IRENA
International Renewable Energy Agency

THE GAMBIA

ASSESSING THE COST-EFFECTIVENESS OF RENEWABLE ENERGY TECHNOLOGY OPTIONS

Technology
and infrastructure

CLIMATE ACTION SUPPORT

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. **www.irena.org**

About this document

This technical report summarises the main outcomes and findings of the assessment of cost-effectiveness of renewable energy technology options in The Gambia and evaluates the potential to reduce greenhouse gas emissions through the implementation of different power sector measures to inform the climate action planning processes.

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ACRONYMS AND ABBREVIATIONS

BAU	business-as-usual
CAEP	Climate Action Enhancement Package
CAPEX	capital expenditure
CCGT	combined cycle gas turbine
CFL	compact fluorescent lamp
EC	European Commission
ECOWAS	Economic Community of West African States
EIB	European Investment Bank
ESMAP	Energy Sector Management Assistance Program
EU TAF	European Union Global Technical Assistance Facility for Sustainable Energy
EUR	euro
GDP	gross domestic product
GHG	greenhouse gas
Gg CO_2-e	gigagram of carbon dioxide equivalent
Gt CO_2-e	gigatonne of carbon dioxide equivalent
GWh	gigawatt hour
HFO	heavy fuel oil
INDC	Intended Nationally Determined Contribution
IRENA	International Renewable Energy Agency
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
kt CO_2-e	kilotonne of carbon dioxide equivalent
LED	light-emitting diode
LFO	light fuel oil
Lm	lumen
LULUCF	land use, land-use change and forestry
MACC	marginal abatement cost curve
MEPS	minimum energy performance standards
MW	megawatt
MWh	megawatt hour
NDC	Nationally Determined Contribution
NGO	non-governmental organisation
OMVG	Gambia River Development Organisation
OPEX	operational expenditure
PV	photovoltaic
PURA	Public Utilities Regulatory Authority
ROGEP	Rural Off-Grid Electrification Programme
SHS	solar home systems
SPLAT	System Planning Test
t CO_2-e	tonne of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
W	watt
WAPP	West African Power Pool
Wh	watt hour

EXECUTIVE SUMMARY

The Gambia submitted its first Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016. The country was one of few developing countries to put forward an ambitious mitigation target of greenhouse gas (GHG) emissions reduction by about 44.4% in 2025 and 45.4% in 2030 compared with the business-as-usual scenario (excluding land use, land-use change and forestry [LULUCF]).

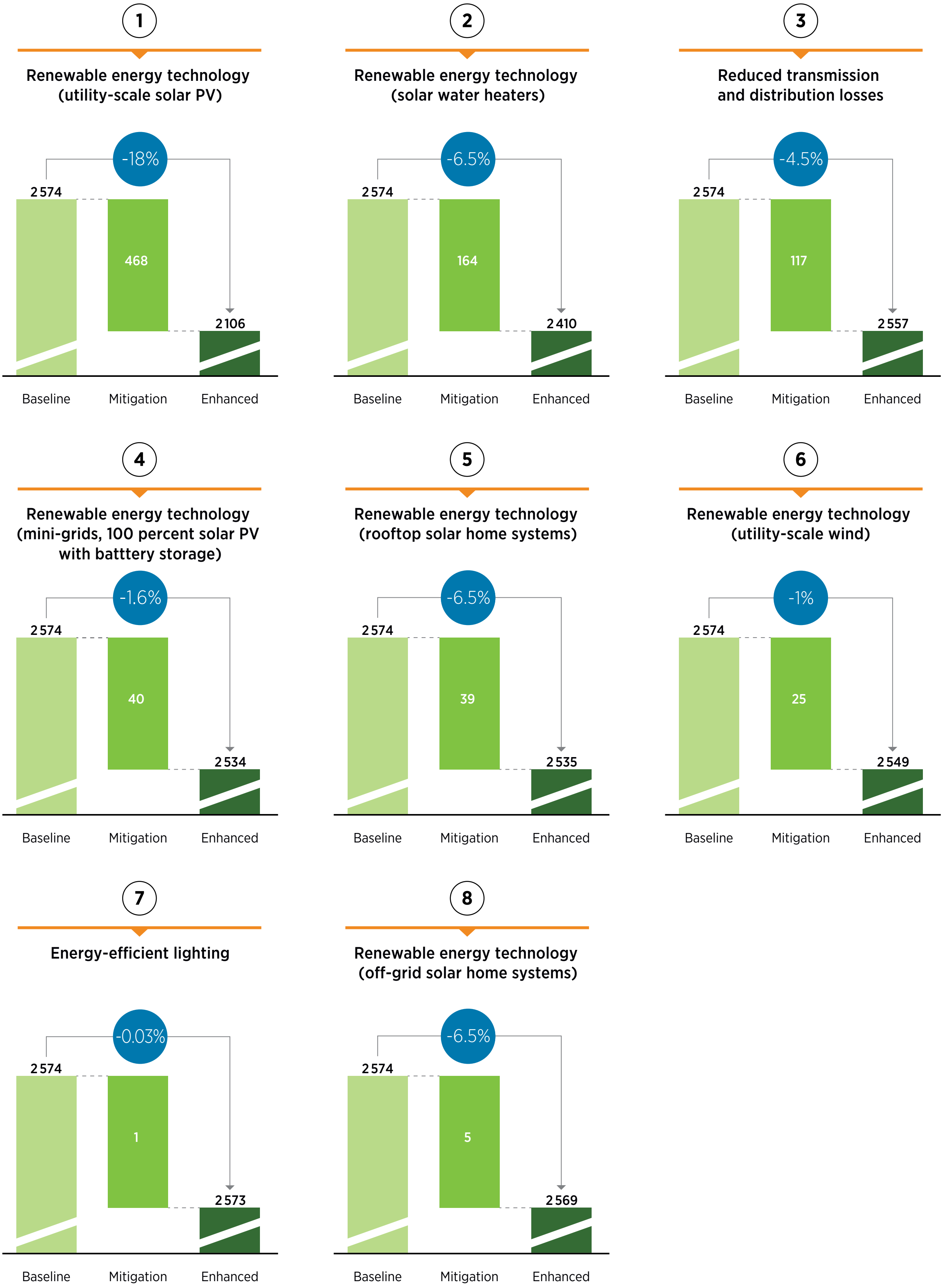
To support The Gambia in the process of revising and updating its NDC, the International Renewable Energy Agency (IRENA) has conducted a cost-effectiveness analysis of mitigation options for the power sector. The overarching aim of the study was to support climate policy decision makers by providing valuable information for the identification, quantification and selection of mitigation measures in the power sector and informing the path to cost-effective achievement of mitigation targets.

