieved through the substitution of gas consumption by biomass and solar PV (particularly in Ghana and Côte d'Ivoire, where utilisation of additional biomass and solar PV capacity replaces both domestic gas production and imported gas from Nigeria). As seen in Figure 21, by 2030 biomass and solar PV capacity increases in the Regional EREP Target Scenario by 3 GW and 1 GW, respectively, relative to the Reference Scenario.

In the National Targets Scenario, ECOWAS member countries' domestic ambitions would, in aggregate, clearly deliver an even greater share of renewable energy in the regional power generation mix. In comparison with the Regional EREP Target Scenario, over 12 GW of additional solar PV capacity and 1 GW of additional biomass capacity are built in Nigeria alone over the model horizon to meet its national renewable energy targets. As seen in Figure 21, under the National Targets Scenario, the size of the grid-connected solar PV market would be over 20 GW by 2030, compared to just over 8 GW in the Reference Scenario.

Figure 19 Electricity capacity in Reference, Regional Target and National Targets Scenarios

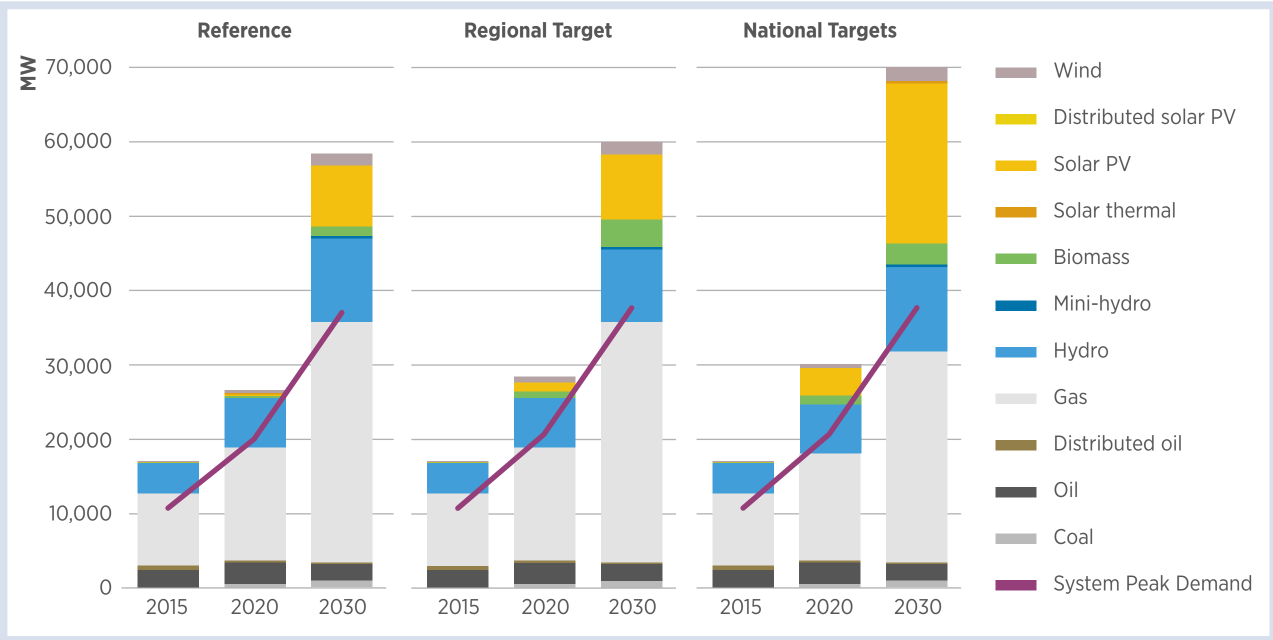


Figure 20 Electricity production in Reference, Regional Target and National Targets Scenarios

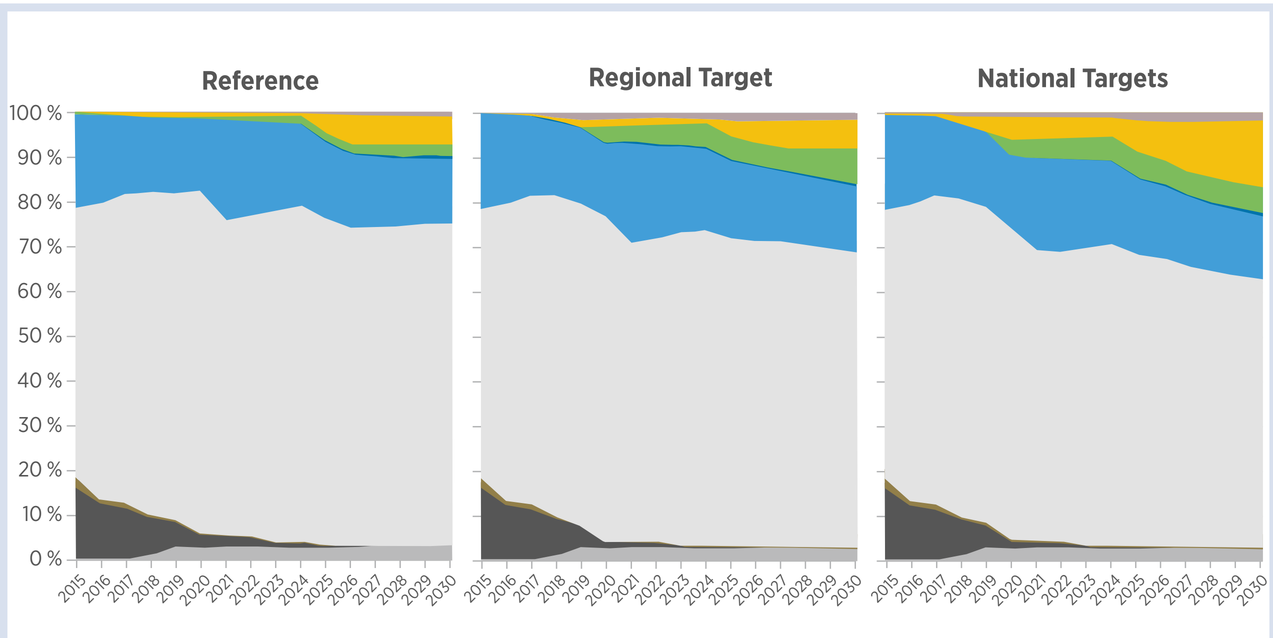
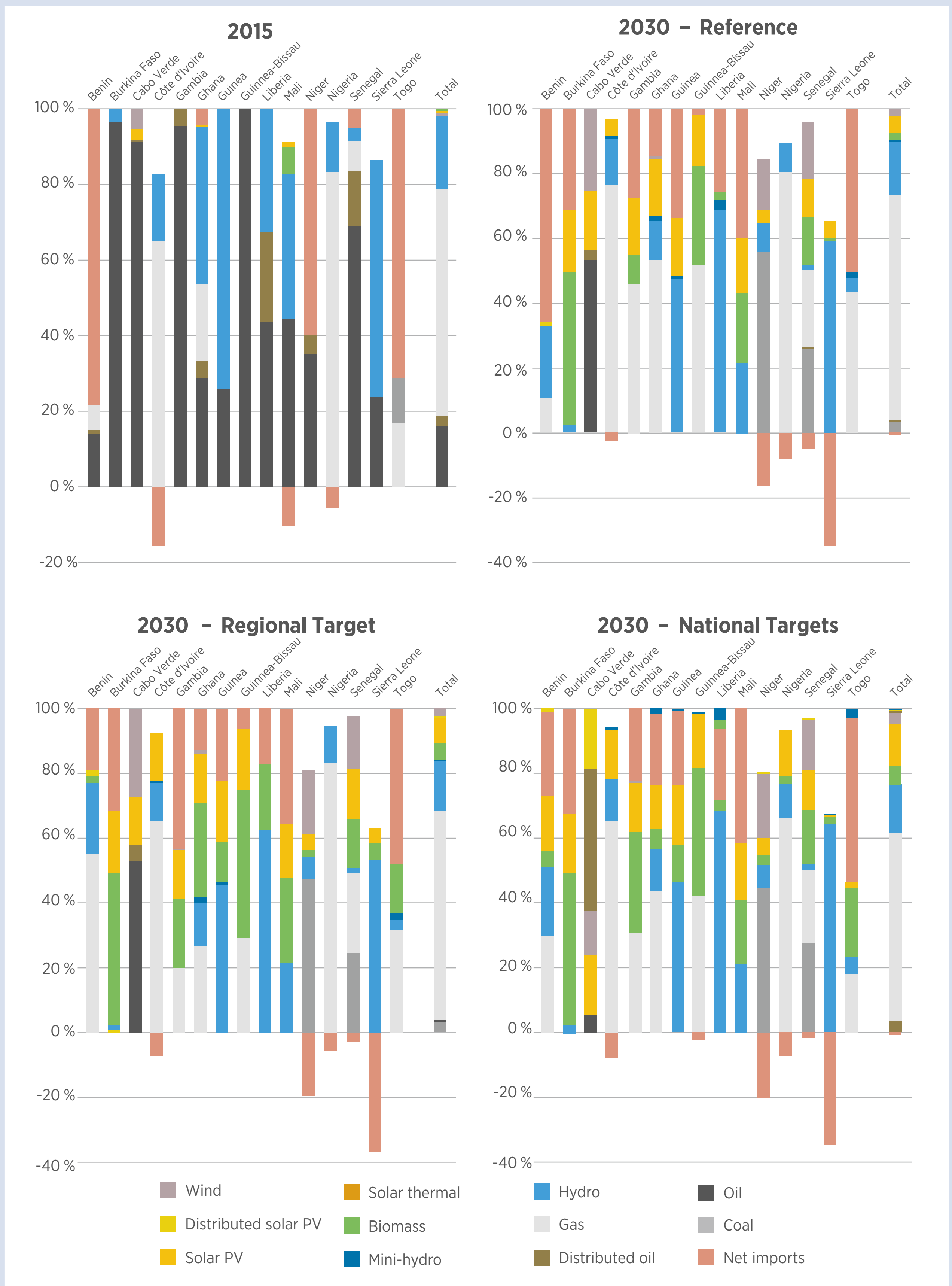


Figure 21 Solar PV, wind and biomass capacity in Reference, Regional Target and National Targets Scenarios

Figure 22 Electricity production shares by country (2015–2030) in Reference, Regional Target and National Targets Scenario



Taking a closer look at the National Targets Scenario, Figure 23 and Figure 24 show the annual investment schedule for the region as a whole, and for solar PV capacity by country. Appendix E provides a detailed list of the specific projects deployed in the SPLAT model under this scenario.

As in the Reference Scenario, under the National Targets Scenario the majority of capacity additions in the coming decade are gas and hydropower, which account for 13 GW (46 %) and 6 GW (21 %) of total new capacity added between 2016 to 2025, respectively. This is to be expected to some extent, given that hydropower and gas projects together make up 85 % of the region's current planned capacity pipeline (53 % hydropower and 32 % gas). However, between 2025 and 2030, ahead of 2030 national targets and as solar PV and wind technology costs decline, non-hydro renewable capacity becomes the driver of new additions, accounting for around 19 GW (66 %) over the period.

Figure 23 New capacity additions under the National Targets Scenario

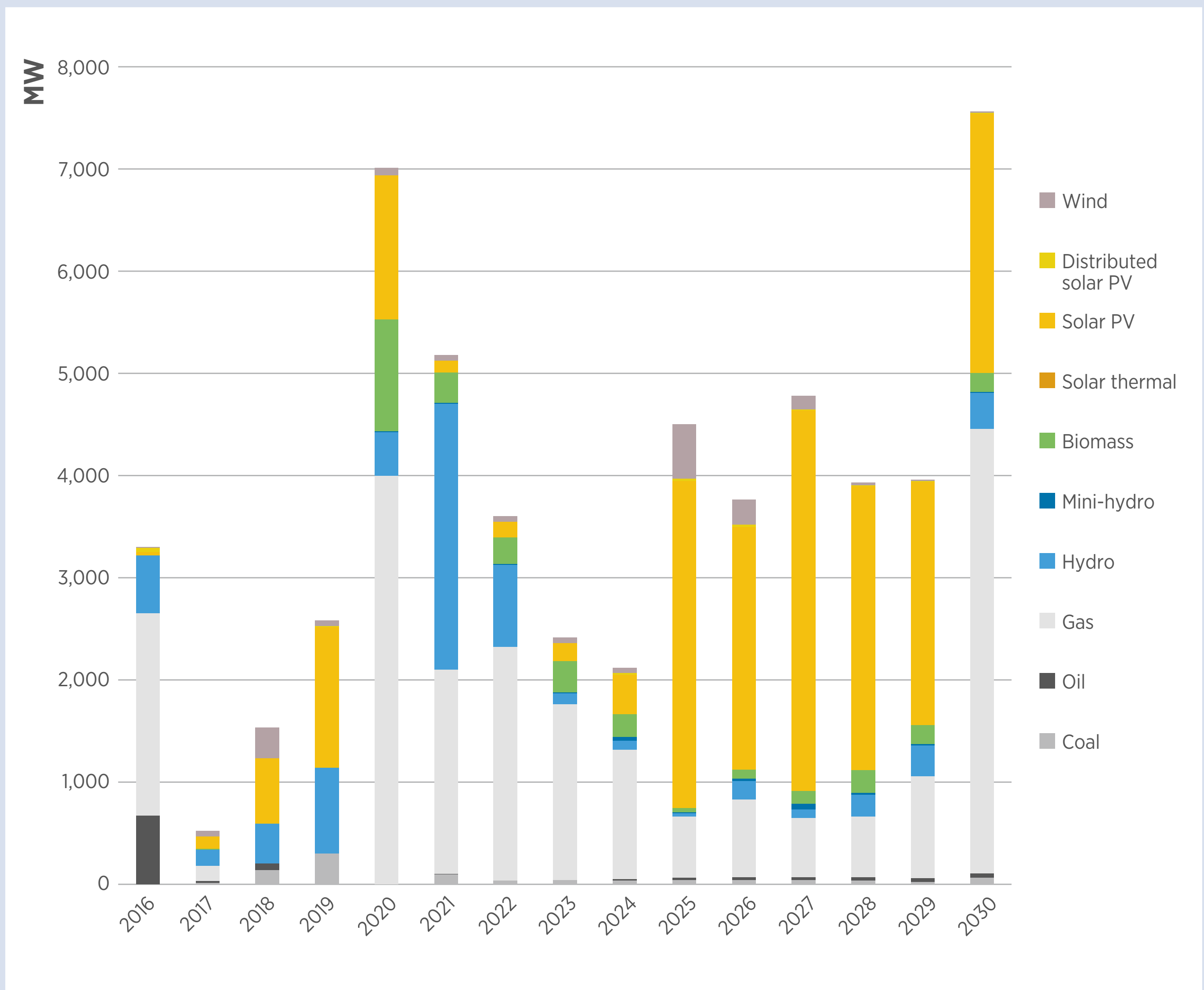
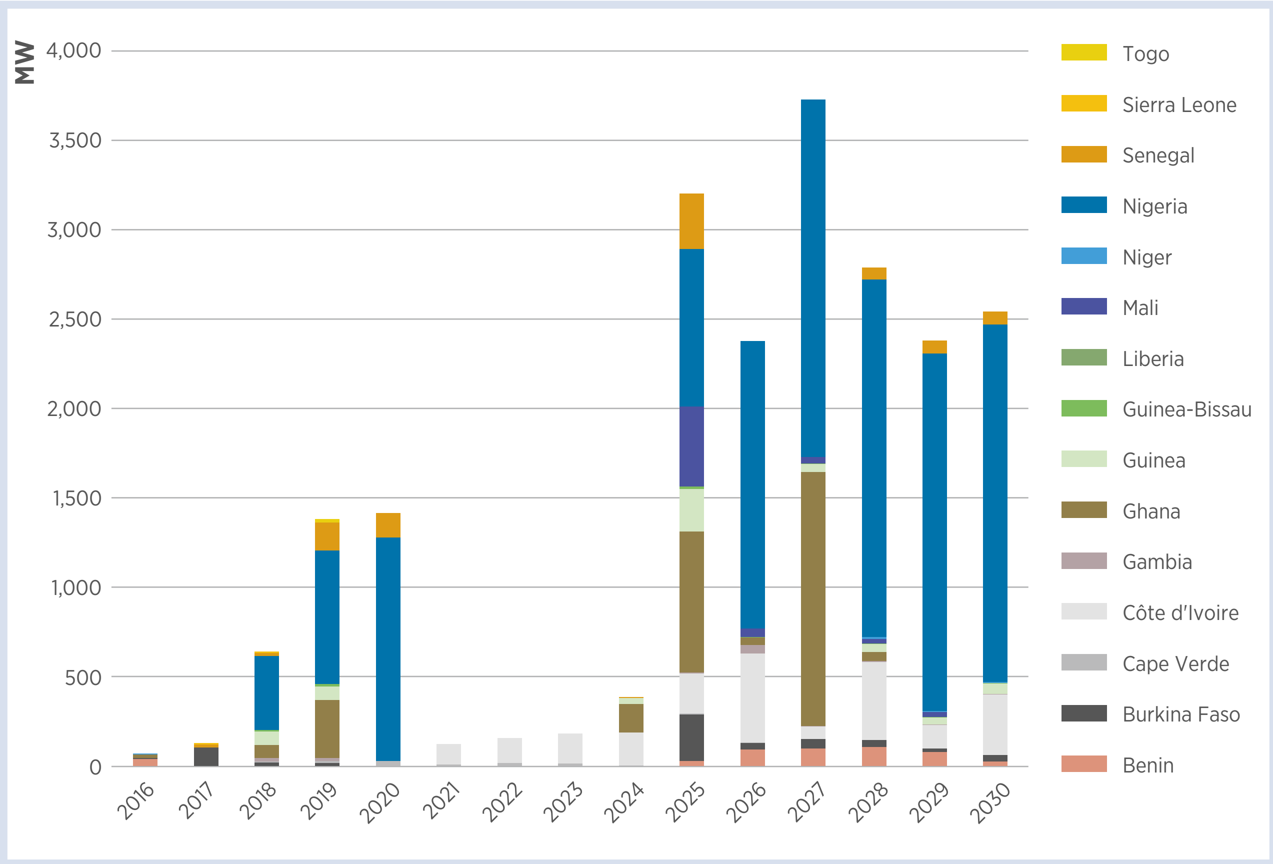


Figure 24 New solar PV capacity additions under the National Targets Scenario



Looking at solar PV in particular, the majority of new capacity in the National Targets Scenario is deployed in Nigeria, Ghana and Côte d'Ivoire, reflecting their large share of regional electricity demand. Relatively smaller countries with better solar resources (*i.e.* >20 % average capacity factor), such as Guinea, Burkina Faso, Senegal and Mali, also deploy significant amounts of solar PV capacity to meet their national targets.

Altogether, the solar PV deployment depicted in Figure 24 reflects an average annual addition of roughly 1.5 GW under the National Targets Scenario. As seen in Figure 25, due to the nature of the wind resource in West Africa, wind capacity deployment is less widespread, with smaller – though nationally significant – amounts concentrated in Senegal and Niger.

An example of how such VRE capacity is reflected in the SPLAT-W model's generation mix can be seen in Figure 26, which displays the modelled generation for Ghana in the year 2030. Complemented by a range of flexible supply options, such as hydropower, biomass, imports, gas and peaking thermal plant, the share of VRE in the overall generation of several countries reaches levels over 25 % by 2030 in the National Targets Scenario.[32]

32 For all countries' hourly dispatch profiles, see Appendix F. Values 1, 2 and 3 in Figure 26 represent the three seasons modelled in SPLAT-W in this report, namely pre-summer (January–April), summer (May–August) and post-summer (September–December). For shares of solar PV and wind in overall generation by country, see Figure 22.

Figure 25 Solar PV and wind capacity in 2030 by country under the National Targets Scenario

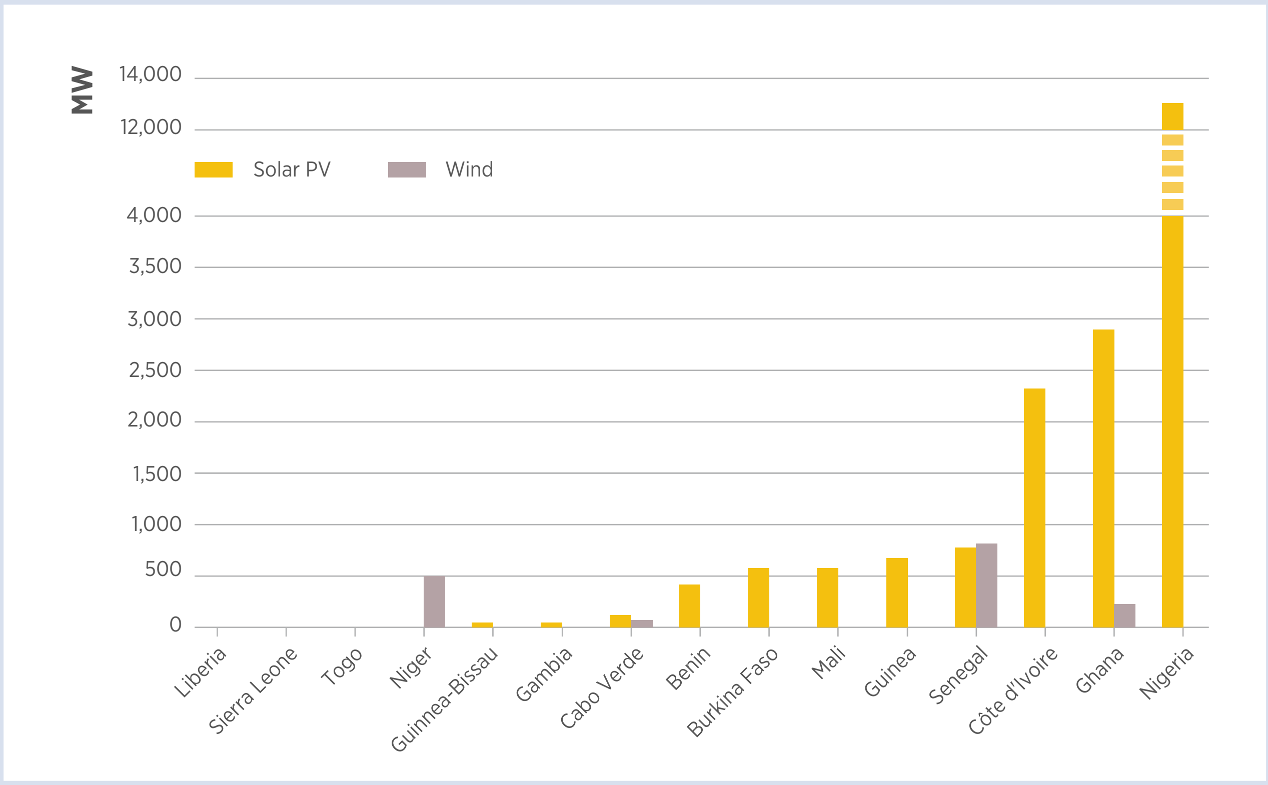
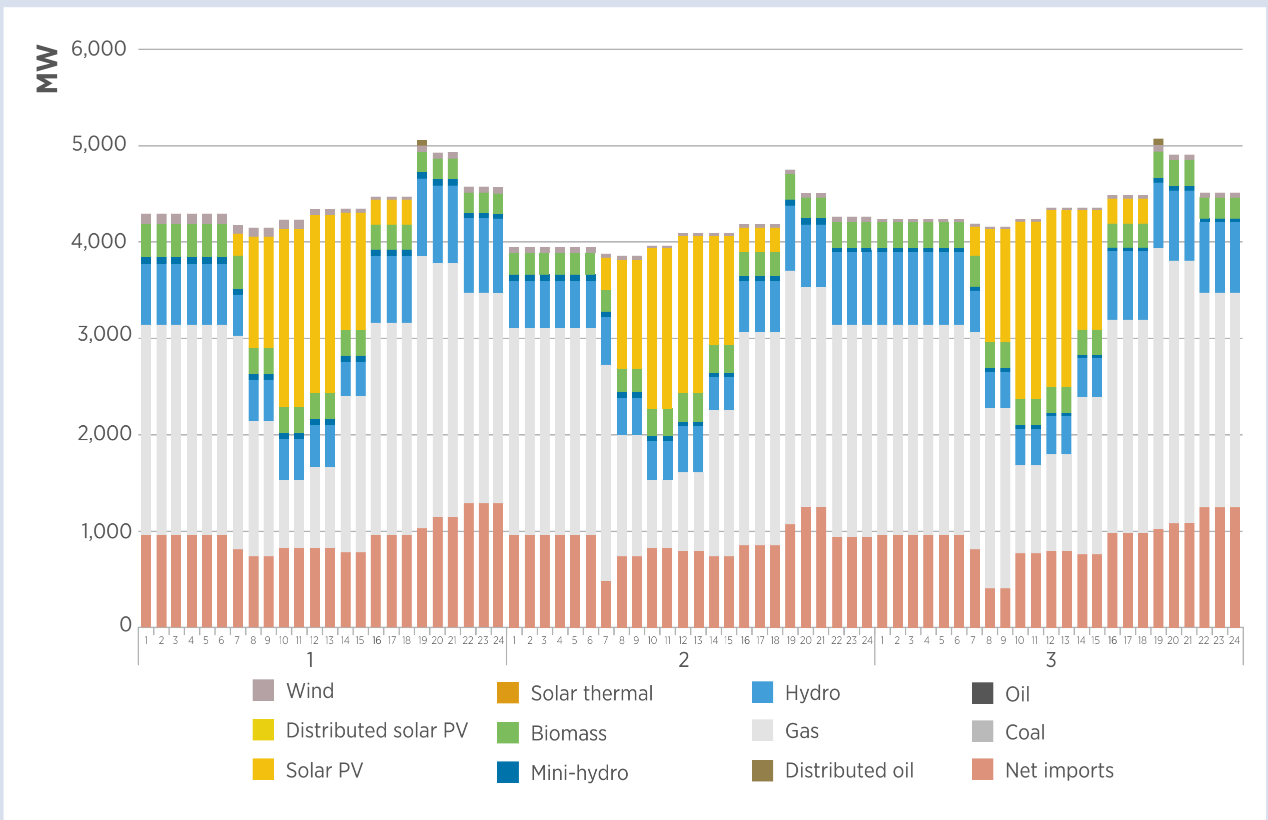


Figure 26 Hourly SPLAT-W generation mix of Ghana over three model seasons in 2030 – National Targets Scenario



Renewable targets and diversity of supply mix

The fact that national ambitions would deliver more renewable capacity in the region, relative to the Reference Scenario explored in this study, is reflected in the renewable energy share of generation across scenarios. As seen in Figure 27, the trajectory of the National Targets Scenario suggests the regional share of renewables in centralised generation would meet the EREP target of 31 % five years earlier than anticipated, by 2025. By 2030 aggregated national targets result in renewable production equivalent to 38 % of the regional total.

Across the scenarios, the main driver of the transition is the addition of solar PV, wind and biomass (together 23 % of total generation by 2030 in the National Targets Scenario), as hydropower settles into a share of about 15–20 % throughout the model horizon (for further discussion see Box 1).

As regards diversity of supply, systems that rely on multiple sources of primary energy are also more robust to shocks, constraints and crises affecting one or another form of supply. A commonly used indicator of systems diversity (in both richness – *i. e.* category count – and evenness – *i. e.* balance) is the Shannon-Weiner Index (SWI), defined as:

$$\mathrm{SWI} = \sum -p_i \ln(p_i)$$

where p_i is the share of installed capacity for resource *i*.

Figure 27 Renewable energy share of centralised electricity production across scenarios

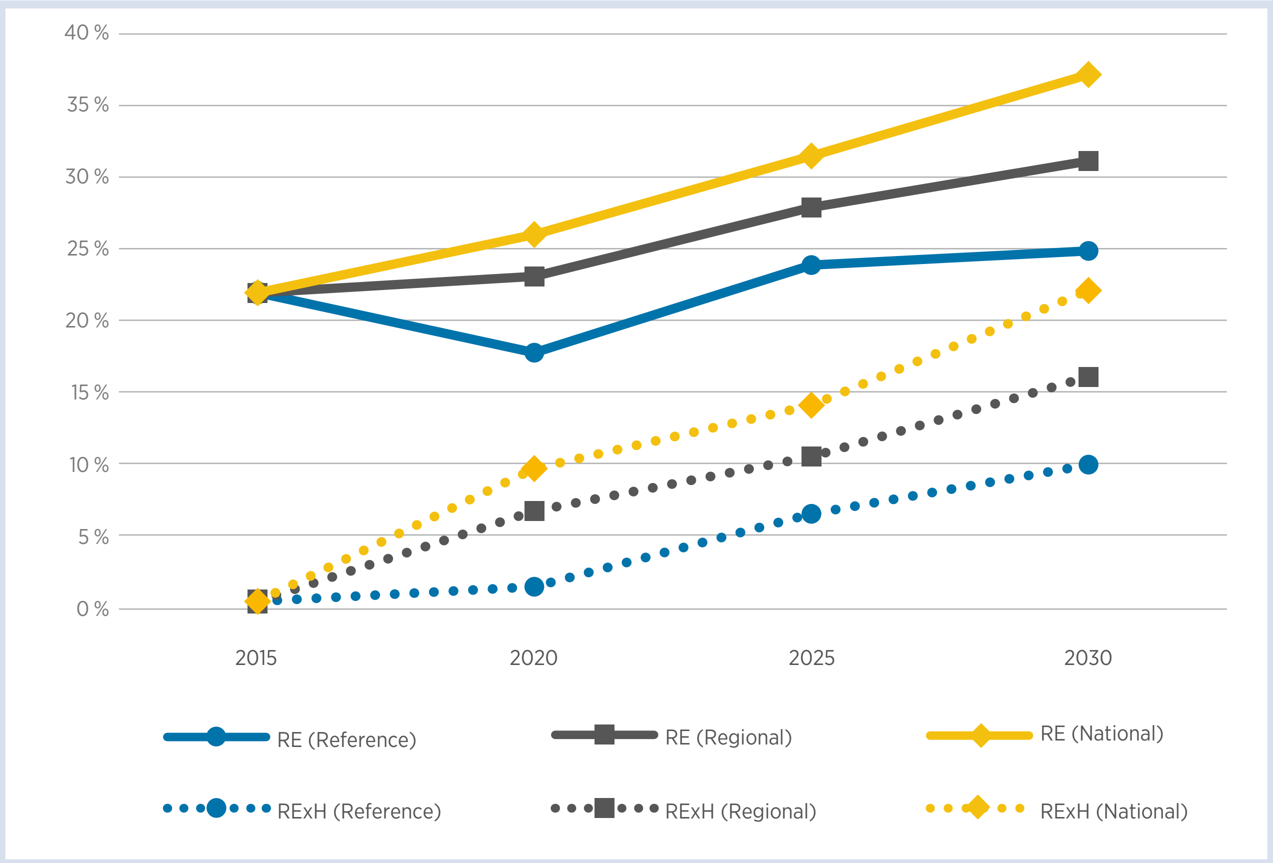


Table 15 shows the SWI diversity indicator for ECOWAS member countries in 2015 and in 2030 across scenarios (full reliance on a single source would yield a result of 0 %, while an even distribution of supply across eight source types would yield 200 %, for example).

With the exception of Liberia and Sierra Leone, which rely to a large extent on hydropower in the National Targets Scenario, the SWI index of all countries significantly increases with the addition of various renewable sources to the centralised capacity mix.

Table 15 Diversity of national electricity supply mix across scenarios

	SWI in 2015	SWI in 2030 – Reference	SWI in 2030 – Regional Target	SWI in 2030 – National Targets
Benin	58 %	67 %	77 %	118 %
Burkina Faso	30 %	120 %	120 %	120 %
Cabo Verde	54 %	109 %	109 %	107 %
Côte d'Ivoire	64 %	98 %	104 %	104 %
Gambia	0 %	122 %	123 %	132 %
Ghana	91 %	124 %	153 %	144 %
Guinea	59 %	97 %	116 %	114 %
Guinea-Bissau	0 %	134 %	131 %	133 %
Liberia	58 %	54 %	89 %	54 %
Mali	93 %	134 %	135 %	134 %
Niger	50 %	146 %	150 %	146 %
Nigeria	41 %	48 %	49 %	105 %
Senegal	56 %	181 %	180 %	181 %
Sierra Leone	83 %	75 %	90 %	46 %
Togo	102 %	74 %	113 %	130 %

Regional trade flows

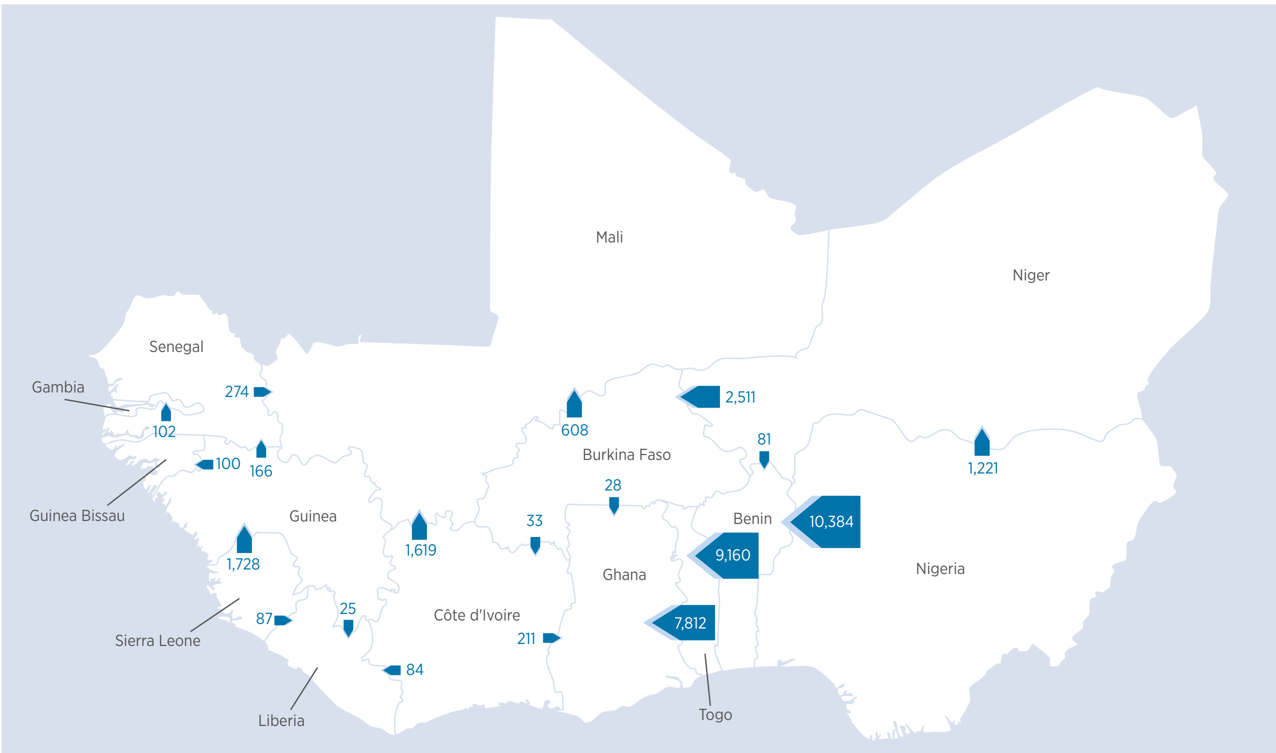
To give an example of the regional trade flows behind the modelling results presented here, Figure 28 displays net cross-border trade direction and volumes (in GWh) under the National Targets Scenario in 2030. Cross-border transmission projects considered in this study are summarised in Appendix D.

As evident in the figure, the main conduit of net cross-border electricity trade flows is the Coastal Backbone/Dorsale infrastructure between Nigeria, Benin, Togo and Ghana. Both committed and planned expansion of this infrastructure is developed across all scenarios explored here, to allow for the export of Nigeria's major domestic hydro, gas and other renewable generation. The Intrazonal Hub (linking Ghana, Burkina Faso, Côte d'Ivoire and Mali) and North-core/Corridor Nord (linking Nigeria, Niger, Benin and Burkina Faso) projects are the next largest sources of net cross-border electricity exchange, and are both significantly expanded across scenarios.

While the Intrazonal Hub is important from 2017 onward to allow export of gas-generated and hydro power from Côte d'Ivoire to Mali, it also becomes important in the late 2020s to facilitate the export of Burkina Faso's daytime surplus of low-cost solar production to Ghana. Similarly, the main development of the North-core/Corridor Nord project occurs in the mid- to late-2020s, to facilitate the export of wind production in Niger, where resource quality is highest in the region.

Although there is relatively less net exchange across the CLSG infrastructure connecting Côte d'Ivoire, Liberia, Sierra Leone and Guinea, this project becomes particularly important for exploiting the diurnal complementarity and exchange between low-cost hydropower in Sierra Leone and solar power in Guinea. The OMVG project between Guinea, Guinea-Bissau, Gambia and Senegal, which is taken to be committed, sees the relatively lowest net trade flows, but plays an important role for Gambia, which relies on a significant national share of imports across all scenarios. The OMVS project, to expand transmission capacity between Mali and Senegal, was not selected for development in the scenarios modelled here.

Figure 28 Regional trade in 2030 in the National Targets Scenario (GWh)

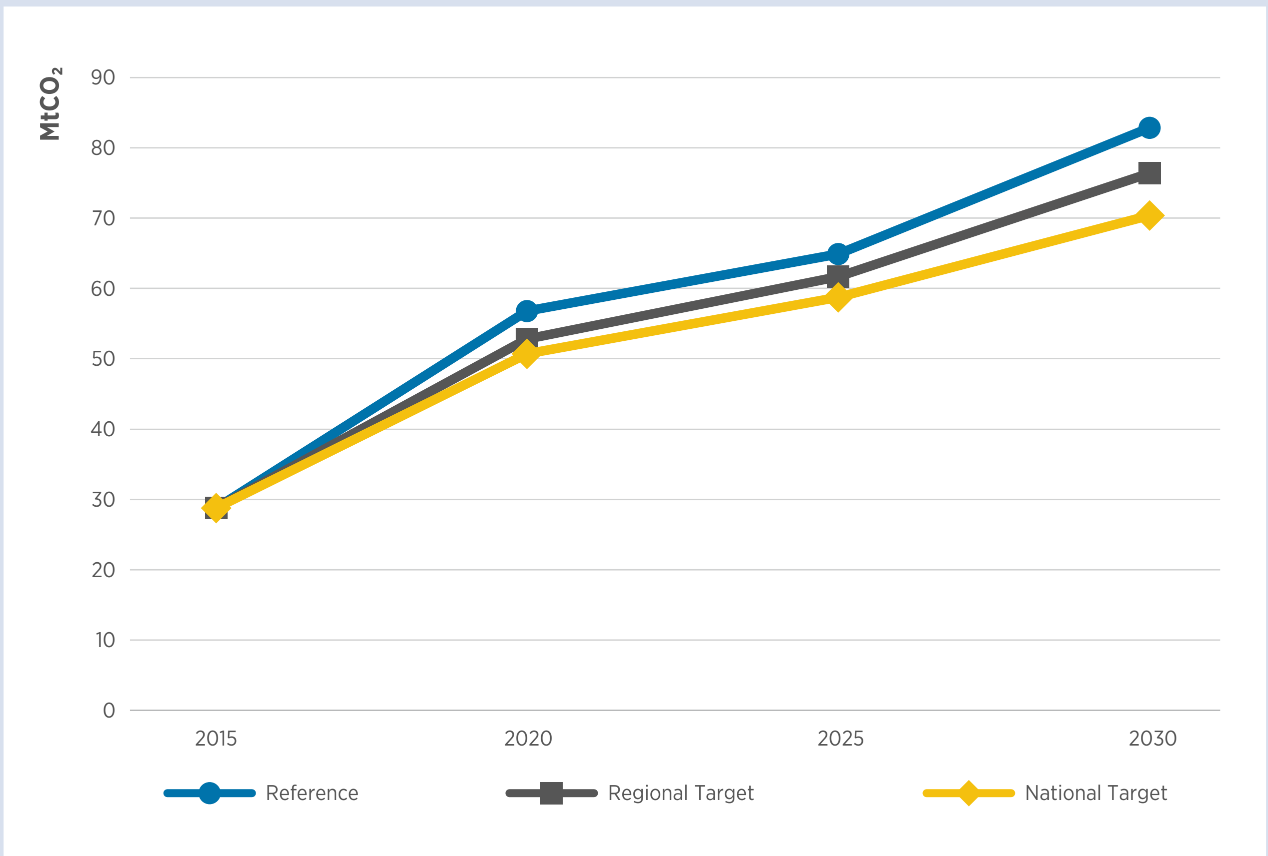


Climate and NDC implications of the National Targets Scenario

The level of carbon dioxide (CO_2) emissions from the power sector across scenarios largely follows the trajectory of renewable energy deployment and the achievement of renewable energy generation targets. Differences in scenario emissions become larger over the modelling horizon and, as seen in Figure 29, by 2030 the National Targets Scenario delivers an emissions reduction of 12.5 $MtCO_2$, or 15 %, versus the Reference Scenario in this analysis.

The current emphasis on NDCs under the Paris Agreement heightens the significance of the indicative climate benefits in the National Targets Scenario presented here. As IRENA's recent report, *Untapped Potential for Climate Action* shows, there is often room to expand NDC ambition simply by reflecting targets set in national energy plans (IRENA, 2017). Robust techno-economic analysis of power systems, using tools such as IRENA's SPLAT-W model, has an integral role to play in exploring such untapped potential, by ensuring regular renewable energy target and NDC updates are supported by transparent, data-informed analysis.

Figure 29 Carbon dioxide emissions across scenarios



Economic implications of the National Targets Scenario

The SPLAT model computes economic implications of a given scenario in terms of investment cost (in generation and T&D), fuel costs and O&M costs. The sum of these cost elements constitutes the system costs that the model aims to minimise.

Figure 30 shows the breakdown of undiscounted system costs between 2015 and 2030 in the National Targets Scenario. Note that the investment costs are annualised over the lifetime of each technology. The figure shows that while fuel costs remain the largest portion of total system costs, their overall share declines substantially as large investments in hydropower and other renewable energy sources are deployed in the 2020s to meet growing demand and national targets.

Between 2016 and 2030, regional spending on fuel falls from 75 % to 50 % of overall system costs, while capacity investment rises from roughly 10 % to 30 %. Despite the buildout of cross-border transmission in the 2020s, both international and domestic T&D remain a less substantial piece of overall system costs, never surpassing 7 % of the total. Cumulatively, system costs between 2016 and 2030 would amount to USD 192 billion (undiscounted), reaching an annualised cost of around USD 20 billion (undiscounted) by 2030.