A three-step process has been followed to evaluate the measures:

- **update and enhancing of the baseline scenario developed for the NDC**
- **identification and revisions of mitigation options**
- **a cost-effectiveness analysis using the most recent data.**

The study finds that utility-scale solar photovoltaic (PV), solar water heating and reductions in transmission and distribution network losses present the highest GHG emissions savings, while all the mitigation measures assessed present negative abatement costs. The GHG mitigation reduction potentials of the assessed mitigation options are presented in Figure ES 1 (in % and kt CO_2-e). The mitigation measures yield the following average GHG emissions savings over the period 2025-30 compared with the baseline scenario: on-grid solar, 18%; solar water heating, 6%; improvements in transmission and distribution efficiency, 5%; and small-scale PV capacity, 3%. Solar home systems and efficient lighting do not present a significant impact on GHG emissions by 2030.

Figure ES 1: Greenhouse gas reduction potential of mitigation options identified and assessed in the study over the period 2025-30 compared with the baseline scenario



Note: kt CO_2-e = kilotonnes of carbon dioxide equivalent.

Five baseline scenarios were developed using an updated methodology from the previous NDC, reflecting various evolutions of the power supply mix. The generation capacity and timeline used in the baseline scenarios have been benchmarked against official Gambian sources, and the dispatch strategy applied follows a least-cost approach. The different baseline scenarios explored are described in Table ES 1.

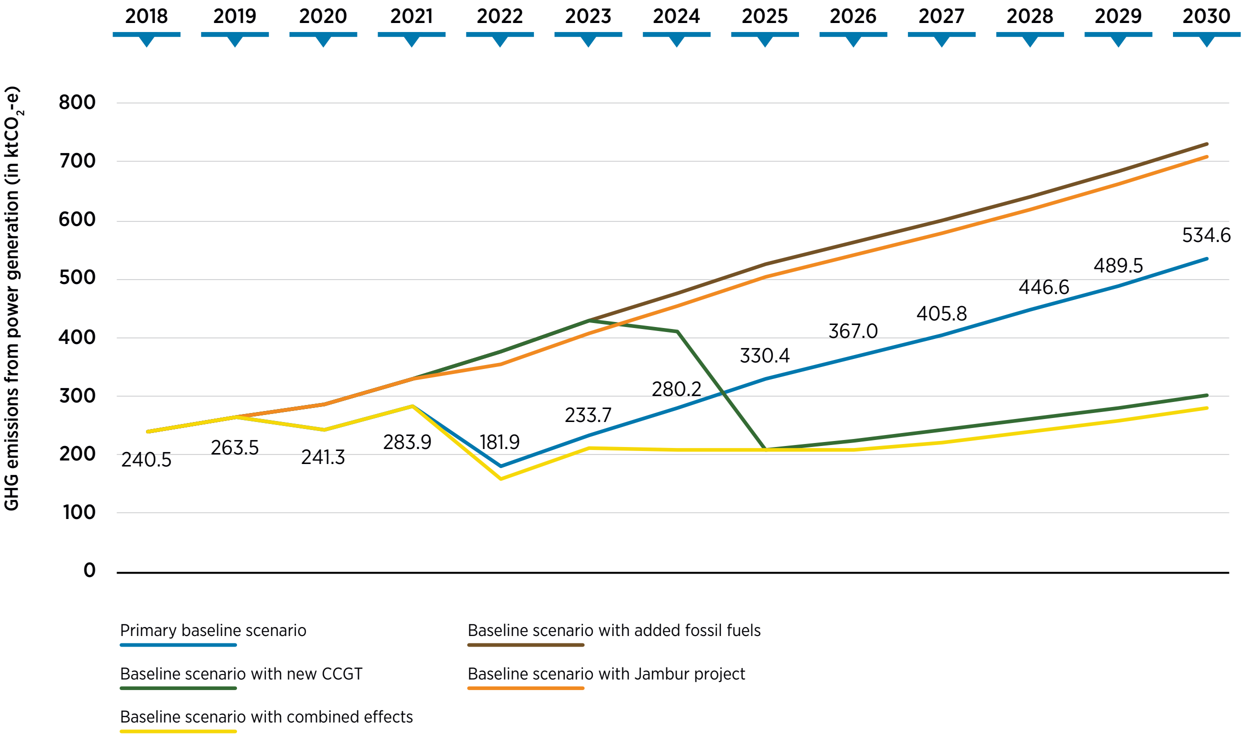
Table ES 1: Descriptions of baseline scenarios

BASELINE SCENARIO	DESCRIPTION
Primary baseline	In addition to heavy fuel oil (HFO) capacity, this scenario also includes hydropower imports from the Gambia River Development Organisation (OMVG) project
Fossil fuels	Includes only HFO capacity
New combined cycle gas turbine (CCGT)	In addition to HFO capacity, this scenario also includes domestically produced as well as imported CCGT-generated electricity
Jambur project	In addition to HFO capacity, this scenario also includes the solar PV project Jambur
Combined effects	In addition to HFO capacity, this scenario also includes hydropower imports from the OMVG project, the solar PV project Jambur and domestically produced as well as imported CCGT-generated electricity

Source: Yong006 / Shutterstock.com.

A single baseline scenario, namely the "Primary baseline" scenario, has been chosen following a validation exercise with national stakeholders. The projected GHG emissions per baseline scenario are shown in Figure ES 2. The baseline scenario with new CCGT and the baseline scenario with combined effects represent the lowest GHG emissions and both include imports of CCGT-generated electricity. It is worth noting that GHG emissions from imported electricity are not included in The Gambia's GHG emissions inventory, which means that imported electricity, regardless of whether it is generated from CCGT or hydropower, results in zero emissions in this analysis. While emissions from imported electricity are not included in this analysis, they are still emitted in the country of origin and contribute to global warming.

Figure ES 2: Greenhouse gas emissions from power generation per baseline scenario 2018-30



Mitigation options have been identified by revising mitigation actions of the 2015 Intended Nationally Determined Contribution as well as by reviewing other national plans and programmes. A mitigation scenario has been developed for each mitigation option to compare its GHG reduction potential and cost-effectiveness with the baseline scenario, utilising technical and financial data from the country when available. Table ES 2 indicates the GHG emissions reduction potential for each mitigation option.