Figure 30 Total undiscounted system costs in the National Targets Scenario

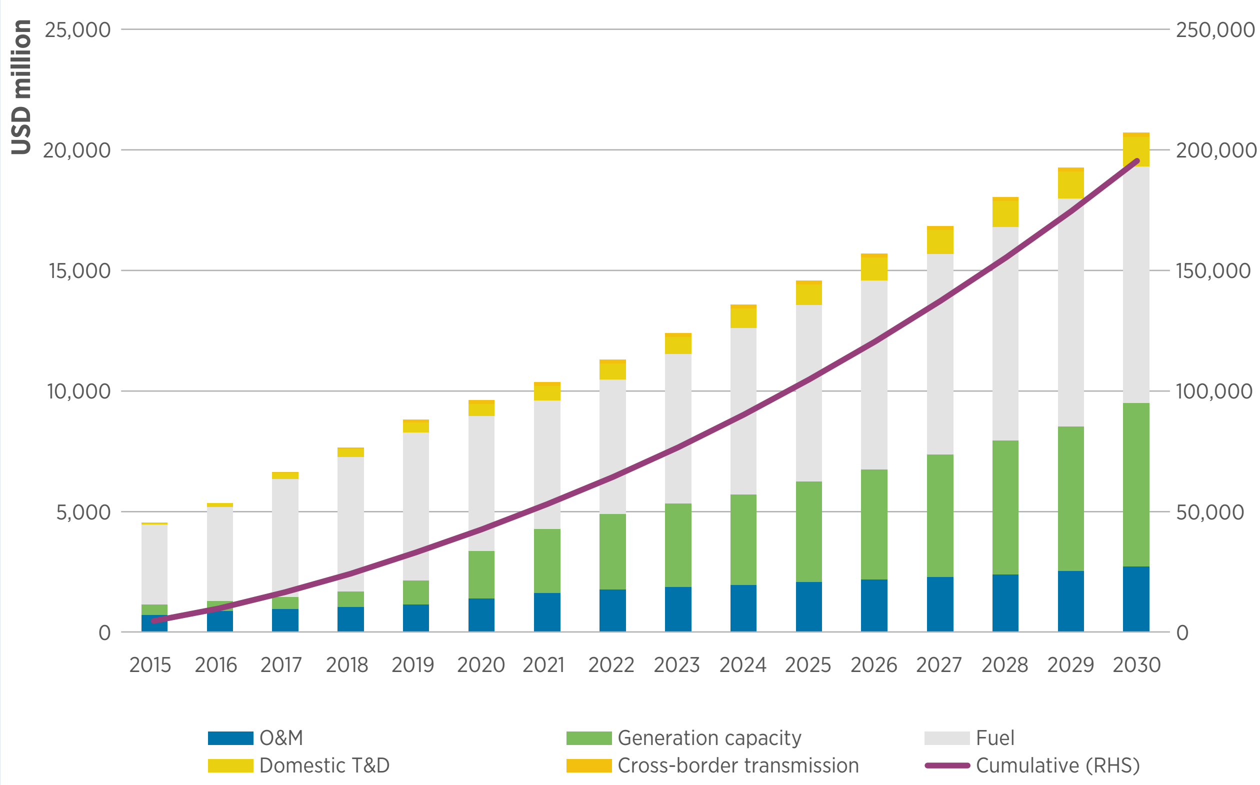


Figure 31 compares the annualised system costs of the National Targets Scenario and the Reference Scenario over the modelling horizon by cost component. Differences up to 2020 are insignificant, as many of the same committed projects would be implemented in both scenarios during this time.

The differences between individual cost components become increasingly large in the longer term, however, as greater capacity investment in renewables such as solar PV, biomass and wind is offset by savings in fuel costs from displaced gas generation. Due to this dynamic, the results here suggest that meeting national renewable targets in ECOWAS would entail essentially the same overall system cost to 2030, with differences in annualised undiscounted costs in the National Targets Scenario never surpassing +/- 1% of the total.

Figure 31 Difference in undiscounted system costs (itemised) between the National Targets Scenario and Reference Scenario

CONCLUSIONS 5

IRENA's SPLAT-W model was developed to provide decision makers and analysts from IRENA member countries in the ECOWAS region with a planning tool to design power systems for the medium to long term, prioritise investment options and assess the economic implications of a given investment path. More specifically, SPLAT-W allows analysts to explore power system pathways that meet various requirements (including reliability and renewable energy targets), while taking into account investment and operation costs to meet daily/seasonally fluctuating demand.

This report is based on recent regional policy developments, inputs and outputs from national experts in 2015–2016 IRENA/ECREEE SPLAT-W model training sessions, and various improvements to the representation of renewables in SPLAT-W. It describes how three scenarios were developed for ECOWAS member countries as a basis for further analysis and possible elaboration.

The main findings from analysing the Reference, Regional Renewable Target, and National Renewable Targets scenarios in this report include the following:

- Despite a projected fourfold increase in regional demand, updated assumptions to reflect significantly lower fossil fuel price projections, and limited large hydropower potential relative to IRENA's 2013 analysis, the share of renewable energy sources increases in this report's Reference Scenario to exceed EREP capacity targets, reaching 65 % of peak load by 2030.

- While renewable capacity deployment in the Reference Scenario exceeds expectations, renewable generation in the same scenario is 6 % points short of the 31 % EREP target, reflecting the complexity of renewable energy target-setting using various metrics. This is mainly due to dry-year assumptions used for hydropower generation, and a lower average capacity factor in the non-hydro renewable mix than assumed in the EREP target-setting process.

- National renewable targets would deliver an even greater amount of renewable capacity relative to the Reference and Regional Target Scenarios, and in aggregate those targets do surpass the regional 2030 renewable generation target of 31 % five years earlier than expected, resulting in a 38 % share of renewable energy in total regional generation by 2030.

- Projected reductions in solar PV and wind technology costs make non-hydro renewables the primary driver of new capacity additions across all scenarios in the mid- to late-2020s, with solar PV, wind and biomass generating 23 % of total regional generation by 2030 in the National Targets Scenario.

- Depending on the scenario analysed, the amount of solar PV in the ECOWAS region ranges from 8 GW to over 20 GW by 2030, implying an annual average deployment of 1.5 GW under a National Targets Scenario.

- The diversity, and thus the resiliency, of the electricity supply mix in the vast majority of ECOWAS member countries significantly increases with the addition of various renewable sources to the capacity mix.

- The development of nearly all cross-border transmission infrastructure projects currently in the pipeline proves to be beneficial across all scenarios analysed.

- The increased capacity investment costs required to deliver national renewable targets are consistently offset by savings in fuel costs from displaced fossil fuel generation, resulting in overall system costs that are essentially equivalent to the Reference Scenario.

The SPLAT-W model allows for the quantification and substantiation of the above points. In the updated version of the SPLAT-W model employed here, improvements to the representation of renewable energy, including increased temporal resolution, improved time slice calibration and country-specific solar and wind generation profiles, allow for additional insights.

With the updated SPLAT-W model, analysts can now perform a country-level analysis of hourly dispatch in representative days, taking into account each country's particularities of composition of demand, available resources and resource profiles, and connection within the regional transmission network.

As seen in this report, this enables a more refined analysis of VRE generation, the sources of system flexibility that can support that generation, and opportunities for complementary trade that would benefit both resource-rich and resource-poor countries.

REFERENCES

Adebisi, A. (2015), "Sustainable Energy for All (SE4ALL) Action Agenda for Nigeria", Abidjan, 13–15 September 2015, www.ecreee.org/sites/default/files/events/presentation_se4all_action_agenda_nigeria.pdf (accessed January 2017).

ECREEE (ECOWAS Centre for Renewable Energy and Energy Efficiency) (2013), *ECOWAS Renewable Energy Policy*, ECREEE, Praia, www.ecreee.org/page/ecowas-renewable-energy-policy-erep (accessed December 2016).

Hughes et al. (2017), "Hybrid renewable energy and hydrogen fuel cell mini-grids for rural off-grid electrification in South Africa", Energy Research Centre, University of Cape Town and the South African National Energy Development Institute, South Africa.

Idrissa, H. (2004), "Projet de création d'une société de traitement et de commercialisation du charbon minéral à des fins domestiques (SNTCD)" (Project to establish a company for the processing and marketing of coal for domestic purposes), Ministry of Mines and Energy, Republic of Niger, www.cilss.bf/predas/Activites%20par%20Pays/NE/34-Projet%20de%20creation%20societe%20charbon%20mineral.pdf (accessed December 2016).

IEA (International Energy Agency) (2016), *World Energy Outlook 2016*, OECD/IEA, Paris, http://dx.doi.org/10.1787/weo-2016-en.

IRENA (International Renewable Energy Agency) (2017), *Untapped Potential for Climate Action: Renewable Energy in Nationally Determined Contributions*, IRENA, Abu Dhabi.

IRENA (2016a), *Investment Opportunities in West Africa: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects*, IRENA, Abu Dhabi.

IRENA (2016b), *Solar PV in Africa: Costs and Markets*, IRENA, Abu Dhabi.

IRENA (2015), *Renewable Energy Target Setting*, IRENA, Abu Dhabi.

IRENA (2014a), *Estimating the Renewable Energy Potential in Africa: A GIS-based Approach*, IRENA, Abu Dhabi.

IRENA (2014b), *Global Bioenergy Supply and Demand Projections: A Working Paper for REmap 2030*, IRENA, Abu Dhabi.

IRENA (2013), *West African Power Pool: Planning and Prospects for Renewable Energy*, IRENA, Abu Dhabi.

IRENA (2011), *Scenarios and Strategies for Africa*, IRENA, Abu Dhabi.

IRENA and LBNL (Lawrence Berkeley National Laboratory) (2015), *Renewable Energy Zones for the Africa Clean Energy Corridor*, IRENA, Abu Dhabi.

N'Goran, N. (2015), "Energie Durable pour Tous (SE4ALL) Agenda d'Actions Côte d'Ivoire", Abidjan, 13–15 September 2015, www.ecreee.org/sites/default/files/events/presentation_se4all_action_agenda_cote_divoire.pdf (accessed January 2017).

Niane, I. (2015), "Energie Durable pour Tous (SE4ALL) Agenda d'Actions Sénégal", Abidjan, 13–15 September 2015, www.ecreee.org/sites/default/files/events/presentation_se4all_action_agenda_senegal.pdf (accessed January 2017).

Raul, J. A. (2015), "Agenda de Ação para a Energia Sustentável para Todos (SE4ALL) Guiné-Bissau", Abidjan, 13–15 September 2015, www.ecreee.org/sites/default/files/events/presentation_se4all_action_agenda_guinea_bissau.pdf (accessed January 2017).

Tettey, G. D. (2015), "Sustainable Energy for All (SE4ALL) Action Agenda for Ghana", Abidjan, 13–15 September 2015, www.ecreee.org/sites/default/files/events/sustainable_energy_action_plan_ghana.pdf (accessed January 2017).

Touré, I. (2015), "Energie Durable pour Tous (SE4ALL) Agenda d'Actions Mali", Abidjan, 13–15 September 2015 www.ecreee.org/sites/default/files/events/sustainable_energy_action_plan_mali.pdf (accessed January 2017).

UNIDO (United Nations Industrial Development Organization) and ICSHP (International Center on Small Hydro Power) (2016), *World Small Hydropower Development Report 2016*, UNIDO, Vienna, and ICSHP, Hangzhou, www.smallhydroworld.org/menu-pages/reports/2016/ (accessed April 2017).

WAPP (West African Power Pool) (2015), *2016–2019 WAPP Business Plan*, WAPP, Cotonou, www.ecowapp.org/en/documentation (accessed January 2017).

WAPP (2011), *Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy*, WAPP, Cotonou, www.ecowapp.org/en/documentation (accessed December 2016).

World Bank (2017), "GDP deflator", *World Development Indicators* (database), http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed January 2017).

World Bank (2007), *Technical and Economic Assessment of Off-Grid, Mini-Grid and Grid Electrification Technologies (English)*, Energy Sector Management Assistance Programme (ESMAP) technical paper series, ESM 121/07, Washington, DC, http://documents.worldbank.org/curated/en/634581468333897517/Technical-and-economic-assessment-of-off-grid-mini-grid-and-grid-electrification-technologies.

APPENDICES

APPENDIX A. DETAILED DEMAND DATA

Table 16 Final electricity demand projections (GWh)

GWh	Benin	Burkina Faso	Cabo Verde	Côte d'Ivoire	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Niger	Nigeria	Senegal	Sierra Leone	Togo	Sum
2015	1,057	1,201	309	6,362	221	10,121	707	38	88	1,416	873	25,467	3,664	216	738	**52,479**
2016	1,173	1,332	325	6,881	225	11,043	938	64	117	1,569	1,033	34,080	3,979	302	791	**63,853**
2017	1,289	1,462	341	7,399	230	11,965	1,170	90	145	1,721	1,194	42,693	4,294	388	844	**75,227**
2018	1,405	1,593	357	7,918	235	12,886	1,401	117	174	1,873	1,355	51,307	4,609	475	897	**86,601**
2019	1,521	1,723	372	8,436	240	13,808	1,633	143	202	2,025	1,516	59,920	4,924	561	951	**97,975**
2020	1,637	1,854	388	8,954	244	14,730	1,864	169	230	2,178	1,677	68,533	5,239	647	1,004	**109,349**
2021	1,847	2,176	410	10,256	275	16,651	2,231	194	262	2,510	1,904	74,000	5,785	742	1,105	**120,347**
2022	2,057	2,498	432	11,558	306	18,572	2,598	218	293	2,842	2,131	79,467	6,331	836	1,205	**131,345**
2023	2,267	2,820	454	12,859	337	20,493	2,965	243	325	3,174	2,358	84,934	6,877	931	1,306	**142,342**
2024	2,477	3,142	476	14,161	367	22,414	3,332	267	356	3,506	2,585	90,401	7,423	1,025	1,407	**153,340**
2025	2,687	3,465	498	15,463	398	24,335	3,699	292	388	3,838	2,812	95,868	7,969	1,120	1,508	**164,338**
2026	2,897	3,787	520	16,764	429	26,256	4,066	316	419	4,170	3,038	101,335	8,515	1,214	1,608	**175,335**
2027	3,107	4,109	542	18,066	460	28,177	4,433	341	451	4,502	3,265	106,802	9,061	1,309	1,709	**186,333**
2028	3,317	4,431	564	19,368	490	30,098	4,800	365	482	4,834	3,492	112,269	9,607	1,404	1,810	**197,331**
2029	3,527	4,753	586	20,669	521	32,019	5,167	390	513	5,166	3,719	117,736	10,153	1,498	1,911	**208,328**
2030	3,737	5,076	608	21,971	552	33,940	5,534	414	545	5,498	3,946	123,203	10,699	1,593	2,011	**219,326**

APPENDIX B. DETAILED POWER PLANT ASSUMPTIONS

Table 17 Existing non-hydropower plants

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Installation year	Life[33] Years
Benin							
CAI	Gas	80	0.86	0.28	20.65	2011	25
Gas Turbine GAS	Gas	20	0.86	0.24	36.8	1998	27
Diesel Generators ODS	Oil	22.95	0.80	0.34	36.8	1998	17
Diesel Generators OHF	Oil	29.75	0.80	0.32	36.8	1998	17
DINa HFO Plant	Oil	12	0.30	0.34	36.8	2005	25
Port Novo HFO Plant	Oil	12	0.40	0.34	36.8	2005	25
Burkina Faso							
Bobo 2	Oil	32.26	0.80	0.38	36.63	2014	30
Diesel Generators ODS	Oil	25.92	0.78	0.34	36.8	1977	30
Diesel Generators OHF	Oil	107	0.79	0.37	36.8	1978	30
Dori	Oil	0.64	0.80	0.35	36.63	2011	30
Gaoua	Oil	0.64	0.80	0.35	36.63	2012	30
Komsilga	Oil	89.59	0.80	0.38	36.63	2012	30
Cabo Verde							
Diesel Generators OHF	Oil	69	0.80	0.38	36.8	2000	30
Existing Diesels 1	Oil	38	0.80	0.35	36.8	2003	10
Existing Diesels 2	Oil	45.59	0.80	0.35	36.8	2005	10
Existing Diesels 3	Oil	7.4	0.80	0.35	36.8	2006	10
Solar PV	Solar PV	5	0.25	1.00	29.35	2011	25
Wind30	Wind	9.35	1.00	1.00	91.31	2011	25
Côte d'Ivoire							
5e centrale IPP (Bassam)	Gas	430	0.86	0.50	31.21	2013	25
Gas Turbine GAS	Gas	290	0.88	0.32	36.8	2000	25
Lushann	Gas	100	0.86	0.50	31.21	2013	25
Vridi (CIPREL)	Gas	333	0.86	0.50	31.21	2014	25
GTVridi	Gas	84	0.89	0.25	36.8	1990	25
GTC1prel	Gas	210	0.88	0.30	36.8	1995	25
GTC3prel	Gas	111	0.88	0.30	36.8	2010	25
Aggreko	Gas	70	0.88	0.30	36.8	2010	25

33 Lifespan should be taken as indicative, as many plants operate beyond reported figures.

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Installation year	Life[33] Years
Gambia							
Diesel Generators ODS	Oil	8.2	0.80	0.29	36.8	1981	30
Diesel Generators OHF	Oil	75.4	0.80	0.37	36.8	1990	30
Ghana							
Aboadze T3 phase 1 (TEMA 1, 2, 2X)	Gas	130	0.86	0.30	31.2	2013	25
Combined Cycle GAS	Gas	180	0.85	0.30	36.8	2010	25
Combined Cycle OLC	Oil	300	0.72	0.30	36.8	1998	35
Gas Turbine ODS	Oil	70	0.80	0.29	36.8	2007	25
Gas Turbine OLC	Oil	320	0.82	0.29	36.8	2001	25
VRA+BXC (2016)	Solar PV	22.5	0.12	1.00	21.74	2013	20
Guinea							
Boké	Oil	1.4	0.80	0.38	35.8	2012	33
Diesel	Oil	3.2	0.80	0.40	36.8	2005	30
Diesel Generators OHF	Oil	41	0.80	0.40	36.8	2006	30
Kaloum1 (rehab) 2014	Oil	24	0.80	0.40	36.7	2014	38
Kaloum2 (rehab) 2012	Oil	26	0.80	0.40	36.7	2012	38
Kamsar Mine (rehab)	Oil	34	0.80	0.39	36.6	2015	30
Tombo 3 (rehab) 2012	Oil	89.6	0.80	0.40	36.7	2012	38
Kaloum5	Oil	32.4	0.80	0.40	36.8	2004	30
Guinea-Bissau							
Bissau	Oil	15	0.80	0.38	36.63	2012	30
Diesel Generators ODS	Oil	3.67	0.67	0.36	36.8	2005	30
Liberia							
Bushrod	Oil	10	0.80	0.31	36.63	2013	30
Diesel Generators ODS	Oil	12.64	0.80	0.31	36.8	2006	30
Mali							
Albatros BOOT	Oil	92	0.80	0.38	36.63	2012	30
Balingue BID	Oil	60	0.80	0.38	36.63	2011	30
Diesel Generators ODS	Oil	56.85	0.80	0.37	36.8	2000	30
Diesel Generators OHF	Oil	57.5	0.80	0.38	36.8	2010	30
Gas Turbine ODS	Oil	20	0.86	0.23	36.8	1999	25
KANGABA (CI)	Oil	0.47	0.80	0.31	36.63	2014	30
KOUTIALA (CI)	Oil	4.4	0.80	0.33	36.63	2012	30
SIKASSO (CO)	Oil	9.2	0.80	0.34	36.63	2011	30
Mopti SOLAR	Solar PV	10	0.12	1.00	21.74	2012	20

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Installation year	Life[33] Years
Niger							
Steam Turbine COA	Coal	32	0.86	0.33	78.2	1980	35
Gas Turbine GAS	Gas	10	0.86	0.28	36.8	1980	50
TAG Niamey 2	Gas	10	0.86	0.28	20.65	2010	25
Diesel Generators ODS	Oil	36.9	0.80	0.35	36.8	1980	30
Diesel Generators OHF	Oil	10	0.80	0.38	36.8	1985	30
Niamey 2	Oil	15	0.80	0.38	36.63	2011	30
AGr diesel	Oil	30	0.80	0.35	36.8	2010	30
Nigeria							
Combined Cycle GAS	Gas	1,460	0.48	0.40	36.8	2005	35
Gas Turbine GAS	Gas	3,002	0.37	0.28	36.8	1982	25
ICSPower(Alaoji)	Gas	600	0.86	0.45	34.86	2015	25
OlorunsogoII	Gas	675	0.86	0.45	34.86	2012	25
Sapele, Geregu, Ihovbor, Omotosho	Gas	2,345	0.86	0.28	20.65	2012	25
Steam Turbine GAS	Gas	2,220	0.30	0.34	36.8	1978	35
Senegal							
Combined Cycle GAS	Gas	49	0.86	0.39	36.8	2000	25
Diesel Generators OHF	Oil	335.5	0.80	0.40	36.8	1989	30
Gas Turbine ODS	Oil	66	0.86	0.22	36.8	1984	25
Location	Oil	150	0.80	0.35	36.63	2011	30
Steam Turbine OHF	Oil	53	0.86	0.28	36.8	1966	30
Sierra Leone							
Addax	Biomass	7.5	0.86	0.38	20.4	2014	30
Diesel Generators ODS	Oil	5	0.80	0.35	36.8	1987	30
Diesel Generators OHF	Oil	16	0.80	0.38	36.8	2006	30
Togo							
Diesel Generators OHF	Gas	100	0.86	0.28	36.8	2010	30
Gas Turbine GAS	Gas	20	0.86	0.28	36.8	2008	27
Diesel Generators ODS	Oil	48.7	0.80	0.27	36.8	1968	45

Table 18 Existing hydropower plants

Name of station	Hydro type	Plant capacity MW	Availability (Avg. year) %	Availability (Dry year) %	Fixed O&M USD/kW	Installation year
Burkina Faso						
Bagre	DAM	12	0.55	0.21	66.24	1993
Kompienga	DAM	10	0.36	0.19	66.24	1988
Niofila	ROR	1	0.28	0.24	66.24	1996
Tourni	ROR	1	0.24	0.17	66.24	1996
Côte d'Ivoire						
Ayame 1	DAM	19.2	0.36	0.27	66.24	1998
Ayame 2	DAM	30.4	0.34	0.26	66.24	1998
Buyo	DAM	164.7	0.62	0.47	66.24	1980
Kossou	DAM	175.5	0.33	0.25	66.24	2004
Taabo	DAM	190	0.51	0.39	66.24	2004
Faye	ROR	5	0.43	0.33	66.24	1984
Ghana						
Akosombo	DAM	1020	0.53	0.37	66.24	2005
Bui	DAM	400	0.33	0.26	78.26	2013
Kpong	ROR	160	0.70	0.45	66.24	1982
Guinea						
Baneah (Rehab)	DAM	5	0.15	0.10	78.26	2015
Donkéa (Rehab)	ROR	15	0.55	0.42	78.26	2015
Garafiri	DAM	75	0.39	0.31	66.24	1999
Grandes Chutes (Rehab)	DAM	27	0.54	0.42	78.26	2015
Kaleta (OMVG) part Guinée 30 %	DAM	240	0.45	0.11	78.26	2015
Kinkon	DAM	3.4	0.39	0.36	66.24	2006
Tinkisso	ROR	1.7	0.44	0.35	66.24	2005
Liberia						
Existing Fire	DAM	4	1.00	0.90	66.24	2009
Existing Yand	DAM	1	0.39	0.30	66.24	2009
Mali						
Manantali (OMVS) part Mali 52 %	DAM	200	0.46	0.29	66.24	1988
Selingué	DAM	43.5	0.59	0.52	66.24	1980
Sotuba	ROR	5.7	0.77	0.75	66.24	1966