Table ES 2: Greenhouse gas emissions reduction potential per mitigation option

MITIGATION OPTION	DESCRIPTION	GHG EMISSIONS REDUCTIONS (KT CO_2-E) VERSUS BASELINE		
		2025	2030	ABSOLUTE 2030
Renewable energy technology (utility-scale solar PV)	89 megawatts (MW) of utility-scale solar PV capacity (incl. Jambur project)	59	97	533.25
Renewable energy technology (utility-scale wind)	3.6 MW of utility-scale wind capacity	4	4	33.35
Reduced transmission and distribution losses	Reduction of transmission and distribution losses to 17%	11	30	134.07
Renewable energy technology (mini-grids)	25% hybridisation of diesel mini-grids with solar PV	2.5	0.1	19.42
Renewable energy technology (mini-grids)	Full replacement of diesel mini-grids with solar PV and battery storage systems	10.2	0.3	77.69
Energy-efficient lighting	Substitution of incandescent light bulbs	0.07	0.18	0.90
Renewable energy technology (off-grid solar home systems)	Solar home systems to supply off-grid consumption	1.6	0.1	9.18
Renewable energy technology (rooftop solar home systems)	6 MW of solar PV rooftop systems by 2024	6.5	6.5	55.61
Renewable energy technology (solar water heaters)	Solar water heating facilities to supply 10% of demand by 2030	18.3	36.5	200.94

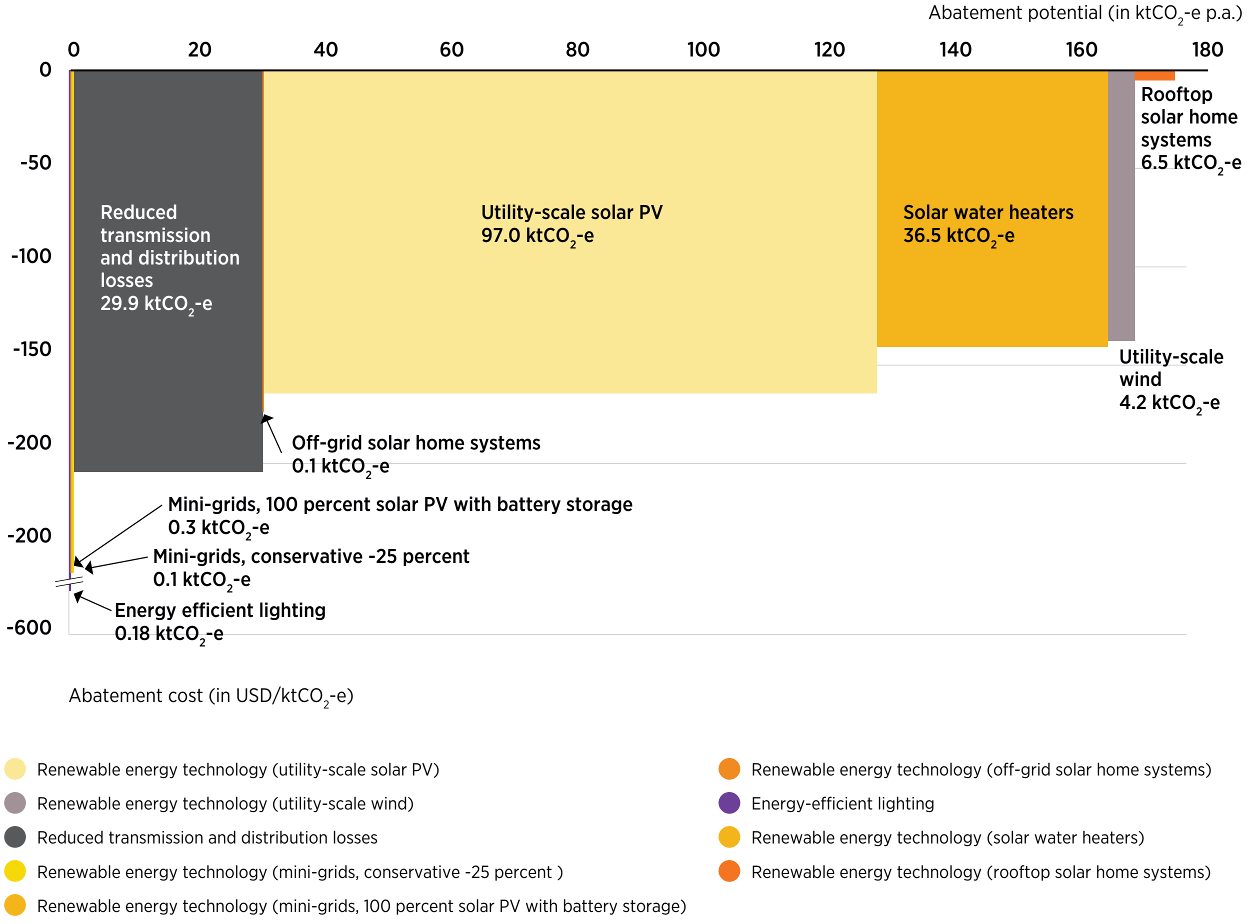
The cost-effectiveness analysis has been performed using the marginal abatement cost curve (MACC) methodology. MACC is a useful tool to support climate policy decision-making as it informs on the GHG abatement potential and associated costs of the policies and technology options assessed. The MACCs have been developed based on the updated baseline and mitigation scenarios. After a detailed literature review, assumptions have been reviewed with national stakeholders in two workshop sessions held on 23-24 February 2021 and on 18 March 2021.

Although the GHG reduction potential varies significantly among the mitigation options, all studied mitigation measures demonstrate a negative GHG abatement cost (Figure ES 3), indicating that under the analysed circumstances, they are attractive from both economic and GHG emissions reduction perspectives.

The mitigation measures are ranked according to the increasing marginal abatement cost per kilotonne of carbon dioxide equivalent (kt CO$_2$-e) reduction (US dollar/kt CO$_2$-e). The most cost-effective measure is efficient lighting, followed by the hybridisation of mini-grids, reductions in transmission and distribution losses, solar home systems, utility-scale solar PV capacity deployment, solar water heaters, utility-scale wind capacity deployment, and solar PV rooftop systems.

All measures are financially attractive and most of them generate revenue ranging between USD 145/kt CO$_2$-e and USD 270/kt CO$_2$-e, while solar rooftops are the least interesting option with a revenue of only USD 5/kt CO$_2$-e. The GHG emissions abatement cost of efficient lighting is USD -580/kt CO$_2$-e, less than half the cost of the second lowest-cost measure, which is hybridisation and substitution of mini-grids with solar PV at an abatement cost of approximately USD -270/kt CO$_2$-e. All measures except efficient lighting and solar rooftops have an abatement cost ranging between USD -145/ kt CO$_2$-e and USD -270/kt CO$_2$-e, while solar rooftops have the highest cost at USD -5/kt CO$_2$-e.

Figure ES 3: Marginal abatement cost curves for year 2030



In light of the findings of this study, IRENA recommends including the mitigation measures listed in Table ES 3, as they are all financially sound investments. Despite the fact that some measures offer only modest emissions reductions, they are extremely beneficial in terms of socio-economic development.

Table ES 3: Recommended mitigation measures for inclusion in the NDC update

MITIGATION OPTION	DESCRIPTION	TARGET YEAR*
Renewable energy technology (utility-scale solar PV)	**89 MW** of utility-scale solar PV capacity	2030
Renewable energy technology (utility-scale wind)	**3.6 MW** of utility-scale wind capacity	2023
Reduced transmission and distribution losses	Reduction of transmission and distribution losses to **17%**	2030
Renewable energy technology (mini-grids)	Replacement of diesel mini-grids with **solar PV and battery storage systems**	2023
Energy-efficient lighting	Substitution of incandescent **light bulbs**	2030
Renewable energy technology (off-grid solar home systems)	**Solar home systems** to supply off-grid consumption	2023
Renewable energy technology (rooftop solar home systems)	**6 MW** of solar PV rooftop systems by 2024	2024
Renewable energy technology (solar water heaters)	Solar water heating facilities to supply **10%** of demand by 2030	2030

*Year of completion

Box 1: The Gambia's second NDC

The Gambia submitted its second NDC on September 12, 2021. The NDC was evaluated by Climate Action Tracker as part of its Global Update, with The Gambia being the only party rated as having overall climate action compatible with the Paris Agreement's 1.5°C target, out of 37 parties, including the European Union. IRENA collaborated with the Government to identify and analyse mitigation measures on the demand and supply side of the power sector in terms of their GHG abatement potential and associated costs, which informed the second NDC and NDC implementation plan. The Government of The Gambia is committed to maintaining and, where possible, enhancing its strong ambition, while strengthening the integration of the identified mitigation measures into national planning processes.

Source: Curioso.Photography / Shutterstock.com.

1. INTRODUCTION

The Gambia submitted its first Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016. NDCs are national climate action plans and serve as the backbone of the Paris Agreement, which was adopted by 197 member states of the UNFCCC in 2015, and thereby committing to pursue the necessary efforts to keep global warming at 1.5°C. NDCs include mitigation actions, and in most cases, adaptation actions that a country takes to stay in line with the goals of the Paris Agreement. A key principle of the Paris Agreement is that NDCs are to be revised, updated and enhanced every five years.

Analysis of the cost-effectiveness of existing and future mitigation options can support countries in their identification, prioritisation, selection and quantification of mitigation measures and inform the pathway to cost-efficiently reach mitigation targets. Such analysis can therefore serve as input to the NDC, the NDC implementation plan and the development of long-term sectoral plans. It can also help to promote the development of renewable electricity, promote access to energy and enhance the involvement of the private sector.

This cost-effectiveness analysis of mitigation options in The Gambia's power sector is undertaken by the International Renewable Energy Agency (IRENA) with support from the European Union Global Technical Assistance Facility for Sustainable Energy (EU TAF) as an effort to support The Gambia in the process of revising and updating its NDC. The activity was carried out under the Climate Action Enhancement Package (CAEP) of the NDC Partnership and is identified as activity B055 under the CAEP Framework.

A three-step process is required to evaluate the cost-effectiveness of measures:

- **development of baseline scenario**
- **identification and revision of mitigation options**
- **cost and greenhouse gas (GHG) mitigation analysis using the most recent data**

The quality of the analysis is directly correlated to the quality of the data, and the most recent and accurate data have been sought. IRENA has assessed renewable energy deployment scenarios for the West African Power Pool (WAPP) by 2040 using the System Planning Test (SPLAT[1]) model (IRENA, 2018). The SPLAT analysis served as the foundation for this study, which was updated with additional and most recent data from national stakeholders.

The cost-effectiveness analysis in this study has been performed based on the marginal abatement cost curve (MACC) methodology. MACC is a useful tool to support climate policy decision-making as it informs on the GHG abatement potential and associated costs of the policies and technology options assessed.

The overarching aim of this study is to support climate policy decision makers by providing valuable information for the identification, quantification and selection of mitigation measures in the power sector and informing the path to cost-effective achievement of mitigation targets.

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[1] See description of IRENA's power system capacity expansion model SPLAT in Box 1.

This report presents the methodology, data, assumptions and findings of the study undertaken, and is structured as follows:

- **Chapter 2** describes the methodology, data and assumptions used to develop the baseline and mitigation scenarios and perform the cost analysis.
- **Chapter 3** provides the updated baseline scenario, the GHG emissions reduction potential and the cost-effectiveness of assessed mitigation measures for the NDC revision.
- **Chapter 4** summarises the validation exercises conducted as part of this study.
- **Chapter 5** discusses the methodology and results presented in Chapter 2 and 3.
- **Chapter 6** summarises the report's findings and provides recommendations on how these findings could be used to inform the NDC update.

Box 2: System Planning Test (SPLAT) Models for Africa

To date, IRENA has developed power system models for 47 African countries, uniquely calibrated to represent their national supply structures and regional interconnections that help national energy planners to assess the possible least-cost supply scenarios for 20 years into the future. IRENA's in-house developed SPLAT tool serves as a user-friendly interface for initial development and ongoing enhancements and updates of these models. These SPLAT Africa models are built on IRENA's rich renewable energy database, comprising up-to-date data on technology cost and performance and resource potentials. Models are customised with the existing institutionally credible national/regional analyses and their respective input data, allowing decision makers to assess investment options in light of specific policy goals. The future system prospects are analysed through a least-cost optimisation framework for energy supply, built using the MESSAGE software from the International Atomic Energy Agency.

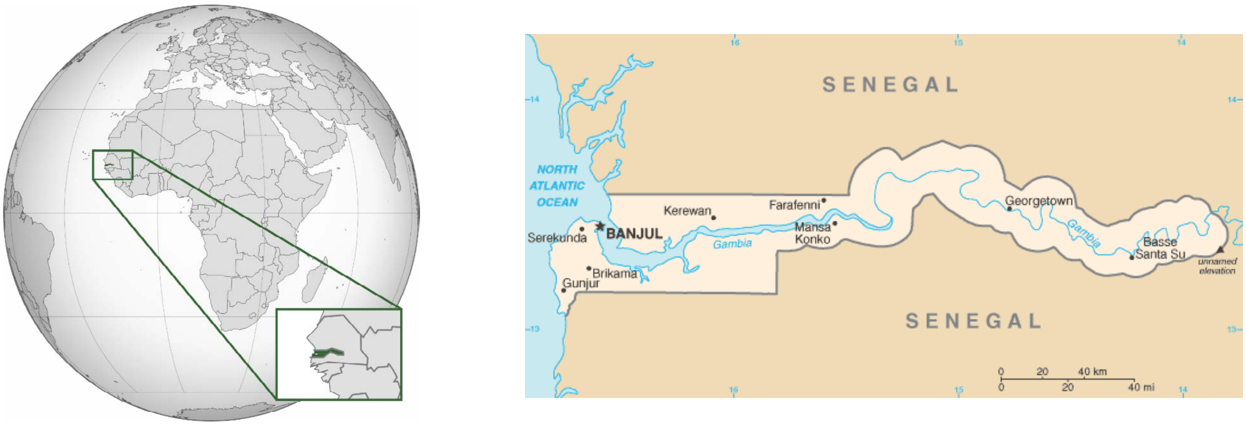
For more information on IRENA's SPLAT models for Africa please visit: www.irena.org/energytransition/Energy-System-Models-and-Data/System-Planning-Test-Model.