Name of station	Hydro type	Plant capacity MW	Availability (Avg. year) %	Availability (Dry year) %	Fixed O&M USD/kW	Installation year
Nigeria						
Jebba	DAM	540	0.59	0.35	66.24	1986
Kainji	DAM	760	0.67	0.35	66.24	1968
Shiroro	DAM	600	0.62	0.46	66.24	1989
Senegal						
Manantali (OMVS) part Sénégal 33 %	DAM	67.7	0.45	0.28	66.24	1988
Sierra Leone						
Bumbuna 1	DAM	50	0.66	0.36	66.24	2007
Goma 1	ROR	6	0.59	0.03	66.24	2010
Togo						
Kpime	ROR	1.6	0.41	0.31	66.24	1963
Nangbeto	DAM	65	0.21	0.16	66.24	1987

Table 19 Planned and committed non-hydropower plants

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Benin									
20 MW Biomass Project	Biomass	20	0.50	0.38	20.4	2,718	2020	30	Planned
IPP_THERMAL	Gas	90	0.86	0.28	20.65	688	2016	25	Planned
MariaGleta	Gas	450	0.86	0.41	64.7	2,157	2020	25	Committed
150 MW CCGT project	Gas	150	0.86	0.28	20.65	688	2035	25	Planned
Satar Gas Project	Gas	20	0.85	0.28	20.65	688	2016	25	Committed
GTBID Gas Project	Gas	100	0.17	0.28	20.65	688	2016	25	Committed
AFD_SOLAR	Solar PV	5	0.12	1.00	21.74	3,978	2016	20	Planned
CEB_SOLAR	Solar PV	5	0.12	1.00	21.74	3,978	2016	20	Planned
IPP_SOLAR	Solar PV	85	0.12	1.00	514.05	3,978	2016	20	Planned
IPP_WIND	Wind	10	0.30	1.00	94.57	1,902	2016	20	Planned
Burkina Faso									
Diapaga	Oil	0.46	0.80	0.35	36.63	1,221	2020	30	Planned
Donsin	Oil	100	0.80	0.38	36.63	1,221	2020	30	Planned
Fada	Oil	7.5	0.80	0.38	36.63	1,221	2018	30	Committed
Gorom-Gorom	Oil	0.3	0.80	0.35	36.63	1,221	2020	30	Planned
Ouaga Est	Oil	108	0.80	0.38	36.63	1,221	2020	30	Planned
Ouahigouya	Oil	30	0.80	0.35	36.63	1,221	2019	30	Planned
PIE Thermique	Oil	100	0.80	0.38	36.63	1,221	2020	30	Planned
Mana (SEMAFO)	Solar PV	20	0.24	1.00	488.06	3,978	2018	20	Committed
Ouaga Solaire	Solar PV	30	0.12	1.00	21.74	3,978	2017	20	Committed
PPP/PIE Solaire BID	Solar PV	12.73	0.12	1.00	21.74	3,978	2017	20	Committed
PPP/PIE Solaire EMOA	Solar PV	18.18	0.12	1.00	21.74	3,978	2018	20	Committed
PPP/PIE Solaire Kodeni	Solar PV	15.45	0.12	1.00	488.06	3,978	2017	20	Committed
PPP/PIE Solaire Pa	Solar PV	15.45	0.12	1.00	488.06	3,978	2017	20	Committed
PPP/PIE Solaire Patte d'Oie	Solar PV	5.82	0.12	1.00	488.06	3,978	2017	20	Committed
PPP/PIE Solaire AfD	Solar PV	2.86	0.12	1.00	21.74	3,978	2016	20	Committed
PPP/PIE Solaire Zig	Solar PV	1.18	0.12	1.00	21.74	3,978	2017	20	Committed
PPP/PIE Solaire Zagtouli	Solar PV	15.45	0.12	1.00	488.06	3,978	2017	20	Committed
PPP/PIE Solaire Zano	Solar PV	10	0.12	1.00	488.06	3,978	2017	20	Committed
Cabo Verde									
Planned Pump Storage 1	Pumped storage	20	0.33	1.00		4,348	2018	60	Planned
Planned Pump Storage 2	Pumped storage	20	0.33	1.00		4,348	2023	60	Planned
Côte d'Ivoire									
4e centrale IPP (Abbata)	Gas	450	0.86	0.50	31.2	1,040	2015	25	Planned

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Gambia									
Brikama	Oil	33	0.80	0.38	23.12	1,541	2015	30	Committed
Kotu	Oil	11	0.80	0.38		1,541	2018	30	Committed
Brikama	Solar PV	3	0.22	1.00		2,174	2018	25	Committed
Bakau	Wind	0.6	0.28	1.00	32.61	2,067	2016	25	Committed
Ghana									
Aboadze T3 phase 1 (TEMA 1,2,2X)	Gas	45	0.86	0.30	31.2	1,040	2013	25	Planned
AMERI	Gas	230	0.86	0.30	31.2	1,040	2016	25	Committed
Sunon Asogli phase 2	Gas	170	0.86	0.30	31.2	1,040	2016	25	Committed
CENIT Energy	Oil	100	0.75	0.30	20.65	688	2014	25	Planned
Karpower	Oil	225	0.86	0.30	31.2	1,040	2016	10	Committed
KTPP	Oil	200	0.86	0.30	31.2	1,040	2016	10	Committed
Ayitepa Wind Farm	Wind	225	0.30	1.00	21.74	1,932	2018	20	Committed
Guinea									
Boké	Oil	1.4	0.80	0.38	35.85	1,163	2012	33	Planned
K-Energie	Oil	75	0.80	0.39	36.63	1,221	2016	30	Committed
Kipé	Oil	50	0.80	0.39	36.63	1,221	2016	30	Committed
Iles de loos	Solar PV	1	0.21	1.00	30.43	1,946	2016	25	Planned
Kankan	Solar PV	8	0.21	1.00	30.43	1,946	2019	25	Planned
Kerouané	Solar PV	1	0.21	1.00	30.43	1,946	2016	25	Planned
Khoummaguély	Solar PV	80	0.21	1.00	30.43	1,946	2017	25	Planned
Kouroussa	Solar PV	1	0.21	1.00	30.43	1,946	2016	25	Planned
Madiana	Solar PV	1	0.21	1.00	30.43	1,946	2016	25	Planned
Liberia									
Biomass MSW	Biomass	5.7	0.50	0.38	20.4	2,718	2022	30	Planned
Bushrod 2	Oil	28	0.80	0.38	36.63	1,221	2017	30	Committed
Mali									
Sosumar 1	Biomass	3	0.86	0.38	140.87	3,917	2014	30	Planned
VICA BOOT	Biomass	30	0.86	0.41	20.4	1,040	2012	25	Planned
BOUGOUNI (CI)	Oil	2.5	0.80	0.33	36.63	1,221	2015	30	Planned
DJENNE (CI)	Oil	0.91	0.80	0.29	36.63	1,221	2018	30	Planned
MOPTI (CI)	Oil	8.4	0.80	0.34	36.63	1,221	2018	30	Planned
OUELESSEBOUGOU (CI)	Oil	0.44	0.80	0.31	36.63	1,221	2016	30	Planned
SAN (CI)	Oil	3.7	0.80	0.35	36.63	1,221	2017	30	Planned
TOMINIAN (CI)	Oil	0.36	0.80	0.31	36.63	1,221	2017	30	Planned
WAPP CC	Oil	150	0.86	0.41	31.2	1,040	2019	25	Planned
WAPP SOLAR	Solar PV	30	0.12	1.00	21.74	3,978	2020	20	Planned

Name of station	Plant type	Plant capacity MW	Availability %	Efficiency %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Niger									
Salkadamna	Coal	600	0.86	0.33	279.63	9,321	2018	35	Planned
Tchiro	Coal	25	0.85	0.37	78.37	2,612	2017	30	Planned
Zinder	Gas	8	0.86	0.41	57.04	1,901	2020	25	Planned
Dosso	Oil	1.5	0.80	0.35	36.63	1,221	2016	30	Planned
Gaya	Oil	1.2	0.80	0.35	36.63	1,221	2016	30	Planned
Goudel	Oil	12	0.80	0.38	67.11	2,237	2020	30	Planned
Niamey 2	Oil	0.4	0.80	0.38	36.63	1,221	2011	30	Planned
Tillabery	Oil	1.5	0.80	0.35	36.63	1,221	2016	30	Planned
Gourou Banda	Oil	80	0.80	0.35	36.65	1,222	2016	30	Planned
Solar Mal	Solar PV	7	0.12	1.00	21.74	4,698	2016	20	Committed
Wind	Wind	30	0.30	1.00	18.48	1,715	2020	20	Planned
Nigeria									
CPG Okija	Gas	1,500	0.86	0.45	34.86	1,162	2016	25	Planned
Ethiope	Gas	2,800	0.86	0.28	20.65	688	2017	25	Planned
SupertekNig.	Gas	1,000	0.86	0.45	34.86	1,162	2017	25	Planned
Westcom	Gas	1,000	0.86	0.28	20.65	688	2020	25	Planned
Senegal									
Mboro	Coal	300	0.86	0.33	575	2,489	2019	35	Planned
Sendou	Coal	125	0.86	0.33	399.9	971	2018	35	Committed
IPP Tobene	Oil	70	0.80	0.38	321.23	1,418	2016	30	Committed
IPP Contour Global	Oil	52	0.80	0.38	289.5	1,418	2016	1	Committed
Centrale Diass financement Kfw	Solar PV	15	0.19	1.00	61.96	5,030	2017	20	Planned
Centrale Niass financement EAU	Solar PV	15	0.19	1.00	61.96	5,030	2018	20	Planned
ziguinchor	Solar PV	7.5	0.19	1.00	330.45	5,030	2021	20	Committed
5 IPP de 20 MW	Solar PV	100	0.19	1.00	330.45	5,030	2017	25	Planned
taiba ndiaye	Wind	150	0.30	1.00	380.45	1,934	2017	20	Committed
Sierra Leone									
Addax	Biomass	7.5	0.86	0.38	20.4	3,917	2014	30	Committed
Western Area Power Project (WB)	Oil	57	0.80	0.38	44.02	2,208	2018	25	Committed
Solar2	Solar PV	11	0.12	1.00	21.74	1,840	2017	20	Committed
Togo									
Diesel Generators OHF	Gas	200	0.86	0.28	36.8	1,163	2010	30	Planned
IPP_THERMAL	Gas	50	0.86	0.28	19.66	655	2020	25	Planned
CEB_SOLAR	Solar PV	5	0.12	1.00	29.35	2,261	2017	20	Planned
IPP_SOLAR	Solar PV	5	0.12	1.00	29.35	2,261	2017	20	Planned
IPP_SOLAR 3 (Kara)	Solar PV	5	0.47	1.00	29.35	2,261	2019	20	Planned
IPP_WIND	Wind	25	0.30	1.00	91.31	2,890	2018	25	Planned

Table 20 Planned and committed hydropower plants

Name of station	Hydro type	Plant capacity MW	Availability (Avg. year) %	Availability (Dry year) %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Benin									
Adjarala	DAM	147	0.28	0.18	73.83	2,461	2020	50	Committed
Dogo-bis	DAM	128	0.35	0.27	68.65	2,288	2018	50	Committed
Ketou	DAM	160	0.35	0.27	68.65	2,288	2018	50	Committed
Yeri Hydro Dam	DAM	1	0.24	0.18	66.24	2,288	2016	50	Committed
Burkina Faso									
Aval	DAM	14	0.29	0.22	330.17	11,006	2023	50	Committed
Bontioli	DAM	5.1	0.29	0.22	330.17	11,006	2022	50	Committed
Bougouriba	DAM	12	0.29	0.22	330.17	11,006	2025	50	Planned
Folonzo	DAM	10.8	0.29	0.22	330.17	11,006	2022	50	Committed
Gongourou	DAM	5	0.29	0.22	330.17	11,006	2022	50	Committed
Noumbiel	DAM	60	0.39	0.29	155.46	5,182	2025	50	Planned
Samandéni	DAM	2.6	0.29	0.22	330.17	11,006	2017	50	Committed
Côte d'Ivoire									
AboissoComoé	DAM	90	0.50	0.38	89.87	2,996	2026	50	Planned
Boutoubré	DAM	156	0.57	0.44	83.81	2,794	2021	50	Planned
GriboPopoli	DAM	112	0.52	0.40	105.95	3,532	2027	50	Planned
Louga	DAM	280	0.54	0.41	154.93	5,164	2020	50	Planned
Soubre	DAM	270	0.47	0.36	74.88	2,496	2018	50	Planned
Tiassalé	ROR	51	0.48	0.37	132.66	4,422	2030	50	Planned
Tiboto/Cavally (Intl.) part CI 50 %	DAM	220	0.61	0.46	83.81	2,794	2022	50	Planned
Ghana									
Daboya	DAM	43	0.52	0.39	153.2	5,107	2020	50	Planned
Hemang	ROR	93	0.42	0.32	87.65	2,922	2020	50	Planned
Juale	DAM	87	0.53	0.40	115.83	3,861	2020	50	Planned
Kulpawn	DAM	36	0.53	0.40	264.5	8,817	2020	50	Planned
Pwalugu	DAM	48	0.44	0.33	118.22	3,940	2020	50	Planned

Name of station	Hydro type	Plant capacity MW	Availability (Avg. year) %	Availability (Dry year) %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Guinea									
Amaria	DAM	280	0.61	0.42	43.89	1,463	2020	50	Committed
Balassa	DAM	181	0.30	0.20	49.89	1,663	2030	50	Committed
Bouréya	DAM	114	0.73	0.38	68.48	2,283	2023	50	Planned
Daboya (recherche de Finance)	DAM	2.8	0.31	0.20	139.35	4,645	2021	50	Planned
Fomi	DAM	90	0.47	0.33	253.64	8,455	2029	50	Planned
Keno (recherche de Finance)	DAM	2.1	0.31	0.20	139.35	4,645	2021	50	Planned
Kogbedou (recherche de Finance)	DAM	44	0.11	0.01	139.35	4,645	2021	50	Planned
Koukoutamba	DAM	294	0.34	0.26	45.66	1,522	2021	50	Committed
Morissananko	DAM	100	0.60	0.48	67.18	2,239	2026	50	Planned
N'Zebela (recherche de Finance)	DAM	27	0.50	0.24	139.35	4,645	2021	50	Planned
Poudaldé	DAM	90	0.43	0.38	54.36	1,812	2040	50	Planned
Samankou (rehab)	DAM	130	0.44	0.49	175.63	5,855	2020	100	Planned
Touba (recherche de Finance)	DAM	5	0.54	0.01	139.35	4,645	2021	50	Planned
Korafindi	DAM	100	0.63	0.48	67.18	2,239	2045	50	Planned
Other Hydro Projects	DAM	61.7	0.30	0.19	81.53	2,718	2030	50	Committed
Digan (OMVG) part Guinée 40 %	DAM	93	0.30	0.03	39.16	1,305	2018	50	Planned
FelloSounga (OMVG) part Guinée 40 %	DAM	82	0.46	0.38	113.28	3,776	2018	50	Planned
Other Dams	DAM	2930	0.50	0.40	78.26	2,609	2031	50	Planned
Souapiti (Construction)	DAM	515	0.52	0.48	139.35	4,645	2021	50	Committed
Tinkisso Upgrade	ROR	4.6	0.44	0.30	130.44	4,348	2016	50	Planned
Guinea-Bissau									
Saltinho (OMVG) part Guinée-Bissau 8 %	ROR	20	0.45	0.13	139.35	4,645	2020	50	Planned
Liberia									
DAMEnvisagée	DAM	702.5	0.49	0.37	97.28	3,243	2030	50	Planned
Mount Coffee (+via reservoir)	DAM	66	0.75	0.59	189.24	6,308	2017	50	Committed
SaintPaul -1B	DAM	78	0.75	0.57	101.84	3,395	2025	50	Planned
SaintPaul -2	DAM	120	0.75	0.57	101.84	3,395	2027	50	Planned
Mali									
Felou (OMVS) part Mali 45 %	DAM	60	0.48	0.57	64	2,145	2018	50	Planned
Gouina (OMVS) part Mali 45 %	ROR	140	0.48	0.19	83.19	2,773	2019	50	Committed
Kenié	ROR	34	0.66	0.54	119.71	3,990	2015	50	Planned
Sotuba2	ROR	6	0.74	0.71	78.26	2,609	2014	50	Planned

Name of station	Hydro type	Plant capacity MW	Availability (Avg. year) %	Availability (Dry year) %	Fixed O&M USD/kW	Inv. cost USD/kW	Earliest year	Life Years	Status
Niger									
Dyodyonga	DAM	26	0.49	0.37	74.77	2,492	2020	50	Planned
Gambou	DAM	122.5	0.49	0.37	153.66	5,122	2020	50	Planned
Kandadji	DAM	130	0.55	0.42	101.58	3,386	2017	50	Committed
Namari Goungo	DAM	80	0.49	0.37	74.77	2,492	2020	50	Planned
Nigeria									
Mambilla	DAM	3050	0.49	0.37	50.16	1,672	2021	50	Planned
Zungeru	DAM	700	0.49	0.37	50.16	1,672	2019	50	Planned
Sierra Leone									
Benkongor1	DAM	34.8	0.78	0.66	79.8	2,660	2025	50	Planned
Benkongor2	DAM	80	0.59	0.48	79.8	2,660	2026	50	Planned
Benkongor3	DAM	85.5	0.69	0.56	79.8	2,660	2027	50	Planned
Bumbuna2	DAM	40	0.63	0.68	63.59	2,120	2022	50	Planned
Bumbuna3 (Yiben)	DAM	90	0.50	0.40	63.59	2,120	2023	50	Planned
Bumbuna4&5	DAM	95	0.59	0.56	63.59	2,120	2024	50	Planned
DAM Envisagée	DAM	323	0.66	0.53	83.51	2,784	2028	50	Planned
Togo									
Amou Oblo	DAM	2	0.34	0.26	103.51	3,450	2019	50	Planned
Banga	DAM	6	0.34	0.26	103.51	3,450	2020	50	Planned
Glei	DAM	2	0.34	0.26	103.51	3,450	2019	50	Planned
Kara (Collège Militaire)	DAM	16	0.34	0.26	103.51	3,450	2022	50	Planned
Kpéssi	DAM	8	0.34	0.26	103.51	3,450	2020	50	Planned
Landa	DAM	4	0.34	0.26	103.51	3,450	2020	50	Planned
Tetetou	DAM	50	0.34	0.26	103.51	3,450	2020	50	Planned
Titira	DAM	12	0.34	0.26	103.51	3,450	2021	50	Planned
Tomegbé	DAM	8	0.34	0.26	103.51	3,450	2021	50	Planned

APPENDIX C. GENERIC TECHNOLOGY PARAMETERS

Table 21 Other parameters for renewable energy technologies

	Availability %	Fixed O&M (2015) USD/kW	Thermal efficiency	Construction duration Years	Life Years
Diesel/gasoline 1 kW system (urban/rural)	30 %	23	16 %	0	10
Diesel 100 kW system (industry)	80 %	21	35 %	0	20
Diesel centralised	80 %	35	35 %	2	25
Heavy fuel oil	80 %	44	35 %	2	25
OCGT	85 %	20	30 %	2	25
CCGT	85 %	35	48 %	3	30
Supercritical coal	85 %	78	37 %	4	35
Small hydropower	50 %	124	–	2	30
Biomass	50 %	82	38 %	4	30
Onshore wind	By country	95	–	2	25
Solar PV (utility)	By country	30	–	1	25
Solar PV (rooftop)	By country	50	–	1	20
PV with battery 2 h storage	By country	61	–	1	20
CSP no storage	By country	65	–	4	25
CSP with storage	By country	93	–	4	25

Table 22 Levelised cost of electricity: generic technologies

	Generation (without T&D)		Industry		Urban		Rural	
LCOE (USD/MWh)	2015	2030	2015	2030	2015	2030	2015	2030
Diesel/gasoline 1 kW system (urban/rural)	311	607			311	607	311	607
Diesel 100 kW system (industry)	131	266	131	266				
Diesel centralised	138	273	148	288	171	313	188	360
Heavy fuel oil	98	178	105	187	121	203	133	234
OCGT (imported gas/LNG)	123	144	132	152	157	165	172	190
OCGT (pipeline gas)	116	136	124	143	143	156	157	179
OCGT (domestic gas)	91	106	98	112	108	122	128	140
CCGT (imported gas/LNG)	92	105	98	111	117	120	129	138
CCGT (pipeline gas)	87	100	94	105	108	114	119	131
CCGT (domestic gas)	72	81	77	86	85	93	101	107
Supercritical coal (imported)	97	103	105	108	124	117	137	135
Supercritical coal (domestic)	83	86	89	91	98	99	109	114
Biomass	95	95	102	100	117	109	129	125
Small hydropower	134	134					134	134

Table 23 Levelised cost of electricity: generic wind and solar technologies[34]