1.1 BACKGROUND

The Gambia is a coastal country in West Africa with a population of approximately 2.17 million people (2020). It is one of Africa's most densely populated countries, with 176 people per square kilometre. The Gambia is the smallest country in continental Africa, with a land area of only 10 689 square kilometres. Most of the population (57%) is concentrated in urban and peri-urban areas. With a gross national income per capita of USD 449 in 2019, the country falls under the category of Least Developed Countries (LDCs).

The global pandemic of COVID-19 is expected to have severe socio-economic consequences. Gross domestic product (GDP) growth in 2020 is expected to be between 2.5% and -2.4%. The Gambia, which is heavily reliant on tourism, is primarily impacted by a decrease in tourists, particularly from key European markets, but also by trade disruption and lower commodity prices.

Figure 1: Location of The Gambia in Western Africa



Source: wikipedia.org.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Figure 2: Banjul, The Gambia's capital city

Source: Damien Pankowiec / Shutterstock.com.

The Gambia's energy mix consists primarily of traditional biomass and petroleum products, with biomass accounting for the vast majority. Petroleum products, despite their negative environmental consequences, play an important role in the country's energy supply because they are the primary source of fuel for transportation and electricity generation.

The Gambian government recognises that developing new local and renewable resources is critical to meeting its economic goals and has thus expressed its desire to promote renewable energy development by creating the necessary policy environment and legal frameworks. Approximately 42% of Gambians have access to electricity nationwide, with 71% in urban areas and 13% in rural areas. The Gambia plans to have full access to electricity at the household level in urban areas and at the community level in rural areas by 2030, as well as universal access to clean cooking.

The Gambia's Renewable Energy Act 2013 aims to promote the use of renewable energy sources in order to increase the country's energy self-sufficiency, thus reducing the country's reliance on fossil fuels, harmful emissions, and the demand burden associated with electricity supply. It also establishes a Renewable Energy Fund, encourages investment in the renewable energy sector, and ensures appropriate training and certification.

1.2 PREVIOUS CLIMATE ACTION PLANS

The Gambia's Intended Nationally Determined Contribution (INDC) was an ambitious commitment with economy-wide mitigation targets of reducing GHG emissions by about 44.4% in 2025 and 45.4% in 2030 compared with the business-as-usual (BAU) scenario (excluding land use, land-use change and forestry [LULUCF]). The country was one of few developing countries to put forward an ambitious conditional emissions reduction target, and its INDC has been considered as compatible with the 1.5°C goal of the Paris Agreement (CAT, 2020). Five mitigation measures were communicated for the energy sector, as described in Table 1. The combined reduction estimated for these measures was 425.7 gigagrams of carbon dioxide equivalent (Gg CO_2-e) in 2020, 541.1 Gg CO_2-e in 2025 and 629.6 Gg CO_2-e in 2030 compared with the BAU scenario.

Table 1: Mitigation measures in the energy sector presented in The Gambia's INDC

MITIGATION ACTIVITY	DESCRIPTION	TARGET YEAR	UNCONDITIONAL	CONDITIONAL UPON*		GHG REDUCTION (GG CO_2-E) IN 2025
				FS	TT	
Reduce transmission losses	Refurbish and upgrade the national grid (from 33 kilovolts [kV] to 132 kV) to reduce losses	2025		×	×	98.7
Renewable energy	Install solar photovoltaic (PV), wind power and hydroelectric power plants	2025	×			78.5
Efficient lighting	Substitute incandescent light bulbs and raise awareness in the residential sector	2025		×	×	42.9
Solar water heating	Install solar water heating facilities in public buildings and support them for hotels and the residential sector	2025		×	×	19.3
Extended renewable energy and energy efficiency	Energy-saving appliances and additional hydroelectric, solar PV and wind power capacities	2025		×	×	121.7

*FS = financial support, TT= technology transfer.

2. METHODOLOGY

This analysis sought to determine the cost-effectiveness of mitigation options in The Gambia's power sector, and three assessments were conducted as part of this effort, as illustrated in Figure 3.

This chapter describes in detail the methodological approaches, data and assumptions applied in those assessments. The first section (2.1) describes the development of the baseline scenario, section 2.2 describes the process of identifying mitigation options and developing mitigation scenarios, and section 2.3 describes how the greenhouse gas (GHG) reduction potential and marginal abatement costs of mitigation options were assessed.

Figure 3: Methodological process of the analysis

2.1 BASELINE SCENARIO

This section describes the methodology, data and assumptions used to develop the baseline scenario, which served as the starting point for the analysis. A baseline scenario must be developed to serve as a benchmark against which the GHG reduction potential and cost-effectiveness of various mitigation options can be compared. It is worth mentioning that the baseline scenario considered in this analysis assumes the achievement of ambitious policy objectives and investment plans such as universal access to electricity by 2030 and the development of electricity import capacity.