LCOE (USD/MWh)	Generation (without T&D) 2015	Generation (without T&D) 2030	Industry 2015	Industry 2030	Urban 2015	Urban 2030	Rural 2015	Rural 2030
Benin								
Solar PV (rooftop – commercial)	221	119	221	119	221	119	221	119
Solar PV (rooftop – rural)	481	249					481	249
Solar PV (rooftop – urban)	232	136			232	136		
Solar PV with 2 h storage (rooftop – rural)	938	493					938	493
Solar PV with 2 h storage (rooftop – urban)	247	143			247	143		
Solar PV (utility)	155	74	166	78	191	84	210	97
CSP no storage	355	227	381	239	438	260	482	299
CSP with storage	360	231	387	243	445	264	489	303
Wind far from grid	337	206	362	217	416	236	458	271
Wind near grid	298	168	320	176	368	192	405	220
Burkina Faso								
Solar PV (rooftop – commercial)	203	109	203	109	203	109	203	109
Solar PV (rooftop – rural)	442	229					442	229
Solar PV (rooftop – urban)	213	125			213	125		
Solar PV with 2 h storage (rooftop – rural)	861	453					861	453
Solar PV with 2 h storage (rooftop – urban)	227	131			227	131		
Solar PV (utility)	142	68	153	71	168	78	181	89
CSP no storage	326	208	350	219	385	238	415	274
CSP with storage	331	212	355	223	391	242	422	279
Wind far from grid	222	136	239	143	263	156	284	179
Wind near grid	197	111	211	116	233	127	251	146
Côte d'Ivoire								
Solar PV (rooftop – commercial)	216	116	216	116	216	116	216	116
Solar PV (rooftop – rural)	470	243					470	243
Solar PV (rooftop – urban)	226	133			226	133		
Solar PV with 2 h storage (rooftop – rural)	916	482					916	482
Solar PV with 2 h storage (rooftop – urban)	242	140			242	140		
Solar PV (utility)	151	72	162	76	187	82	205	95
CSP no storage	346	222	372	233	428	254	471	292
CSP with storage	352	225	378	237	434	258	478	296
Wind far from grid	335	205	359	216	413	234	455	270
Wind near grid	296	166	318	175	366	190	402	219

34 *As resource quality of generic wind and solar PV technologies are country-specific in this analysis, the LCOE for these technologies is similarly country-specific. For more detail, see Section 3.7 (Electricity generation options).*

LCOE (USD/MWh)	Generation (without T&D) 2015	Generation (without T&D) 2030	Industry 2015	Industry 2030	Urban 2015	Urban 2030	Rural 2015	Rural 2030
Gambia								
Solar PV (rooftop – commercial)	207	112	207	112	207	112	207	112
Solar PV (rooftop – rural)	453	234					453	234
Solar PV (rooftop – urban)	218	128			218	128		
Solar PV with 2 h storage (rooftop – rural)	882	464					882	464
Solar PV with 2 h storage (rooftop – urban)	233	134			233	134		
Solar PV (utility)	145	69	156	73	186	79	204	91
CSP no storage	334	214	358	225	426	244	468	281
CSP with storage	339	217	364	228	432	248	475	285
Wind far from grid	389	238	418	251	496	273	546	313
Wind near grid	344	193	370	204	439	221	483	255
Ghana								
Solar PV (rooftop – commercial)	212	114	212	114	212	114	212	114
Solar PV (rooftop – rural)	463	240					463	240
Solar PV (rooftop – urban)	223	131			223	131		
Solar PV with 2 h storage (rooftop – rural)	902	474					902	474
Solar PV with 2 h storage (rooftop – urban)	238	137			238	137		
Solar PV (utility)	149	71	160	75	184	81	202	93
CSP no storage	341	218	366	230	421	250	463	287
CSP with storage	346	222	372	233	428	254	470	292
Wind far from grid	257	158	276	166	318	180	350	207
Wind near grid	228	128	245	135	281	146	309	168
Guinea								
Solar PV (rooftop – commercial)	205	111	205	111	205	111	205	111
Solar PV (rooftop – rural)	448	232					448	232
Solar PV (rooftop – urban)	216	127			216	127		
Solar PV with 2 h storage (rooftop – rural)	873	459					873	459
Solar PV with 2 h storage (rooftop – urban)	230	133			230	133		
Solar PV (utility)	144	69	155	72	184	79	202	90
CSP no storage	330	211	355	223	421	242	463	278
CSP with storage	335	215	360	226	428	246	471	282
Wind far from grid	295	180	316	190	376	206	414	237
Wind near grid	261	147	280	154	333	168	366	193

LCOE (USD/MWh)	Generation (without T&D) 2015	Generation (without T&D) 2030	Industry 2015	Industry 2030	Urban 2015	Urban 2030	Rural 2015	Rural 2030
Guinea-Bissau								
Solar PV (rooftop – commercial)	211	113	211	113	211	113	211	113
Solar PV (rooftop – rural)	460	238					460	238
Solar PV (rooftop – urban)	221	130			221	130		
Solar PV with 2 h storage (rooftop – rural)	896	471					896	471
Solar PV with 2 h storage (rooftop – urban)	236	137			236	137		
Solar PV (utility)	148	71	159	74	189	81	207	93
CSP no storage	339	217	364	228	432	248	476	285
CSP with storage	344	220	370	232	439	252	483	290
Wind far from grid	279	171	299	180	355	195	391	224
Wind near grid	246	139	265	146	314	158	346	182
Liberia								
Solar PV (rooftop – commercial)	235	127	235	127	235	127	235	127
Solar PV (rooftop – rural)	514	266					514	266
Solar PV (rooftop – urban)	247	145			247	145		
Solar PV with 2 h storage (rooftop – rural)	1,000	526					1,000	526
Solar PV with 2 h storage (rooftop – urban)	264	152			264	152		
Solar PV (utility)	165	79	177	83	210	90	232	104
CSP no storage	378	242	406	255	483	277	531	319
CSP with storage	384	246	413	259	490	281	539	324
Wind far from grid	802	491	862	517	1,024	562	1,126	646
Wind near grid	710	399	762	420	906	456	996	525
Mali								
Solar PV (rooftop – commercial)	202	109	202	109	202	109	202	109
Solar PV (rooftop – rural)	442	229					442	229
Solar PV (rooftop – urban)	213	125			213	125		
Solar PV with 2 h storage (rooftop – rural)	860	452					860	452
Solar PV with 2 h storage (rooftop – urban)	227	131			227	131		
Solar PV (utility)	142	68	152	71	175	77	193	89
CSP no storage	325	208	349	219	401	238	442	274
CSP with storage	330	212	355	223	407	242	449	278
Wind far from grid	197	120	211	127	242	138	267	158
Wind near grid	174	98	187	103	214	112	236	129

LCOE (USD/MWh)	Generation (without T&D) 2015	Generation (without T&D) 2030	Industry 2015	Industry 2030	Urban 2015	Urban 2030	Rural 2015	Rural 2030
Niger								
Solar PV (rooftop – commercial)	190	102	190	102	190	102	190	102
Solar PV (rooftop – rural)	414	214					414	214
Solar PV (rooftop – urban)	199	117			199	117		
Solar PV with 2 h storage (rooftop – rural)	806	424					806	424
Solar PV with 2 h storage (rooftop – urban)	213	123			213	123		
Solar PV (utility)	133	63	143	67	157	73	175	83
CSP no storage	305	195	327	205	361	223	401	257
CSP with storage	310	198	333	209	366	227	407	261
Wind far from grid	111	68	120	72	132	78	147	90
Wind near grid	99	55	106	58	117	63	130	73
Nigeria								
Solar PV (rooftop – commercial)	216	116	216	116	216	116	216	116
Solar PV (rooftop – rural)	472	244					472	244
Solar PV (rooftop – urban)	227	134			227	134		
Solar PV with 2 h storage (rooftop – rural)	920	484					920	484
Solar PV with 2 h storage (rooftop – urban)	243	140			243	140		
Solar PV (utility)	152	72	163	76	179	83	213	95
CSP no storage	348	223	373	234	411	255	488	293
CSP with storage	353	226	379	238	418	259	496	297
Wind far from grid	272	166	292	175	322	190	382	219
Wind near grid	241	135	258	142	284	155	338	178
Senegal								
Solar PV (rooftop – commercial)	203	109	203	109	203	109	203	109
Solar PV (rooftop – rural)	420	218					420	218
Solar PV (rooftop – urban)	213	126			213	126		
Solar PV with 2 h storage (rooftop – rural)	864	455					864	455
Solar PV with 2 h storage (rooftop – urban)	228	132			228	132		
Solar PV (utility)	143	68	153	72	177	78	194	89
CSP no storage	327	209	351	220	406	239	444	275
CSP with storage	332	212	357	224	412	243	451	280
Wind far from grid	154	94	166	99	192	108	210	124
Wind near grid	136	77	147	81	170	88	185	101

LCOE (USD/MWh)	Generation (without T&D) 2015	Generation (without T&D) 2030	Industry 2015	Industry 2030	Urban 2015	Urban 2030	Rural 2015	Rural 2030
Sierra Leone								
Solar PV (rooftop – commercial)	228	123	228	123	228	123	228	123
Solar PV (rooftop – rural)	499	258					499	258
Solar PV (rooftop – urban)	240	141			240	141		
Solar PV with 2 h storage (rooftop – rural)	971	511					971	511
Solar PV with 2 h storage (rooftop – urban)	256	148			256	148		
Solar PV (utility)	160	76	172	80	204	87	225	101
CSP no storage	367	235	394	247	469	269	515	309
CSP with storage	373	239	401	251	476	273	523	314
Wind far from grid	538	330	578	347	687	377	756	434
Wind near grid	476	268	512	282	608	306	669	352
Togo								
Solar PV (rooftop – commercial)	197	107	197	107	197	107	197	107
Solar PV (rooftop – rural)	444	230					444	230
Solar PV (rooftop – urban)	207	122			207	122		
Solar PV with 2 h storage (rooftop – rural)	885	466					885	466
Solar PV with 2 h storage (rooftop – urban)	220	127			220	127		
Solar PV (utility)	159	76	171	80	196	87	216	100
CSP no storage	365	234	392	246	451	267	496	307
CSP with storage	371	237	398	250	458	271	503	312
Wind far from grid	283	173	304	182	349	198	384	228
Wind near grid	250	141	269	148	309	161	340	185

APPENDIX D. DETAILED TRANSMISSION DATA

Table 24 Detailed data for existing cross-border transmission infrastructure

Country 1	Country 2	Line voltage kV	Line capacity MW	Distance km	Loss coefficient	Forced outage rate
Ghana	Côte d'Ivoire	225	327	220	3.03 %	0.40 %
Ghana	Togo	161×2	438	91	2.50 %	0.20 %
Senegal	Mali	225	100	1,200	5.46 %	2.20 %
Côte d'Ivoire	Burkina Faso	225	327	222	3.48 %	0.40 %
Nigeria	Benin	330	686	75	2.50 %	0.10 %
Togo	Benin	161	345	65	2.50 %	0.10 %
Nigeria	Niger	132×2	169	162	2.62 %	0.30 %

Table 25 Detailed data for future cross-border transmission projects

From	To	Stations	Voltage kV	Capacity per line MW	Distance km	Losses %	Total investment USD million	Investment cost USD/kW	Earliest year
Dorsale 330 kV (Committed)									
Ghana	Togo/Benin	Volta–Sakete	330	655.2	240	2.50 %	90	137.4	2017
Côte d'Ivoire	Ghana	Riviera–Presea	330	655.2	240	2 %	90	137.4	2017
CLSG (Committed)									
Côte d'Ivoire	Liberia	Man (CI)–Yekepa (LI)	225	337.6	140	2.50 %	59.7	176.9	2018
Liberia	Guinea	Yekepa (LI)–Nzerekore (GU)	225	337.6	140	2.50 %	59.7	176.9	2018
Liberia	Sierra Leone	Yekepa (LI)–Buchanan (LI) – Monrovia (LI)–Bumbuna (SI)	225	303.4	580	6.79 %	247.5	815.6	2018
Sierra Leone	Guinea	Bumbuna (SI)–Linsan (GU)	225	333.7	190	2.50 %	81.1	242.9	2018
OMVG (Committed)									
Senegal	Guinea	Kaolack (SE)–Linsan (GU)	225	286.3	800	9.37 %	289.8	1 012.3	2019
Senegal	Gambia	Birkelane (SE)–Soma (GA)	225	340.7	100	2.50 %	36.2	106.3	2019
Gambia	Guinea-Bissau	Soma (GA)–Bissau (GB)	225	329.1	250	2.93 %	90.6	275.3	2019
Guinea-Bissau	Guinea	Mansoa (GB)–Linsan (GU)	225	309.6	500	5.86 %	181.2	585	2019
Corridor Nord									
Nigeria	Niger	Birnin Kebbi (NG)–Niamey (NI)	330	653.1	268	3.14 %	143.1	219.1	2020
Niger	Togo/Benin	Zabori (NI)–Bembereke (TB)	330	649.7	312	3.65 %	166.6	256.4	2020
Niger	Burkina Faso	Niamey (NI)–Ouagadougou (BU)	330	637.5	469	5.49 %	250.4	392.8	2020

From	To	Stations	Voltage kV	Capacity per line MW	km	Losses %	Total investment USD million	Investment cost USD/kW	Earliest year
Hub Intrazonal (Committed)									
Ghana	Burkina Faso	Han (GH)–Bobo Dioulasse (BU)	225	332.2	210	2.50 %	67	201.7	2017
Burkina Faso	Mali	Bobo Dioulasse (BU)–Sikasso (MA)	225	305.8	550	6.44 %	175.5	573.9	2017
Mali	Côte d'Ivoire	Segou (MA)–Ferkessedougou (CI)	225	319.7	370	4.33 %	136.9	428.3	2017
Guinea	Mali	Fomi (GU)–Bamako (MA)	225	321.3	350	4.10 %	117.6	366.1	2020
Dorsale Mediane									
Nigeria	Togo/Benin	Kaindhji (NG)–Kara/Bembereke/Parakou (TB)	330	646.7	350	4.10 %	164.6	254.6	2020
Togo/Benin	Ghana	Kara/Bembereke/Parakou (TB)–Yendi (GH)	330	654.5	250	2.93 %	117.6	179.7	2020
OMVS									
Mali	Senegal	Gouina (MA)–Tambacounda (SE)	225	329.1	250	2.93 %	94.6	287.6	2020

Table 26 Detailed transmission and distribution losses by country

	Transmission losses	Distribution losses		
		2015	2020	2030
Benin				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	14.75 %	10 %	8 %
Rural	5 %	22.50 %	20 %	20 %
Burkina Faso				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	11 %	10 %	8 %
Rural	5 %	17.50 %	20 %	20 %
Côte d'Ivoire				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	14.75 %	10 %	8 %
Rural	5 %	23 %	20 %	20 %
Gambia				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	17.50 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Ghana				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	14.75 %	10 %	8 %
Rural	5 %	22.50 %	20 %	20 %

	Transmission losses	Distribution losses		
		2015	2020	2030
Guinea				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	17.50 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Guinea-Bissau				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	17.50 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Liberia				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	17.50 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Mali				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	14.50 %	10 %	8 %
Rural	5 %	22.50 %	20 %	20 %
Niger				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	11 %	10 %	8 %
Rural	5 %	20 %	20 %	20 %
Nigeria				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	11 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Senegal				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	15.25 %	10 %	8 %
Rural	5 %	22.50 %	20 %	20 %
Sierra Leone				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	17.50 %	10 %	8 %
Rural	5 %	25 %	20 %	20 %
Togo				
Heavy industry	5 %	2 %	2 %	0 %
Urban/commercial	5 %	14.75 %	10 %	8 %
Rural	5 %	22.50 %	20 %	20 %

APPENDIX E. SELECT REGIONAL RESULTS BY SCENARIO

Scenario	Reference	Regional EREP Target	National Targets
Description	Full background and description provided in Chapters 1 and 3	Reference Scenario, with region-wide minimum target of 23 % renewable energy in overall grid-connected power generation by 2020, and 31 % by 2030, in line with EREP targets	Reference Scenario, with minimum country-level targets for the percentage of renewable energy in total domestic generation based on national renewable energy targets
Additional solar PV capacity 2015–2030 (total capacity by 2030) (GW)	8.2 (8.2)	9.0 (9.0)	21.5 (21.5)
Additional wind capacity 2015–2030 (total capacity by 2030) (GW)	1.6 (1.6)	1.6 (1.6)	1.6 (1.6)
Additional biomass capacity 2015–2030 (total capacity by 2030) (GW)	1.4 (1.4)	4.5 (4.5)	3.1 (3.1)
Additional hydropower capacity 2015–2030 (total capacity by 2030) (GW)	7.3 (11.4)	7.4 (11.5)	7.4 (11.5)
Renewable energy share of centralised electricity production by 2030 (non-hydro)	25 % (10 %)	31 % (16 %)	37 % (22 %)
Total emissions 2015–2030 ($MtCO_2$)	936	891	855
Average emissions intensity of centralised power generation in 2030 (tCO_2/MWh)	0.34	0.31	0.29
Total undiscounted system costs 2015–2030 (USD billion)	195.4	193.6	195.4
Total undiscounted O&M costs 2015–2030 (% of total system costs) (USD billion)	25.6 (13 %)	26.9 (14 %)	27.6 (14 %)
Total undiscounted CAPEX costs 2015–2030 (% of total system costs) (USD billion)	40.4 (21 %)	44.3 (23 %)	50.1 (26 %)
Total undiscounted fuel costs 2015–2030 (% of total system costs) (USD billion)	116.8 (60 %)	109.7 (56 %)	105.1 (54 %)
Total undiscounted domestic T&D costs 2015–2030 (% of total system costs) (USD billion)	10.7 (5 %)	10.7 (5 %)	10.7 (5 %)
Total undiscounted cross-border transmission costs 2015–2030 (% of total system costs) (USD billion)	1.9 (1 %)	1.9 (1 %)	2 (1 %)
Average electricity price 2015–2030 (average price in 2030) (USD/MWh)	89 (95)	88 (94)	89 (94)

Note: tCO_2/MWh = tonnes of carbon dioxide per megawatt hour.

APPENDIX F. DETAILED BUILD PLAN IN THE NATIONAL RENEWABLE TARGETS SCENARIO

New transmission capacity summary

Dorsale

- 2017 Ghana to Togo 655 MW, Togo to Benin 655 MW
- 2019 Côte d'Ivoire to Ghana 655 MW

CLSG

- 2018 Côte d'Ivoire to Liberia 338 MW, Liberia to Guinea 338 MW, Liberia to Sierra Leone 303 MW, Sierra Leone to Guinea 334 MW

OMVG

- 2019 Senegal to Guinea 286 MW, Senegal to Gambia 341 MW, Guinea to Senegal 286 MW, Gambia to Senegal 341 MW

Hub Intrazonal

- 2017 Ghana to Burkina Faso 332 MW
- 2020 Burkina Faso to Mali 306 MW

Corridor Nord

- 2023 Niger to Burkina Faso 137 MW
- 2024 Niger to Burkina Faso 11 MW
- 2026 Niger to Burkina Faso 59 MW
- 2027 Niger to Burkina Faso 21 MW
- 2028 Niger to Burkina Faso 31 MW
- 2029 Niger to Burkina Faso 53 MW
- 2030 Niger to Benin 30 MW, Niger to Burkina Faso 46 MW

Dorsale Mediane

- 2027 Nigeria to Benin 65 MW
- 2028 Nigeria to Benin 126 MW
- 2029 Nigeria to Benin 173 MW
- 2030 Nigeria to Benin 130 MW

New generation capacity summary

Benin

- 2016 Yerikpo Hydro Dam 1 MW, GTBID Gas Project 100 MW, Satar Gas Project 20 MW, Planned PV System (utility) 40 MW
- 2018 Dogo-bis 128 MW, Ketou 160 MW
- 2020 Adjarala 147 MW, MariaGleta 450 MW
- 2025 Generic PV System (utility) 27 MW
- 2026 Generic PV System (utility) 91 MW
- 2027 Generic PV System (utility) 97 MW
- 2028 Generic PV System (utility) 106 MW
- 2029 Generic Biomass 12 MW, Generic PV System (utility) 78 MW
- 2030 Generic Biomass 35 MW, Generic PV System (utility) 23 MW

Burkina Faso

- 2016 PPP/PIE Solaire AfD 3 MW
- 2017 Samandéni 3 MW, Ouaga Solaire 30 MW, PPP/PIE Solaire BID 13 MW, PPP/PIE Solaire Kodeni 15 MW, PPP/PIE Solaire Pa 15 MW, PPP/PIE Solaire Patte d'Oie 6 MW, PPP/PIE Solaire Zagtouli 15 MW, PPP/PIE Solaire Zano 10 MW
- 2018 Fada 8 MW, Mana (SEMAFO) 20 MW
- 2019 Generic Diesel 100 kW system (industry) 15 MW, Generic PV System (utility) 16 MW
- 2020 Generic Biomass 55 MW
- 2021 Generic Biomass 120 MW
- 2022 Generic Biomass 65 MW, Bontioli 5 MW, Folonzo 11 MW, Gongourou 5 MW
- 2023 Generic Biomass 78 MW, Aval 14 MW
- 2024 Generic Biomass 66 MW, Generic Diesel 100 kW system (industry) 10 MW, Generic Diesel Centralised 9 MW
- 2025 Generic Biomass 38 MW, Generic Diesel 100 kW system (industry) 2 MW, Generic Diesel Centralised 25 MW, Generic PV System (utility) 261 MW
- 2026 Generic Biomass 38 MW, Generic Diesel 100 kW system (industry) 2 MW, Generic Diesel Centralised 29 MW, Generic PV System (utility) 37 MW

- 2027 Generic Biomass 38 MW, Generic Diesel 100 kW system (industry) 2 MW, Generic Diesel Centralised 29 MW, Generic PV System (utility) 52 MW
- 2028 Generic Biomass 38 MW, Generic Diesel Centralised 37 MW, Generic PV System (utility) 38 MW
- 2029 Generic Biomass 38 MW, Generic Diesel Centralised 37 MW, Generic PV System (utility) 20 MW
- 2030 Generic Biomass 37 MW, Generic Diesel 100 kW system (industry) 7 MW, PIE Thermique 40 MW, Generic PV System (utility) 36 MW