Electricity demand

To estimate total annual electricity demand for the period 2017-30, it was necessary to estimate the number of consumers with access to electricity over time, the electricity consumption of urban and rural populations, and whether consumers are connected to the main grid or regional mini-grids (as the supply mix – and thus the carbon intensity – varies). Additionally, the productive uses had to be estimated. Three major drivers were used to forecast demand evolution:

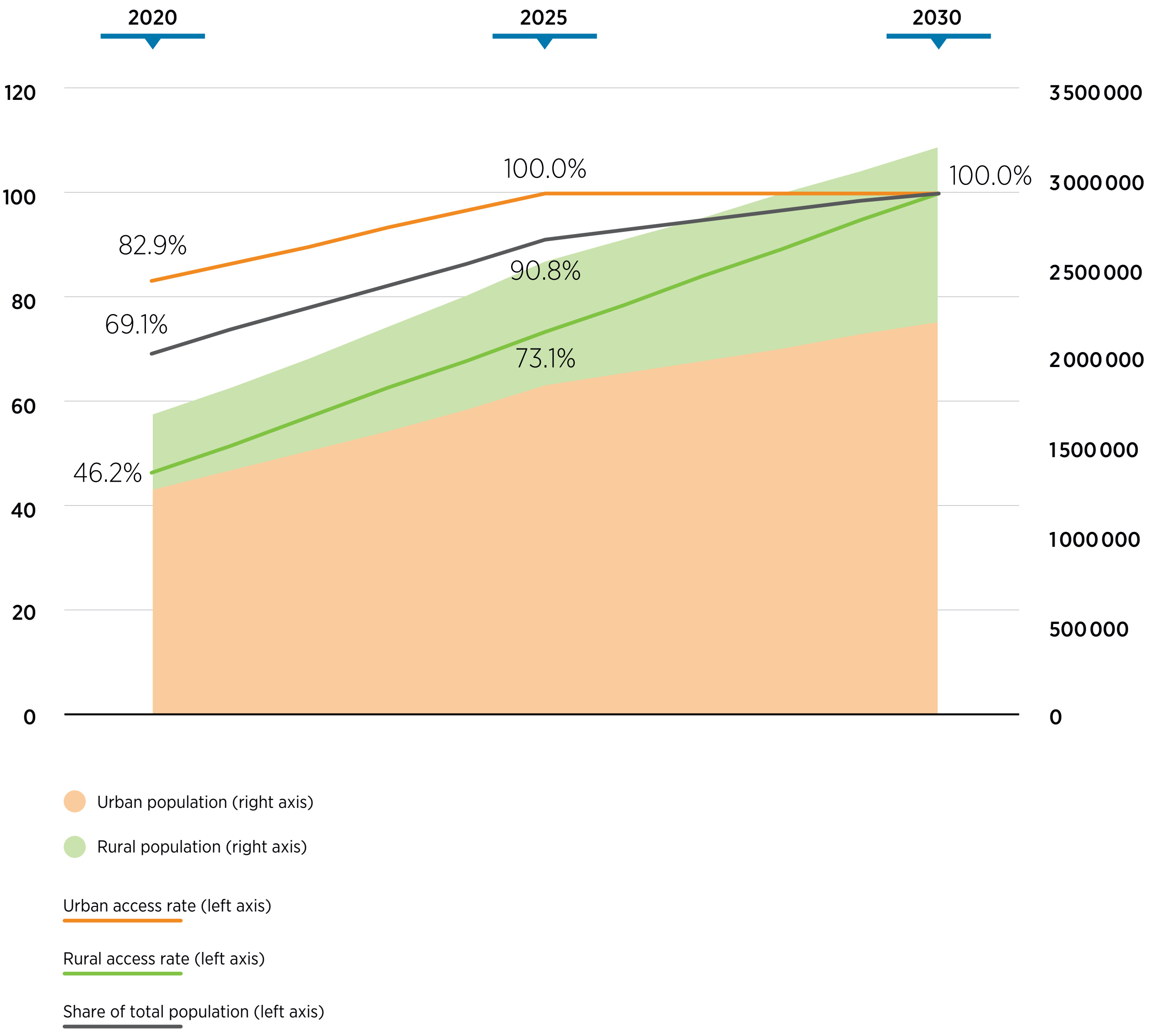
- **economic growth, in a post-COVID recovery scenario, which is correlated with increasing demand over time**
- **population growth and urban/rural population trends**
- **the grid structure itself, as well as The Gambia's ongoing efforts to expand its grid and connect regional mini-grids.**

The total population was estimated using the United Nations World Population Prospects: 2019 Revision's Medium Fertility scenario. The rural/urban population ratio was calculated using World Bank data (World Development Indicators) for the period 2010-19. The linear trend for this time period was then extrapolated to 2030.

To estimate the number of consumers, the national electrification targets of 100% access to electricity for urban populations by 2025 and 100% access to electricity for rural populations by 2030 were used. Between 2018-25 and 2018-30, linear interpolation was used to calculate the urban and rural access rates, respectively. The access rate for each year's urban and rural population was then multiplied by the estimated population for that year to determine the rural and urban population with access to electricity from 2017 to 2030.

The results are presented in Figure 4. In 2030, the total population is projected to reach approximately 3.2 million. The overall access rate is projected to increase from 56% in 2017 to 90.8% in 2025 and 100% in 2030. Universal access will be achieved in urban areas as early as 2025.

Figure 4: Electricity access trajectories for urban and rural population



The proportion of the population connected to the main grid, with mini-grids and off grid was then calculated. To more accurately describe the production from diesel mini-grids and their progressive interconnection to the main grid, as well as to simulate the mitigation effects of hybrid mini-grids, a supply mix/demand intensity combination had to be made. It was therefore necessary to distinguish between urban and rural communities that are connected to the main grid or to mini-grids. Thus, the following segmented approach to the electricity market was employed:

- **on-grid, urban**
- **on-grid, rural**
- **mini-grids, rural**
- **off-grid, rural (with an adapted demand)**
- **productive uses, on-grid**
- **productive uses, off-grid.**

The characteristics of each segment were investigated, including the number of people addressed and their annual electricity consumption. The Rural Off-Grid Electrification Programme (ROGEP) analysis used mini-grid and off-grid scenarios to estimate the share of the population served by electricity via the main grid, mini-grid and off-grid (World Bank Group, 2019). The least-cost universal access option used in this analysis considers a gradual interconnection of all mini-grids to the main grid.

As a result, a shift from 1.8% of the total population connected to diesel mini-grids in 2023 to 0% in 2030 is assumed, as the on-grid population reaches 100% by 2030.1F1F[2] As the number of people connected to the main grid increases to 100% in 2030, the proportion of the population served by off-grid services decreases from 18.6% in 2023 to 0% in 2030. If production data and the number of connections for the mini-grids were available, the scenario could be refined.2F2F[3] After estimating the share of the population connected to the main grid and to mini-grids and off grid for the time period in question, the total population was multiplied by the share of the population connected to each service type (i.e. on-grid, mini-grid and off-grid). All mini-grid and off-grid users were assumed to reside in rural areas. Table 2 shows the urban and rural population powered by on-grid, mini-grid and off-grid services from 2017 to 2030.

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[2] According to the 2018 annual report of the Public Utilities Regulatory Authority (PURA), The Gambia has several diesel mini-grids with an installed capacity of approximately 3.38 megawatts (MW) and an operating capacity of 1.5 MW to 2 MW diesel generation (Public Utilities Regulatory Authority, 2019). The mini grids' short-term demand (2017-23) had to be estimated. Following several iterations, a level of 1.8% of the population currently connected to mini-grids appeared realistic. In the baseline scenario, the load factor of the mini grids is 30% to 48% after the productive uses are added.