Cabo Verde

- 2018 Planned Pump Storage 1 2 MW, Generic PV System (utility) 5 MW, Generic Wind Near Grid 5 MW
- 2019 Generic Diesel 100 kW system (industry) 3 MW, Generic PV system (rooftop – commercial) 1 MW, Generic PV System (utility) 10 MW, Generic Wind Near Grid 10 MW
- 2020 Generic PV System (utility) 27 MW, Generic Wind Near Grid 32 MW
- 2021 Generic PV System (utility) 9 MW
- 2022 Planned Pump Storage 1 5 MW, Generic PV System (utility) 14 MW, Generic Wind Near Grid 6 MW
- 2023 Generic Diesel 100 kW system (industry) 2 MW, Planned Pump Storage 1 6 MW, Generic PV System (utility) 13 MW, Generic Wind Near Grid 4 MW
- 2024 Generic Diesel 100 kW system (industry) 2 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 1 MW, Planned Pump Storage 1 6 MW, Planned Pump Storage 2 2 MW, Generic PV system (rooftop – commercial) 18 MW, Generic PV System (utility) 2 MW, Generic Wind Near Grid 1 MW
- 2025 Generic Diesel 100 kW system (industry) 1 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 1 MW, Planned Pump Storage 2 9 MW, Generic PV system (rooftop – commercial) 19 MW, Generic PV system (rooftop – urban) 4 MW, Generic PV System (utility) 5 MW, Generic Wind Near Grid 2 MW
- 2026 Generic Diesel 100 kW system (industry) 1 MW, Generic Diesel/Gasoline 1 kW system (commercial) 1 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 1 MW, Planned Pump Storage 2 7 MW, Generic PV system (rooftop – commercial) 7 MW, Generic PV system (rooftop – urban) 15 MW, Generic PV System (utility) 3 MW
- 2027 Generic Diesel 100 kW system (industry) 1 MW, Generic Diesel/Gasoline 1 kW system (commercial) 7 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 1 MW, Generic Diesel/Gasoline 1 kW system (Rural) 4 MW, Planned Pump Storage 2 1 MW, Generic PV system (rooftop – commercial) 3 MW
- 2028 Generic Diesel 100 kW system (industry) 1 MW, Generic Diesel/Gasoline 1 kW system (commercial) 10 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 4 MW, Generic PV with 2 h Battery (rooftop – rural) 2 MW
- 2029 Generic Diesel 100 kW system (industry) 1 MW, Generic Diesel/Gasoline 1 kW system (commercial) 6 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 4 MW, Generic PV with 2 h Battery (rooftop – rural) 5 MW
- 2030 Generic Diesel 100 kW system (industry) 12 MW, Generic Diesel/Gasoline 1 kW system (commercial) 3 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 10 MW, Generic PV with 2 h Battery (rooftop – rural) 5 MW

Côte d'Ivoire

- 2016 4e centrale IPP (Abbata) 150 MW
- 2017 4e centrale IPP (Abbata) 150 MW
- 2020 Generic Gas Combined Cycle 545 MW
- 2021 Generic PV System (utility) 112 MW
- 2022 Generic PV System (utility) 140 MW
- 2023 Generic Gas Combined Cycle 299 MW, Generic PV System (utility) 168 MW
- 2024 Generic Gas Combined Cycle 141 MW, Generic PV System (utility) 186 MW
- 2025 Generic PV System (utility) 222 MW
- 2026 Generic Gas Combined Cycle 42 MW, Generic Hydro (small) 16 MW, Generic PV System (utility) 498 MW
- 2027 Generic Gas Combined Cycle 181 MW, Generic Hydro (small) 17 MW, Generic PV System (utility) 86 MW
- 2028 Tiboto/Cavally (Intl.) part CI 50 % 81 MW, Generic Gas Combined Cycle 101 MW, Generic Hydro (small) 4 MW, Generic PV System (utility) 417 MW
- 2029 Boutoubré 82 MW, Tiboto/Cavally (Intl.) part CI 50 % 113 MW, Generic Hydro (small) 4 MW, Generic PV System (utility) 135 MW
- 2030 Boutoubré 74 MW, Soubre 85 MW, Tiboto/Cavally (Intl.) part CI 50 % 27 MW, Generic PV System (utility) 340 MW

Gambia

- 2016 Bakau 1 MW
- 2017 Brikama 20 MW
- 2018 Generic PV System (utility) 18 MW
- 2019 Generic PV System (utility) 18 MW
- 2020 Generic Biomass 6 MW
- 2021 Generic Biomass 6 MW
- 2022 Generic Biomass 4 MW, Generic Gas Combined Cycle 29 MW
- 2023 Generic Biomass 8 MW
- 2024 Generic Biomass 6 MW
- 2025 Generic PV System (utility) 5 MW
- 2026 Generic PV System (utility) 3 MW
- 2027 Generic Biomass 3 MW, Generic PV System (utility) 3 MW
- 2028 Generic Biomass 4 MW, Generic PV System (utility) 3 MW
- 2029 Generic Biomass 4 MW, Generic PV System (utility) 3 MW
- 2030 Generic Biomass 4 MW, Generic PV System (utility) 3 MW

Ghana

- 2016 Karpower 225 MW, Aboadze T3 phase 1 (TEMA1, 2, 2X) 30 MW, AMERI 230 MW, Sunon Asogli phase 2,170 MW, KTPP 200 MW, VRA+BXC(2016) 20 MW
- 2018 Generic PV System (utility) 74 MW, Ayitepa Wind Farm 225 MW
- 2019 Generic PV System (utility) 325 MW
- 2020 Generic Biomass 141 MW, Generic Gas Combined Cycle 1000 MW
- 2021 Generic Biomass 94 MW
- 2022 Generic Biomass 99 MW, Generic Gas Combined Cycle 129 MW
- 2023 Generic Biomass 113 MW, Generic Gas Combined Cycle 104 MW
- 2024 Generic Biomass 75 MW, Generic Gas Combined Cycle 210 MW, Generic Hydro (small) 33 MW, Generic PV System (utility) 92 MW
- 2025 Generic Gas Combined Cycle 67 MW, Generic PV System (utility) 845 MW
- 2026 Generic Gas Combined Cycle 276 MW, Generic PV System (utility) 40 MW
- 2027 Generic Gas Combined Cycle 98 MW, Generic Hydro (small) 33 MW, Generic PV System (utility) 1423 MW
- 2028 Generic Gas Combined Cycle 136 MW, Generic Hydro (small) 13 MW
- 2029 Generic Gas Combined Cycle 55 MW, Generic Hydro (small) 4 MW
- 2030 Generic Diesel/Gasoline 1 kW system (Rural) 9 MW, Generic Gas Combined Cycle 280 MW, Generic Hydro (small) 4 MW

Guinea

- 2016 K-Energie 75 MW, Kipé 50 MW, Loffa(rehab) 1 MW
- 2018 Generic PV System (utility) 10 MW, Kerouané 1 MW, Khoummaguély 64 MW
- 2019 Generic Diesel 100 kW system (industry) 23 MW, Generic PV System (utility) 50 MW, Iles de loos 1 MW, Kankan 8 MW, Khoummaguély 16 MW, Kouroussa 1 MW, Madiana 1 MW
- 2020 Generic Biomass 56 MW, Amaria 280 MW, Generic Hydro (small) 3 MW
- 2021 Generic Biomass 26 MW, Koukoutamba 294 MW
- 2022 Generic Biomass 27 MW, Generic Hydro (small) 1 MW
- 2023 Generic Biomass 27 MW
- 2024 Generic Biomass 13 MW, Generic PV System (utility) 36 MW
- 2025 Generic PV System (utility) 240 MW
- 2026 Morissananko 100 MW, Generic PV System (utility) 42 MW
- 2027 Generic PV System (utility) 42 MW
- 2028 Generic PV System (utility) 42 MW
- 2029 Generic PV System (utility) 41 MW
- 2030 Other Hydro Projects 62 MW, Generic PV System (utility) 57 MW

Guinea-Bissau

- 2018 Generic Diesel 100 kW system (industry) 1 MW, Generic PV System (utility) 7 MW
- 2019 Generic PV System (utility) 11 MW
- 2020 Generic Biomass 19 MW
- 2021 Generic Biomass 5 MW, Generic Gas Combined Cycle 2 MW
- 2022 Generic Gas Combined Cycle 26 MW
- 2025 Generic PV System (utility) 14 MW
- 2026 Generic PV System (utility) 3 MW
- 2027 Generic PV System (utility) 3 MW
- 2028 Generic Biomass 4 MW, Generic PV System (utility) 3 MW
- 2029 Generic Biomass 8 MW, Generic PV System (utility) 3 MW
- 2030 Generic Biomass 8 MW, Generic PV System (utility) 3 MW

Liberia

- 2016 Generic Diesel 100 kW system (industry) 2 MW, Generic Diesel/Gasoline 1 kW system (Rural) 1 MW
- 2017 Mount Coffee (+via reservoir) 22 MW
- 2018 Mount Coffee (+via reservoir) 44 MW
- 2022 Biomass MSW 2 MW
- 2028 Generic Hydro (small) 1 MW
- 2029 Generic Hydro (small) 2 MW
- 2030 Generic Biomass 3 MW, Saint Paul -2 7 MW, Generic Hydro (small) 2 MW

Mali

- 2017 Diesel Generators OHF 2 MW
- 2018 Diesel Generators OHF 2 MW, Felou (OMVS) part Mali 45 % 60 MW
- 2019 Gouina (OMVS) part Mali 45 % 140 MW
- 2021 Diesel Generators OHF 2 MW
- 2022 Generic Biomass 10 MW, Diesel Generators OHF 2 MW
- 2023 Generic Biomass 30 MW, Diesel Generators OHF 2 MW
- 2024 Generic Biomass 34 MW, Diesel Generators OHF 2 MW
- 2025 Diesel Generators OHF 2 MW, Generic PV System (utility) 447 MW
- 2026 Generic Biomass 43 MW, Diesel Generators OHF 2 MW, Generic PV System (utility) 47 MW
- 2027 Generic Biomass 60 MW, Diesel Generators OHF 2 MW, Generic PV System (utility) 39 MW
- 2028 Generic Diesel/Gasoline 1 kW system (Rural) 2 MW, Diesel Generators OHF 2 MW, Generic PV System (utility) 29 MW
- 2029 Generic Diesel/Gasoline 1 kW system (Rural) 2 MW, Diesel Generators OHF 2 MW, Generic PV System (utility) 26 MW
- 2030 Generic Biomass 85 MW, Generic Diesel 100 kW system (industry) 5 MW, Generic Diesel/Gasoline 1 kW system (residential/commercial) 17 MW, Generic Diesel/Gasoline 1 kW system (Rural) 2 MW, Diesel Generators OHF 2 MW

Niger

- 2016 Generic Diesel 100 kW system (industry) 6 MW, Solar Mal 7 MW
- 2017 Tchiro 11 MW, Kandadji 130 MW
- 2018 Tchiro 14 MW
- 2020 Generic Biomass 27 MW, Generic Wind Near Grid 12 MW, Generic Wind Away From Grid 30 MW
- 2021 Generic Coal 99 MW, Generic Wind Near Grid 49 MW
- 2022 Generic Coal 39 MW, Generic Wind Near Grid 44 MW
- 2023 Generic Coal 39 MW, Generic Wind Near Grid 47 MW
- 2024 Generic Coal 39 MW, Generic Wind Near Grid 49 MW
- 2025 Generic Coal 39 MW, Generic PV System (utility) 6 MW, Generic Wind Away From Grid 89 MW, Generic Wind Near Grid 27 MW
- 2026 Generic Coal 40 MW, Generic Wind Away From Grid 12 MW, Generic Wind Near Grid 18 MW
- 2027 Generic Coal 38 MW, Generic PV System (utility) 9 MW, Generic Wind Near Grid 18 MW
- 2028 Generic Coal 36 MW, Generic PV System (utility) 55 MW, Generic Wind Near Grid 20 MW
- 2029 Generic Coal 36 MW, Generic PV System (utility) 76 MW, Generic Wind Near Grid 22 MW
- 2030 Generic Biomass 33 MW, Generic Coal 31 MW, Generic PV System (utility) 4 MW, Generic Wind Near Grid 16 MW

Nigeria

- 2016 Jebba 80 MW, Kainji 340 MW, Shiroro 150 MW, CPG Okija 1277 MW
- 2018 Generic PV System (utility) 417 MW
- 2019 Zungeru 700 MW, Generic PV System (utility) 750 MW
- 2020 Generic Biomass 729 MW, Generic Gas Combined Cycle 2000 MW, Generic PV System (utility) 1250 MW
- 2021 Mambilla 2305 MW, Generic Gas Combined Cycle 2000 MW
- 2022 Mambilla 745 MW, Generic Gas Combined Cycle 2000 MW
- 2023 Generic Gas Combined Cycle 1221 MW
- 2024 Generic Gas Combined Cycle 793 MW
- 2025 Generic Gas Combined Cycle 509 MW, Generic PV System (utility) 882 MW
- 2026 Generic Gas Combined Cycle 434 MW, Generic PV System (utility) 1608 MW
- 2027 Generic Gas Combined Cycle 236 MW, Generic PV System (utility) 2000 MW
- 2028 Generic Gas Combined Cycle 370 MW, Generic PV System (utility) 2000 MW
- 2029 Generic Gas Combined Cycle 577 MW, Generic Gas Open Cycle 276 MW, Generic PV System (utility) 2000 MW
- 2030 Generic Gas Combined Cycle 2000 MW, Generic Gas Open Cycle 2000 MW, Generic PV System (utility) 2000 MW

Senegal

- 2016 IPP Contour Global 52 MW, IPP Tobene 70 MW
- 2017 Centrale Diass financement Kfw 15 MW, taiba ndiaye 50 MW
- 2018 Sendou 125 MW, Centrale Niass financement 15 MW, Generic Wind Near Grid 22 MW, taiba ndiaye 50 MW
- 2019 Mboro 300 MW, Generic PV System (utility) 156 MW, taiba ndiaye 50 MW
- 2020 Generic Biomass 47 MW, Generic PV System (utility) 134 MW
- 2021 Generic Biomass 44 MW
- 2022 Generic Biomass 50 MW, Generic Gas Combined Cycle 100 MW
- 2023 Generic Biomass 47 MW, Generic Gas Combined Cycle 100 MW
- 2024 Generic Biomass 47 MW, Generic Gas Combined Cycle 100 MW, Generic PV System (utility) 5 MW
- 2025 Generic PV System (utility) 308 MW, Generic Wind Near Grid 400 MW
- 2026 Generic Wind Near Grid 212 MW
- 2027 Generic Gas Combined Cycle 57 MW, Generic Wind Near Grid 109 MW
- 2028 Generic Biomass 158 MW, Generic PV System (utility) 63 MW, Generic Wind Near Grid 13 MW

- 2029 Generic Biomass 76 MW, Generic Gas Combined Cycle 81 MW, Generic PV System (utility) 72 MW
- 2030 Generic Coal 34 MW, Generic Diesel 100 kW system (industry) 42 MW, Generic Gas Open Cycle 56 MW, Generic PV System (utility) 72 MW

Sierra Leone

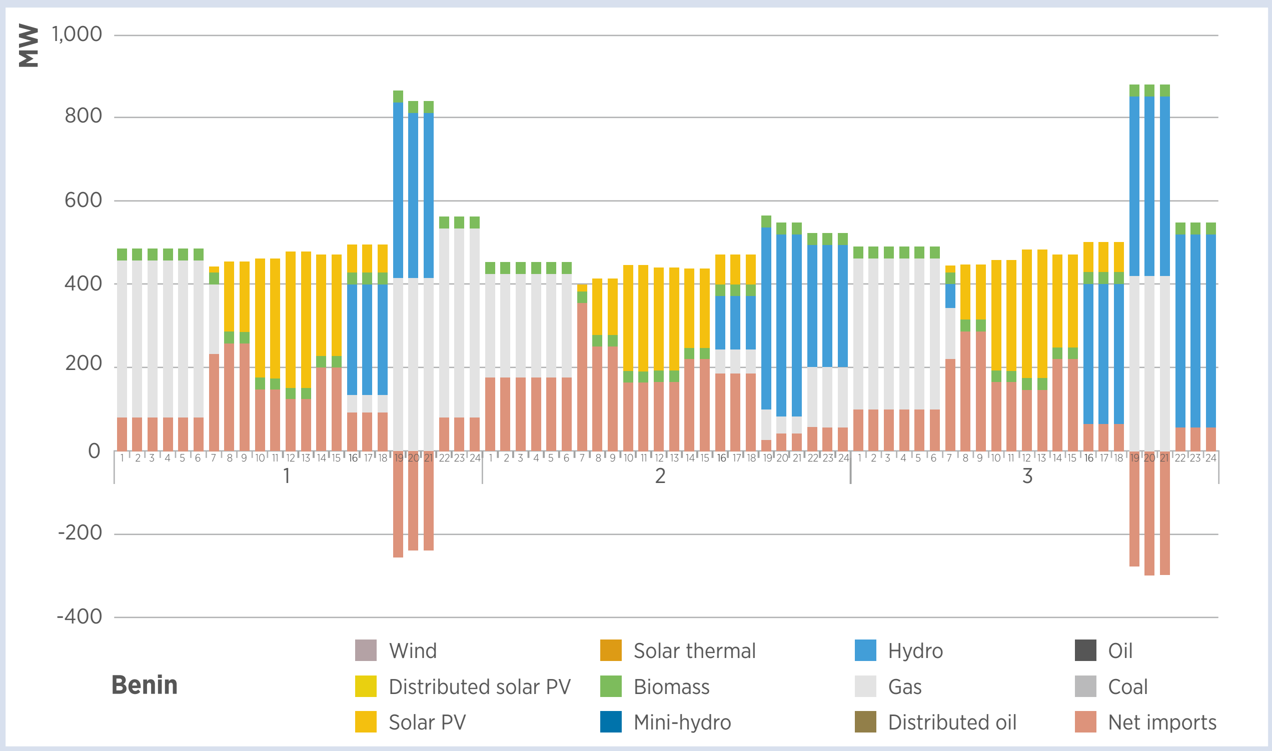
- 2016 Generic Diesel 100 kW system (industry) 7 MW
- 2017 Addax 8 MW, Generic Diesel 100 kW system (industry) 7 MW, Solar2 6 MW
- 2018 Western Area Power Project (WB) 57 MW, Solar2 6 MW
- 2021 Generic Biomass 6 MW
- 2022 Bumbuna2 40 MW
- 2023 Bumbuna3 (Yiben) 90 MW
- 2024 Bumbuna4&5 95 MW
- 2025 Benkongor1 35 MW
- 2026 Benkongor2 80 MW
- 2027 Benkongor3 86 MW
- 2028 DAM Envisagée 100 MW
- 2029 DAM Envisagée 100 MW
- 2030 DAM Envisagée 100 MW

Togo

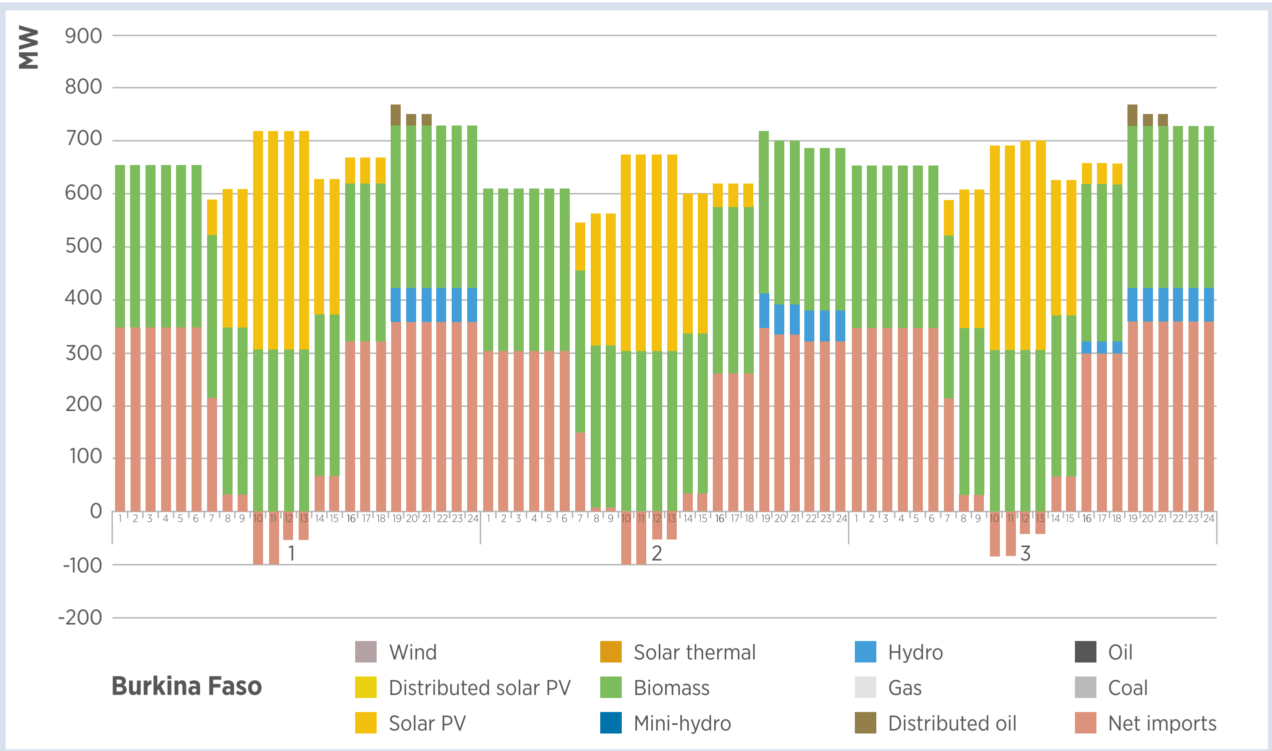
- 2019 Generic PV System (utility) 17 MW
- 2020 Generic Biomass 16 MW, Generic Gas Combined Cycle 5 MW
- 2021 Generic Biomass 8 MW
- 2022 Generic Biomass 9 MW
- 2023 Generic Biomass 10 MW
- 2024 Generic Biomass 10 MW, Generic Gas Combined Cycle 17 MW
- 2025 Generic Biomass 9 MW, Generic Gas Combined Cycle 10 MW, Generic Hydro (small) 5 MW
- 2026 Generic Biomass 10 MW, Generic Gas Combined Cycle 10 MW, Generic Hydro (small) 5 MW
- 2027 Generic Biomass 12 MW, Generic Gas Combined Cycle 12 MW, Generic Hydro (small) 1 MW
- 2028 Generic Biomass 12 MW, Generic Gas Combined Cycle 11 MW, Generic Hydro (small) 1 MW
- 2029 Generic Biomass 26 MW, Generic Gas Combined Cycle 4 MW, Generic Hydro (small) 1 MW
- 2030 Generic Diesel/Gasoline 1 kW system (Rural) 1 MW, Generic Gas Open Cycle 16 MW, Generic Hydro (small) 1 MW