[3] The ROGEP is ambitious and deviates from a linear growth in electricity access rates between 2018 and 2030 by 3% over the period 2023-26. Between 2027 and 2030, the gap closes. ROGEP implies a gap of 7% to 8% from a linear baseline in 2022-23. This calls for a possible review of the ROGEP, with less ambitious electrification levels in 2023 (77.6% versus 81.4% from ROGEP). This assumption is open for discussion with stakeholders.

Table 2: Number of persons per source of electricity service: On-grid, mini-grid and off-grid

NUMBER OF PERSONS SERVED BY CATEGORY OF SERVICE	2020	2025	2030
On-grid	1 626 849	2 369 572	3 148 493
Urban	*1 219 943*	*1 718 690*	*2 178 201*
Rural	*406 906*	*650 882*	*970 292*
Mini-grids	16 289	36 541	3 171
Urban	*0*	*0*	*0*
Rural	*16 289*	*36 541*	*3 171*
Off-grid	0	374 143	19 024
Urban	*0*	*0*	*0*
Rural	*0*	*374 143*	*19 024*
Total population served	**1 643 138**	**2 780 256**	**3 170 688**

Demand intensity

The average electricity consumption per household and the average household size had to be estimated in order to estimate the electricity demand.

The average consumption for urban and rural populations connected to the main grid and mini-grids was derived from the Gambia electricity roadmap update (ECA et al., 2021), which was revised to account for the effects of COVID-19 and includes a low case, base case and high case for average consumption. After several iterations, the base case scenario was used, which brought the overall demand closer to the ECA et al. scenario (461 gigawatt hours [GWh] per year versus 418 GWh/year for ECA et al., and 371 GWh/year to 443 GWh/year for the Intended Nationally Determined Contribution [INDC], 2015). PURA (2019) reports an energy demand of 1 005 GWh in 2018, which cannot be replicated given the number of consumers and productive uses. For the urban population, the average consumption in 2020 was 124 kilowatt hours (kWh) per month per household; in 2025, it is 161 kWh/month/household, and in 2030 it is 175 kWh/month/household.

For the rural population, the average monthly consumption per household in 2020 was 66 kWh, in 2025 it is 79 kWh, and in 2030 it is 86 kWh. The average consumption estimated for the rural population connected to an off-grid system was the access Tier 2 from *Beyond Connections: Energy Access Redefined*, namely 6 kWh per month per household for 2020, 2025 and 2030 (Bhatia and Angelou, 2015). The different access Tiers are presented in Table 3. The rural population household size was estimated to be 8.4 people/household, and urban was 5.9 people/household (GBoS, 2017).

Table 3: Definitions of access Tiers

ACCESS TIER	TIER CRITERIA	DAILY CONSUMPTION LEVELS
1	Task lighting AND phone charging	≥ 12 watt hours (Wh)
2	General lighting AND phone charging AND Television AND fan (if needed)	≥ 200 Wh
3	Tier 2 AND any medium-power appliances	≥ 1.0 kWh
4	Tier 3 AND any high-power appliances	≥ 3.425 kWh
5	Tier 2 AND any very high-power appliances	≥ 8.219 kWh

Source: Bhatia and Angelou, 2015.

The PURA 2018 annual report includes several connections per customer category for 2017 and 2018. On-grid or off-grid applications were assigned to the categories. Commercial (non-governmental organisations [NGOs], schools), large customers (industries, banks) and central government were assumed to be connected to the main grid, while local government authorities, provincial services and agriculture were assumed to be connected to mini-grids. The energy intensity factors for productive uses were calculated using the Energy Sector Management Assistance Program (ESMAP) access Tier definitions: Tier 3 in rural areas and Tiers 4 and 5 in urban areas. The assumption that productive uses increase by 5% per year was also used.

Table 4 presents the demand intensity considered per consumer category in the analysis (ESMAP, 2021; Bhatia and Angelou, 2015).

Table 4: Demand intensity per consumer category

INDICATOR	CONSUMER CATEGORY	UNIT	2020	2025	2030
Average consumption per household and month	Urban	kWh/month/household	124	161	175
	Rural	kWh/month/household	66	79	86
	Off-grid rural (Tier 2)	kWh/month/household	6	6	6
Average consumption per customer and year	Commercial (NGOs, schools, etc.)	Megawatt hours (MWh)/ year	1.241	1.241	1.241
	Major customers (industries, banks)	MWh/year	2.993	2.993	2.993
	Central government	MWh/year	0.365	0.365	0.365
	Local government authorities	MWh/year	0.365	0.365	0.365
	Provincial services	MWh/year	0.365	0.365	0.365