APPENDIX G. DETAILED COUNTRY DISPATCH IN 2030 IN THE NATIONAL RENEWABLE TARGETS SCENARIO

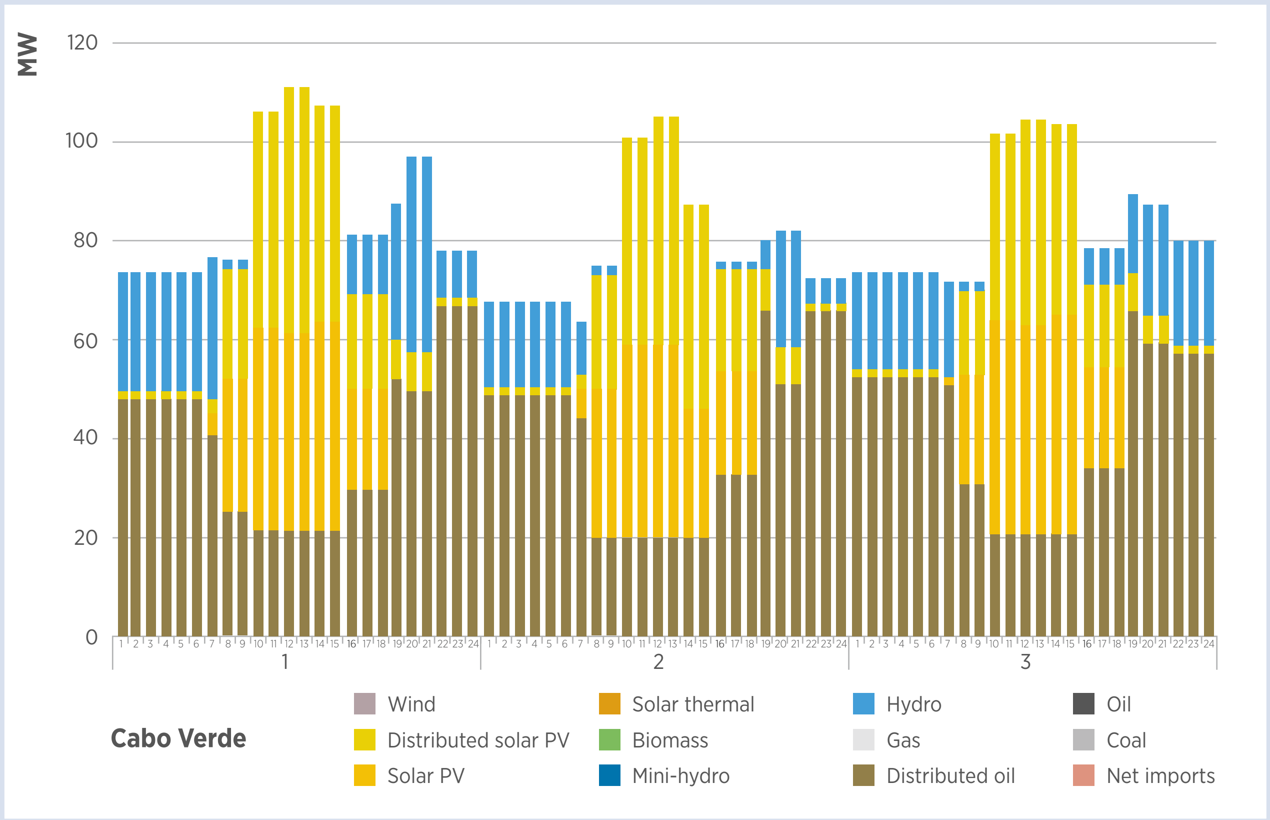
Benin



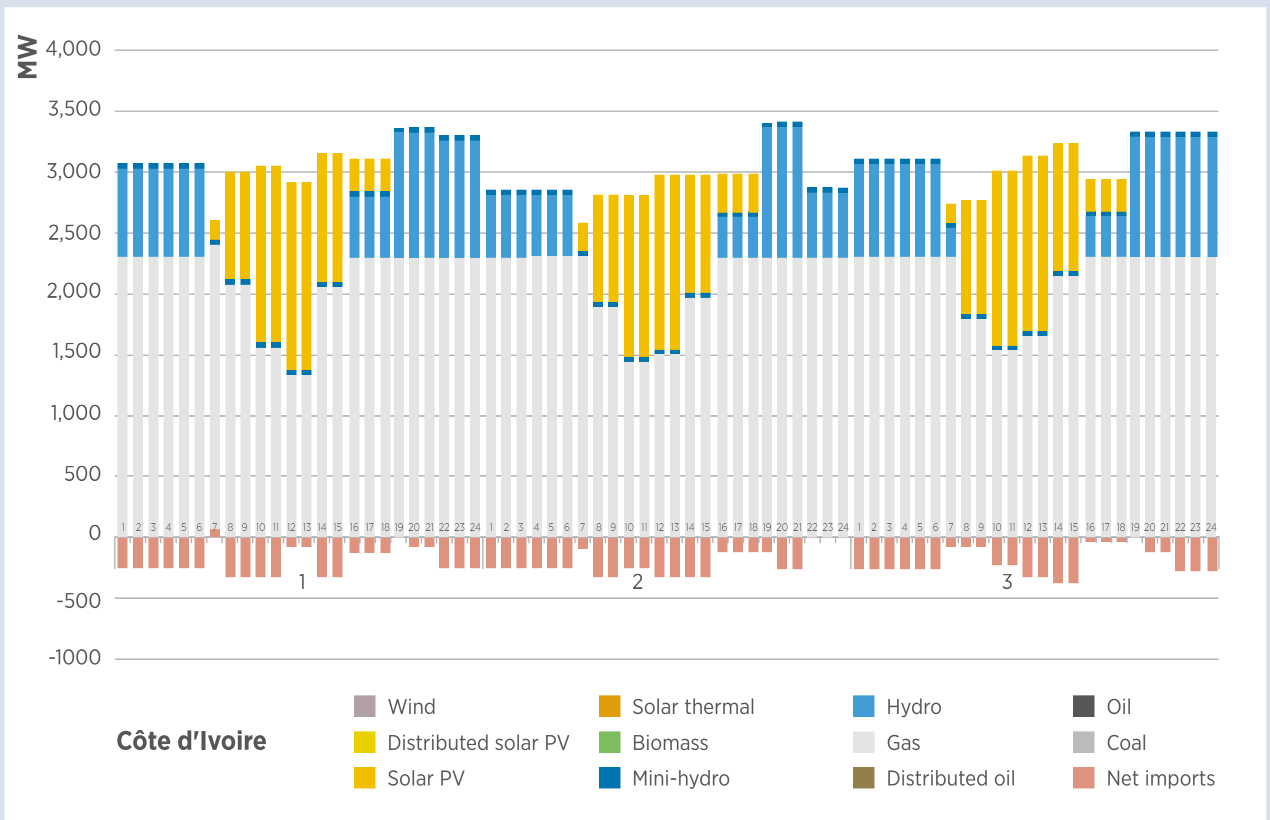
Burkina Faso



Cabo Verde

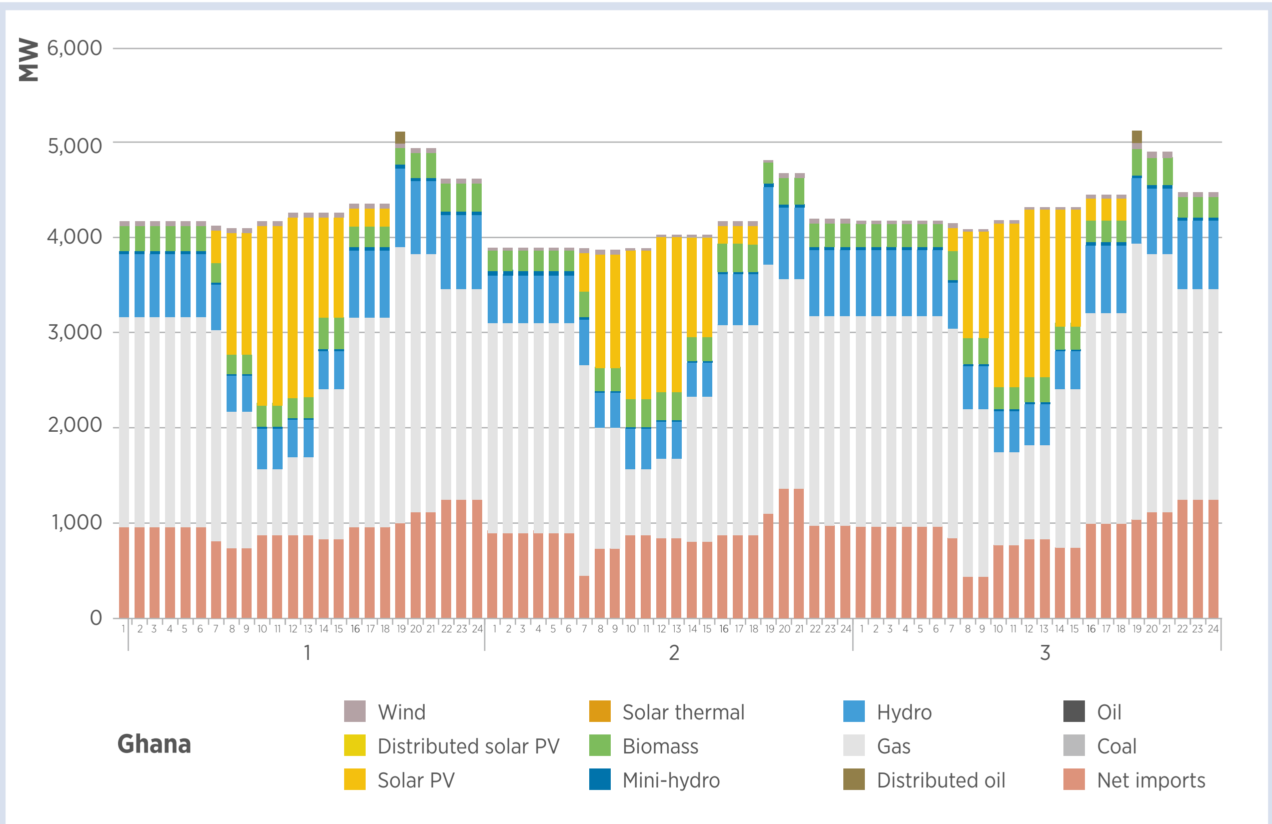


Côte d'Ivoire

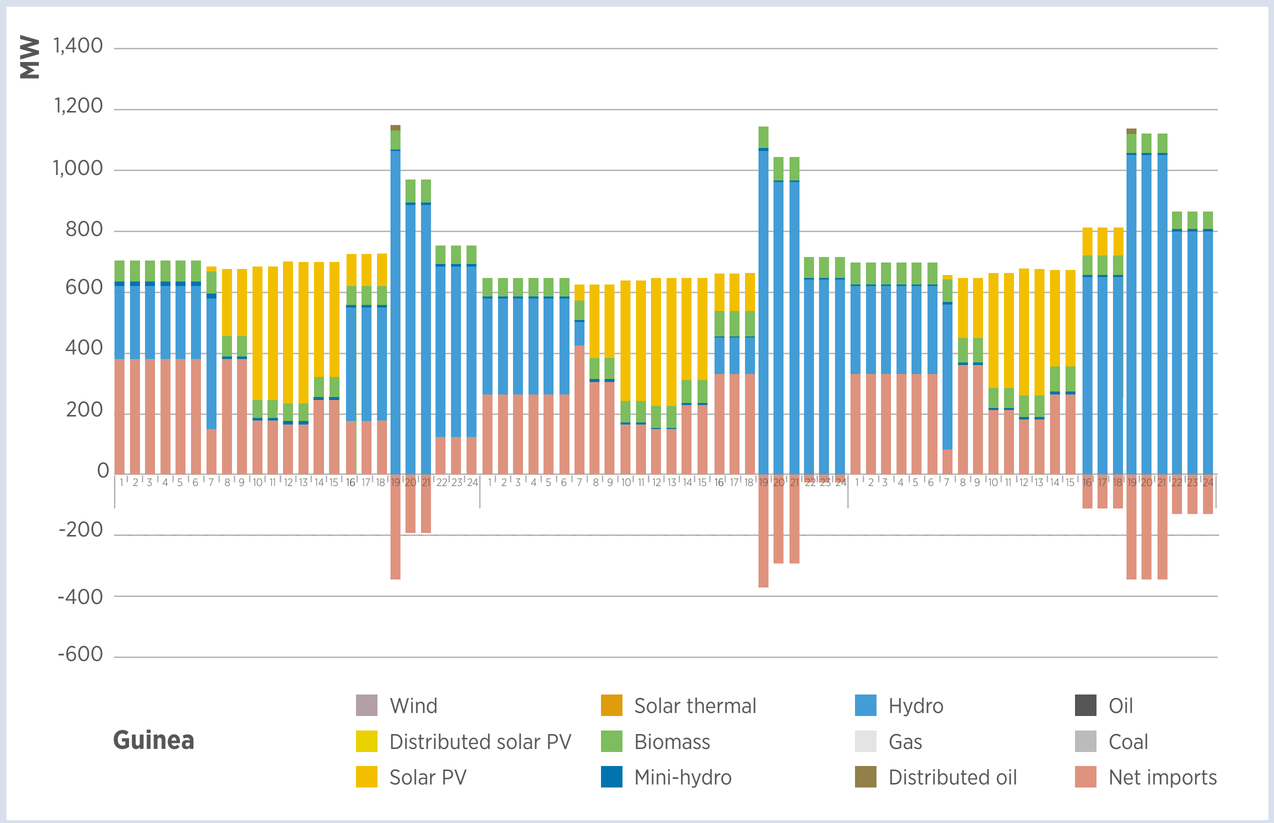


Gambia

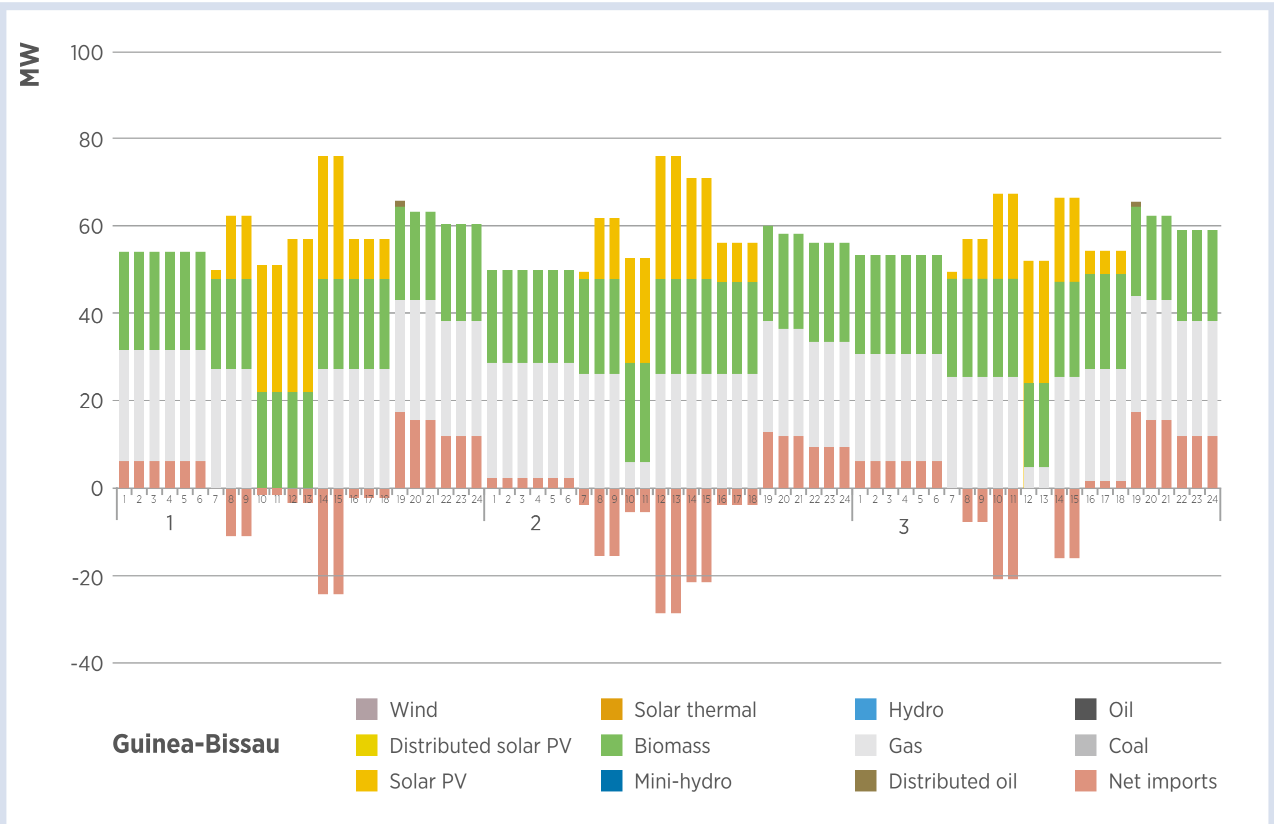
Ghana



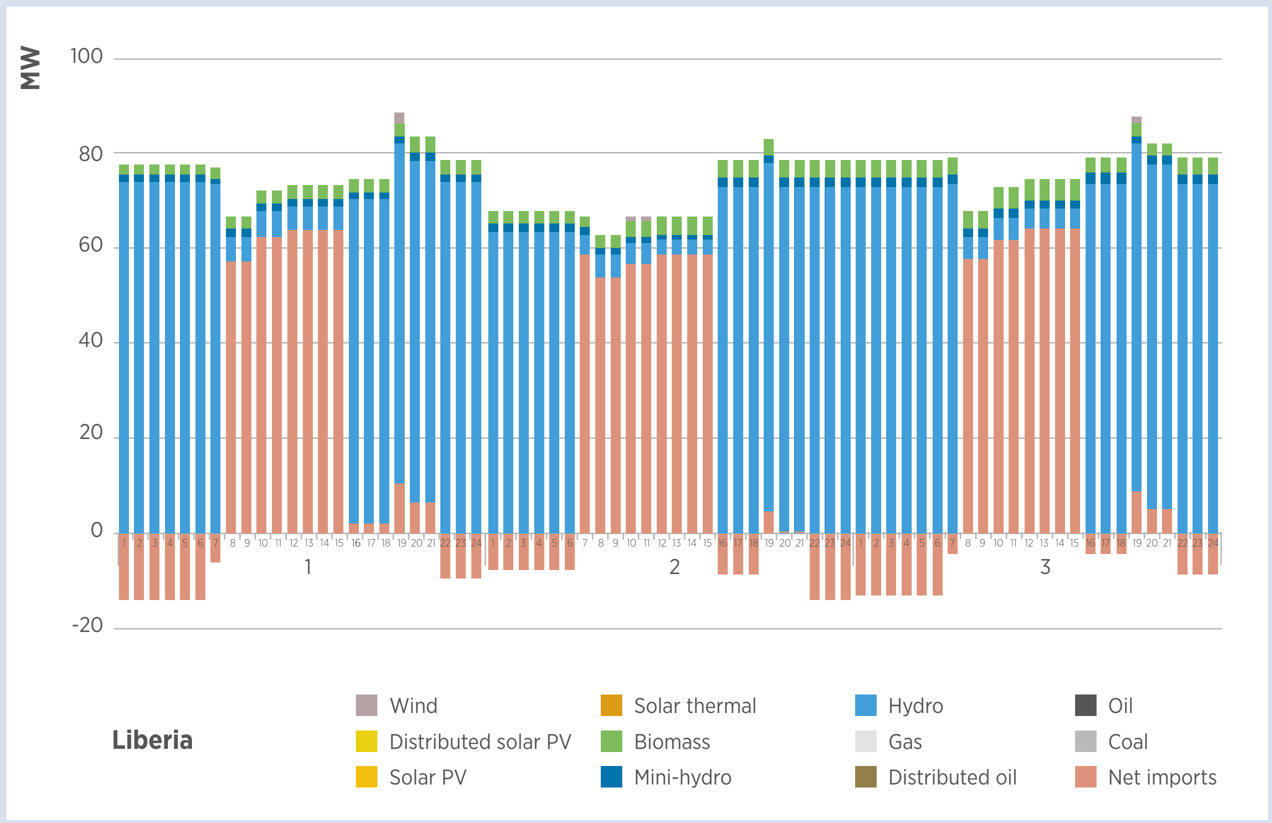
Guinea



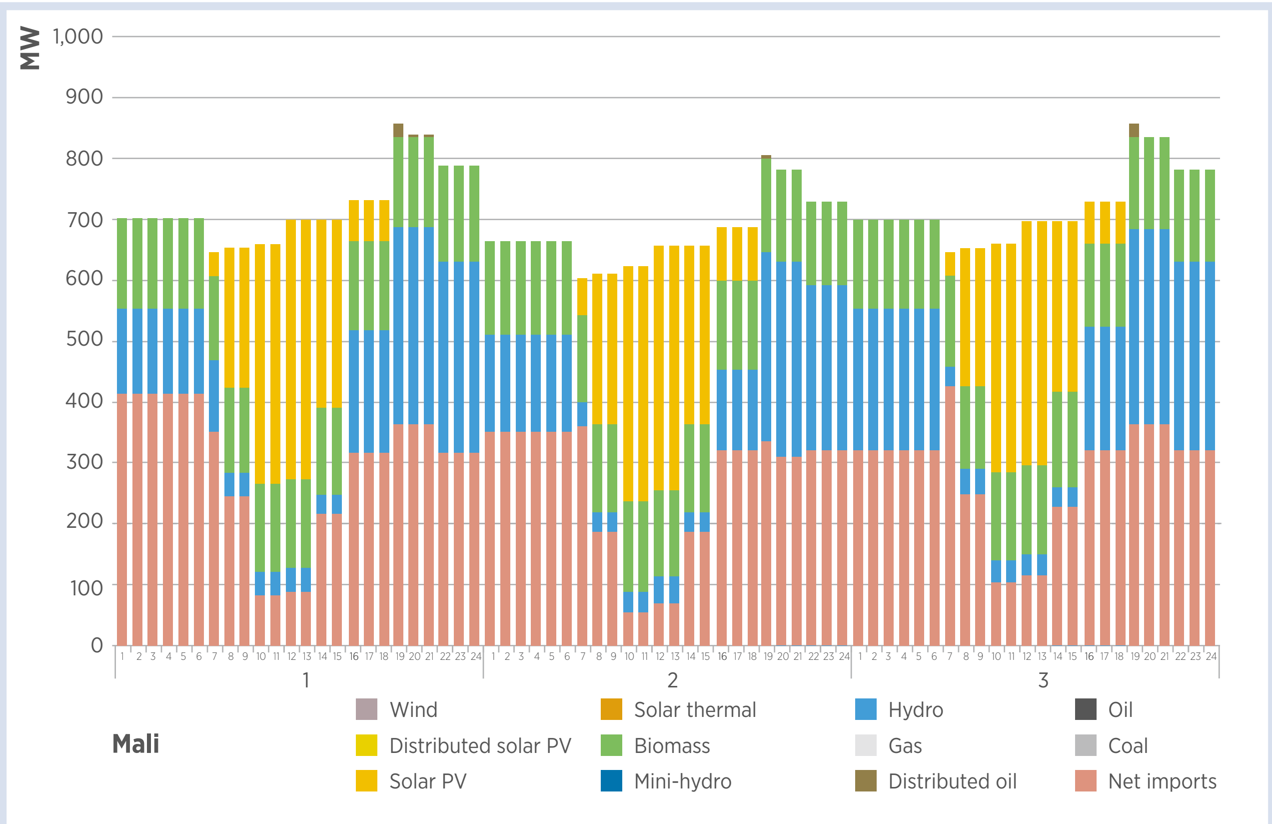
Guinea-Bissau



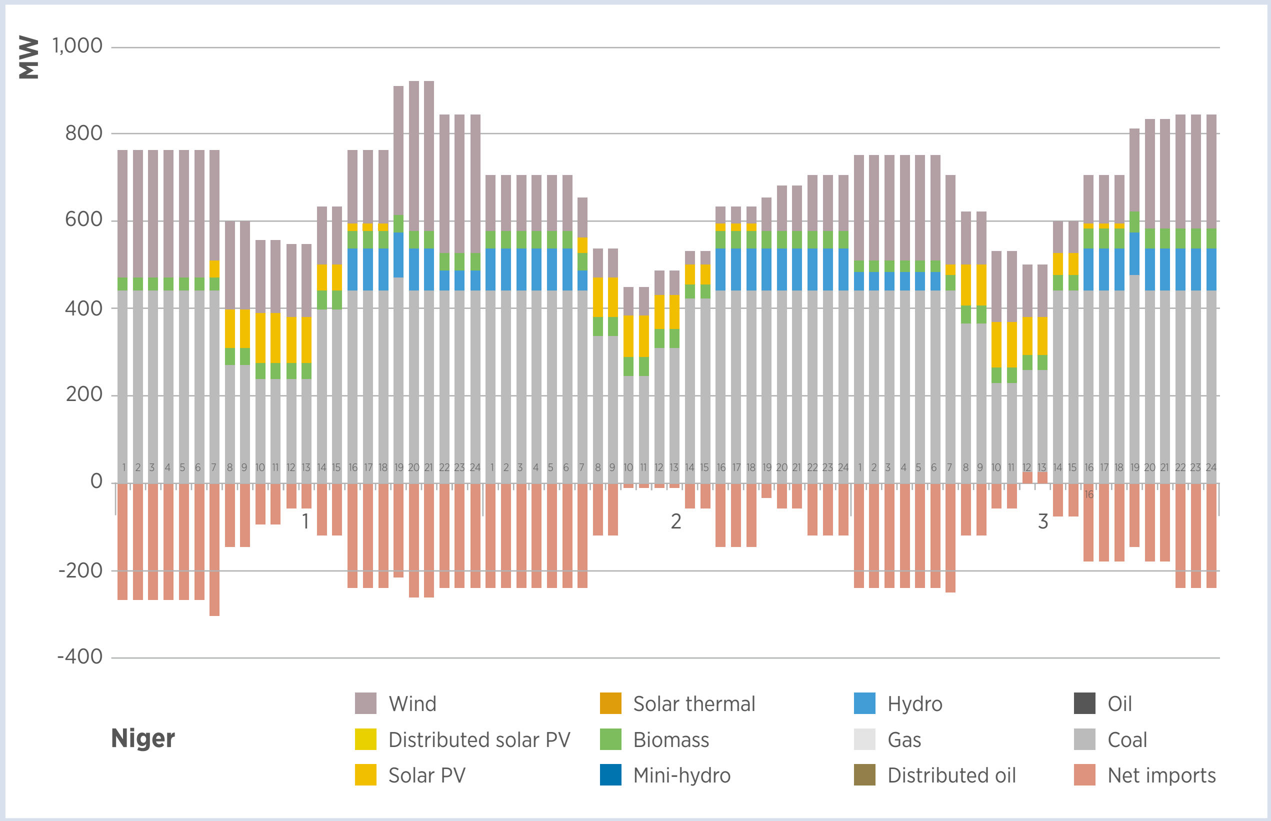
Liberia



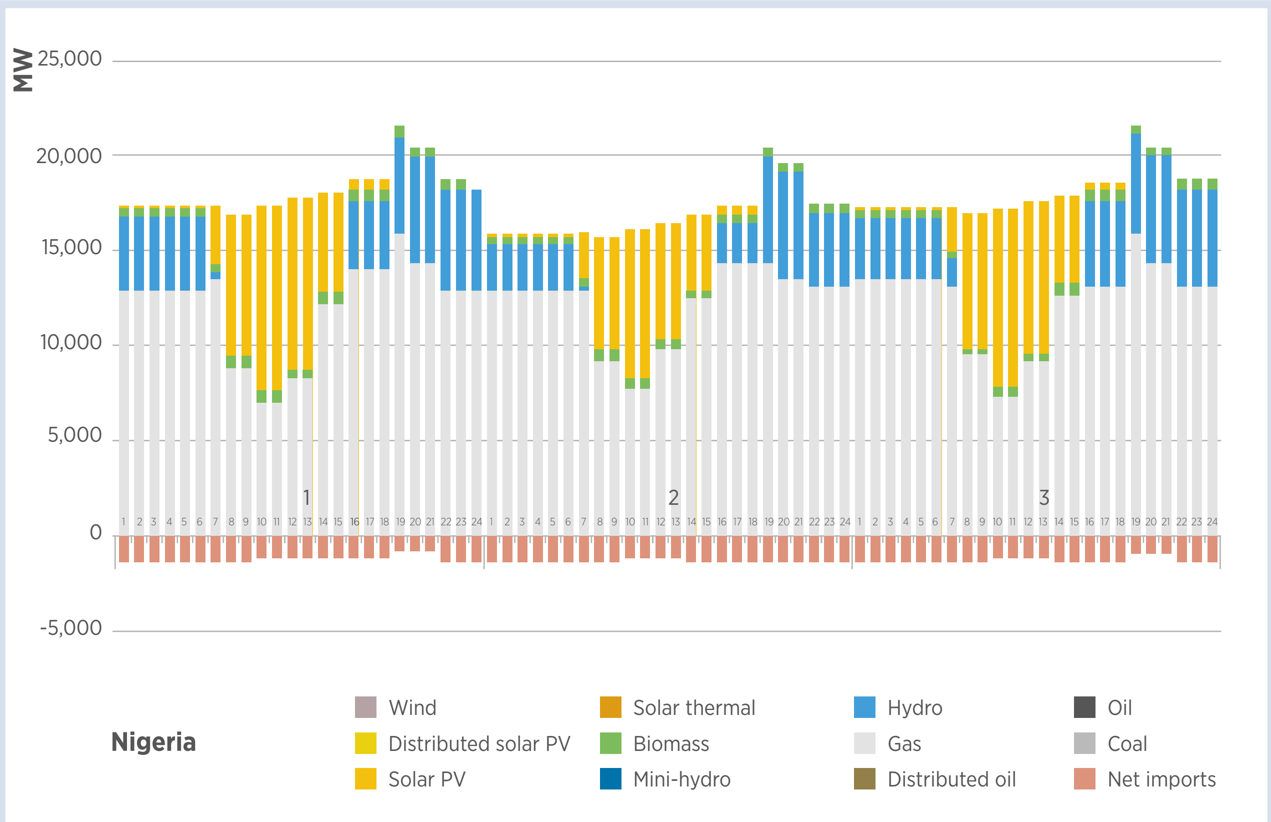
Mali



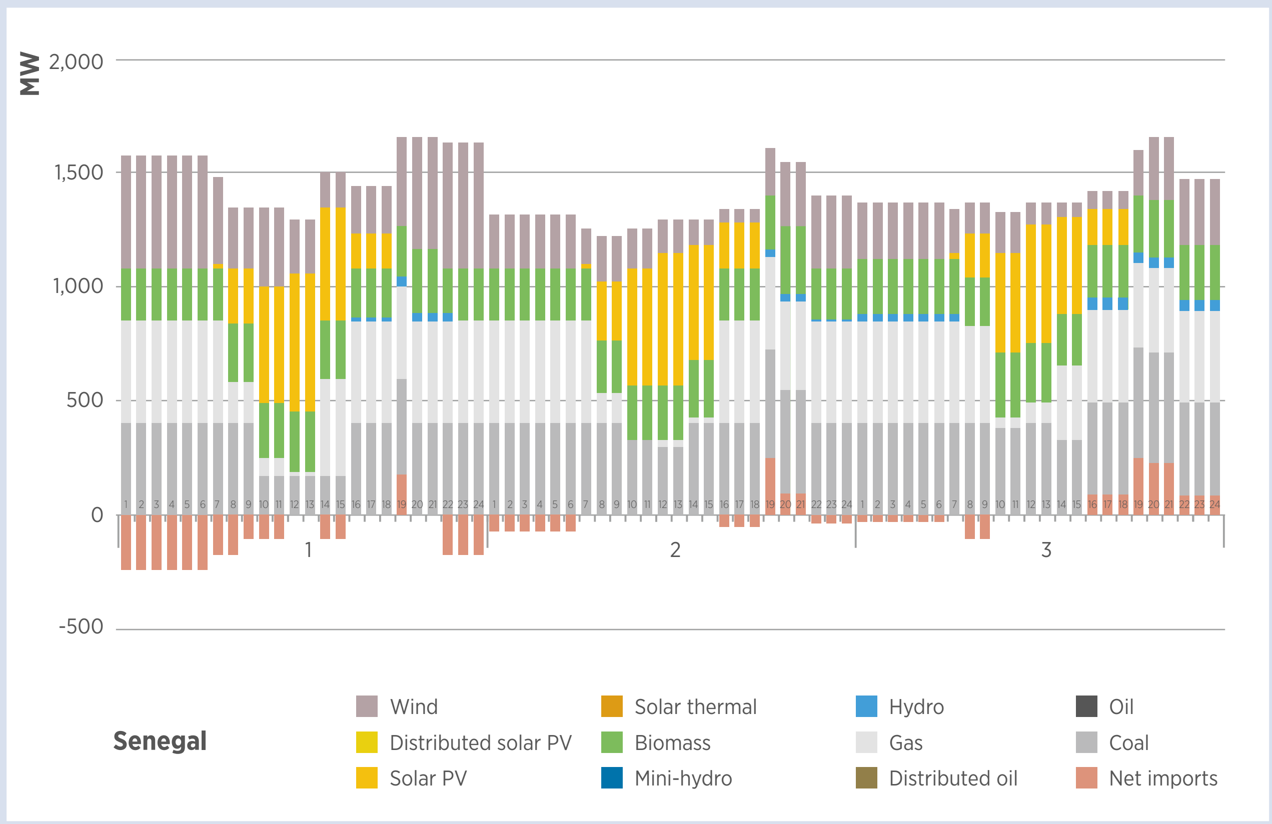
Niger



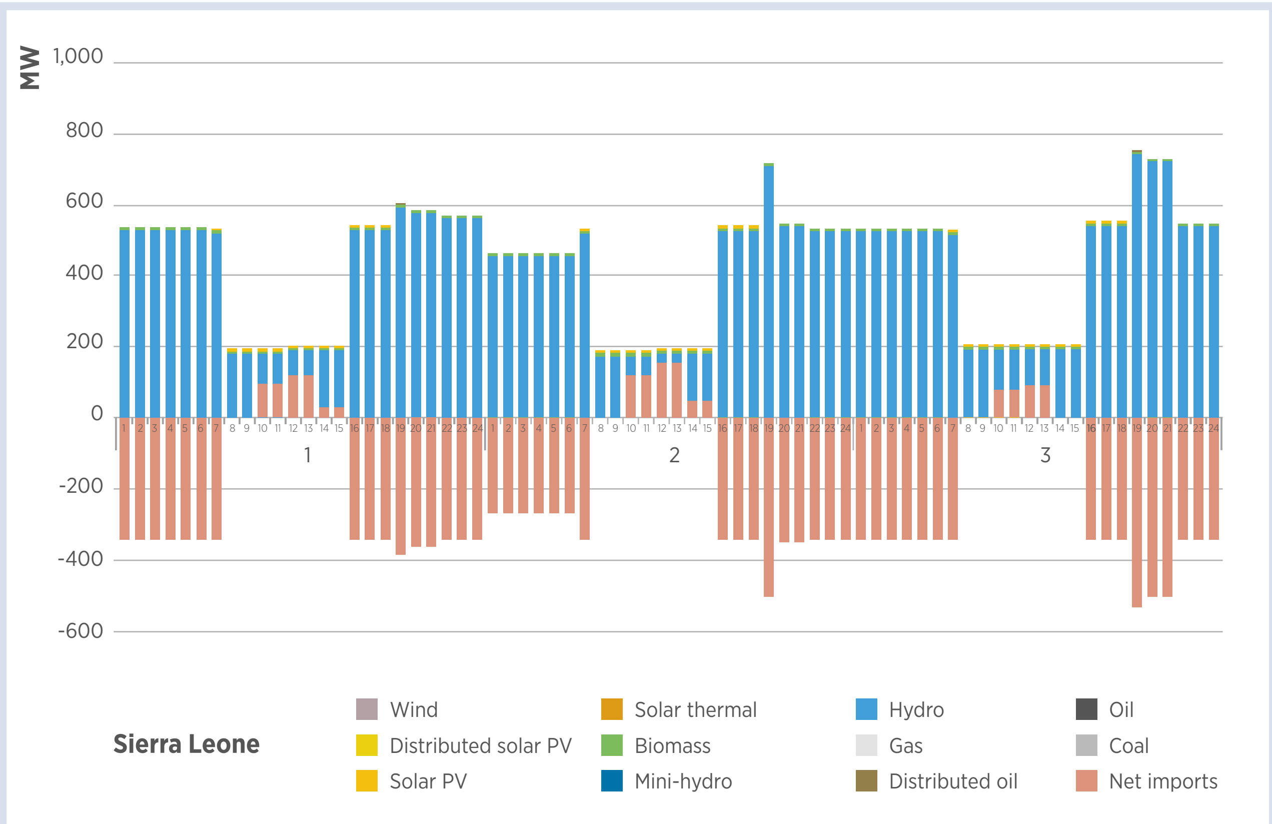
Nigeria



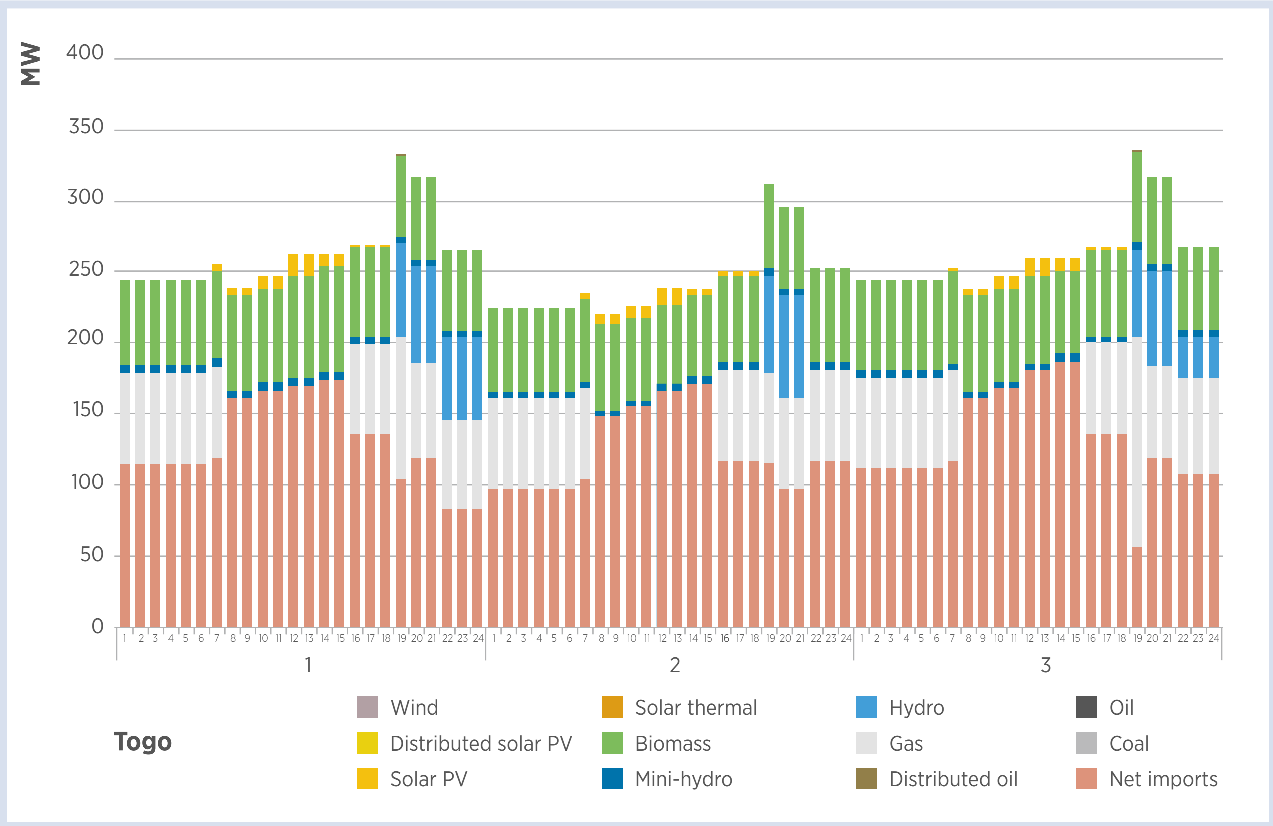
Senegal



Sierra Leone



Togo



MW
400
350
300
250
200
150
100
50
0
1
2
3
Togo
Wind
Distributed solar PV
Solar PV
Solar thermal
Biomass
Mini-hydro
Hydro
Gas
Distributed oil
Oil
Coal
Net imports

National experts participating in SPLAT-W workshops, 2015–2016

Todéman F. Assan, Directorate General of Energy, Benin

Massombé Crespin Kabore, Ministry of Mines and Energy, Burkina Faso

Ariel Cruz Assunção, Directorate-General for Energy, Cabo Verde

Lamin K. Marong, Ministry of Energy, The Gambia

Momodou Lamin Sompo Ceesay, Public Utilities Regulatory Authority, The Gambia

Alhaji Salifu Cham, National Water and Electricity Company, The Gambia

Momo Maninka Bangoura, Ministry of Energy and Water, Guinea

Albert Saa Dembadouno, Ministry of Energy and Water, Guinea

Mamadou Diouma Bah, Ministry of Energy and Water, Guinea

Prince C. Wilson, Ministry of Lands, Mines and Energy, Liberia

Varney K. Garpue, Rural and Renewable Energy Agency, Liberia

Oumarou Adamou, Ministry of Energy and Oil, Niger

Pape Daouda Tine, National Power Company, Senegal

Issa Rouhou Laye Sonko, Ministry of Energy and Development of Renewable Energy, Senegal

Sinneh Abdulsallam Kamara, Electricity Generation and Transmission Company, Sierra Leone

Robin Fola Mansaray, Ministry of Energy, Sierra Leone

Paul Charles Saffa, Ministry of Energy, Sierra Leone

Gbaty Tiadja Gbandey, Ministry of Mines and Energy, Togo

Hodabalo Assih, Ministry of Mines and Energy, Togo

N'bouéké Afanou, Ministry of Mines and Energy, Togo

Note: Honorific titles are omitted.

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