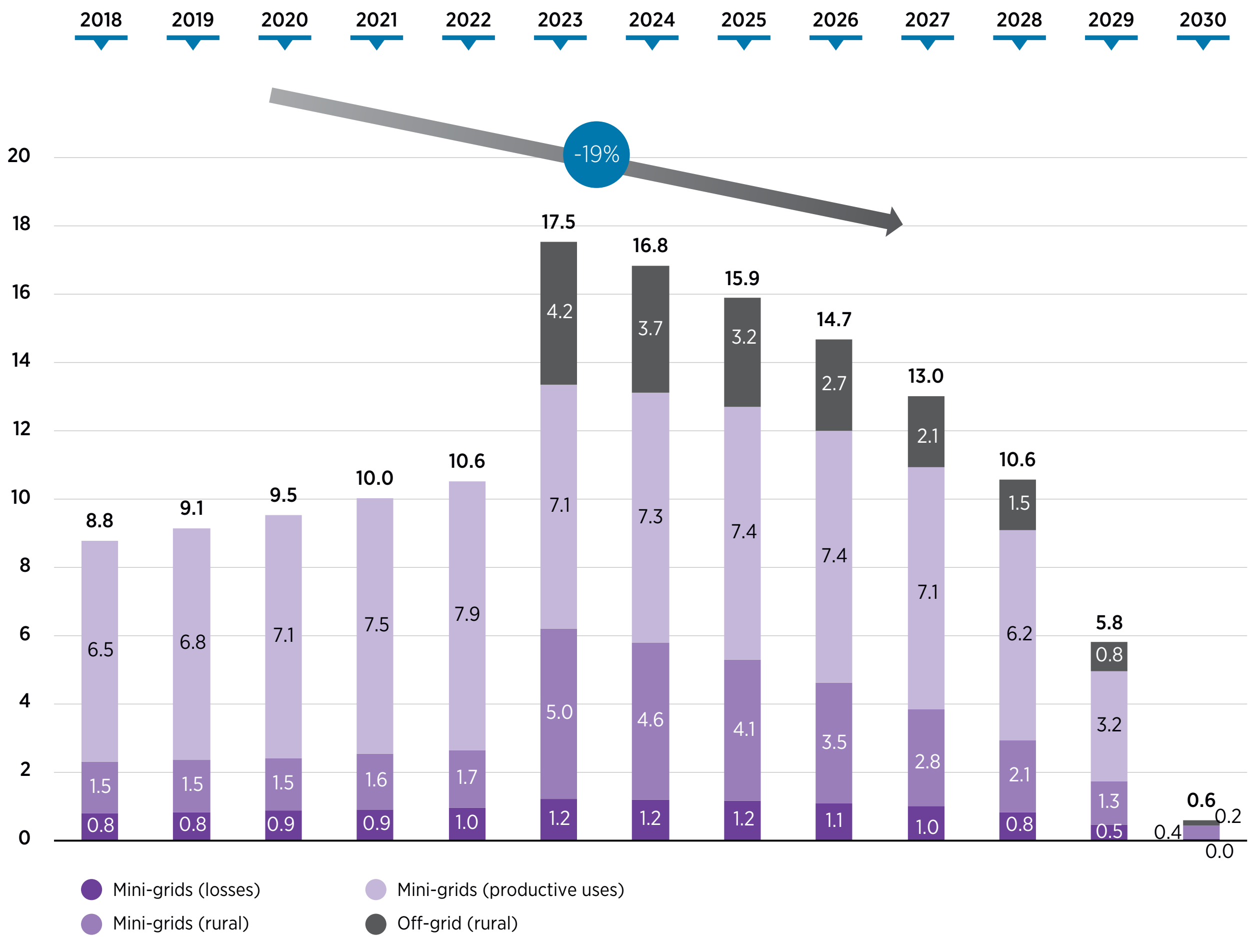
Losses

To account for both transmission and distribution losses, losses on the main grid were estimated at 22% in the baseline scenario, consistent with the estimation made by the World Bank's Gambia Electricity Restoration and Modernisation project. Of the 22%, 14% are estimated to be technical and 8% commercial (World Bank, 2018). The losses on mini-grids were estimated to be constant at 10% over the period.

Electricity demand projections

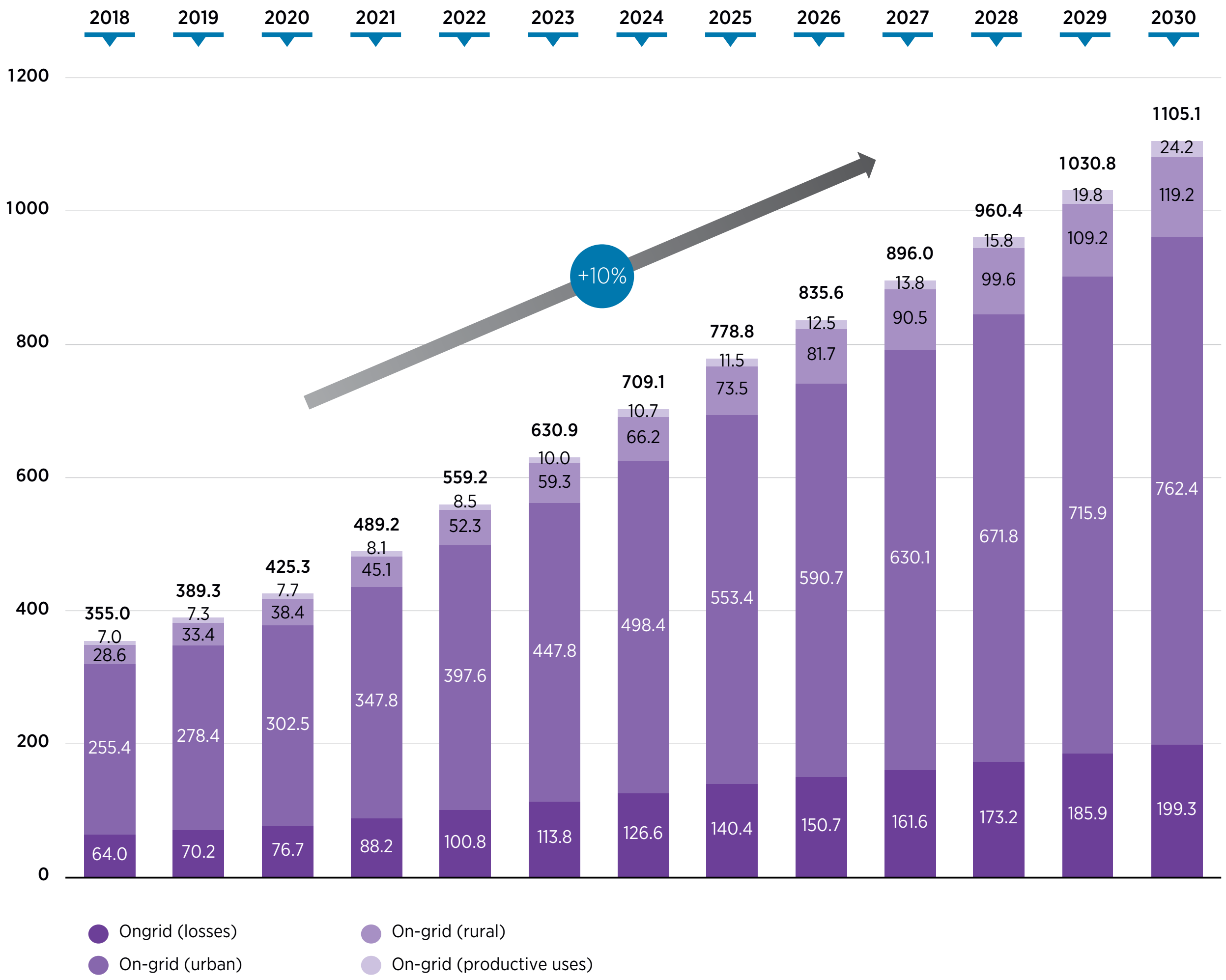
As a result of the methodology described in the preceding sections, Figure 5 and Figure 6 present electricity demand projections for the 2018-30 period by type of electricity service and customer category (in GWh). As shown in Figure 5, mini-grid and off-grid consumption progressively decreases towards 2030 as mini-grid and off-grid systems are interconnected to the main grid.

Figure 5: Projected off-grid and mini-grid electricity demand



Note: T&D = transmission and distribution.

Figure 6: Projected on-grid electricity demand



Electricity supply

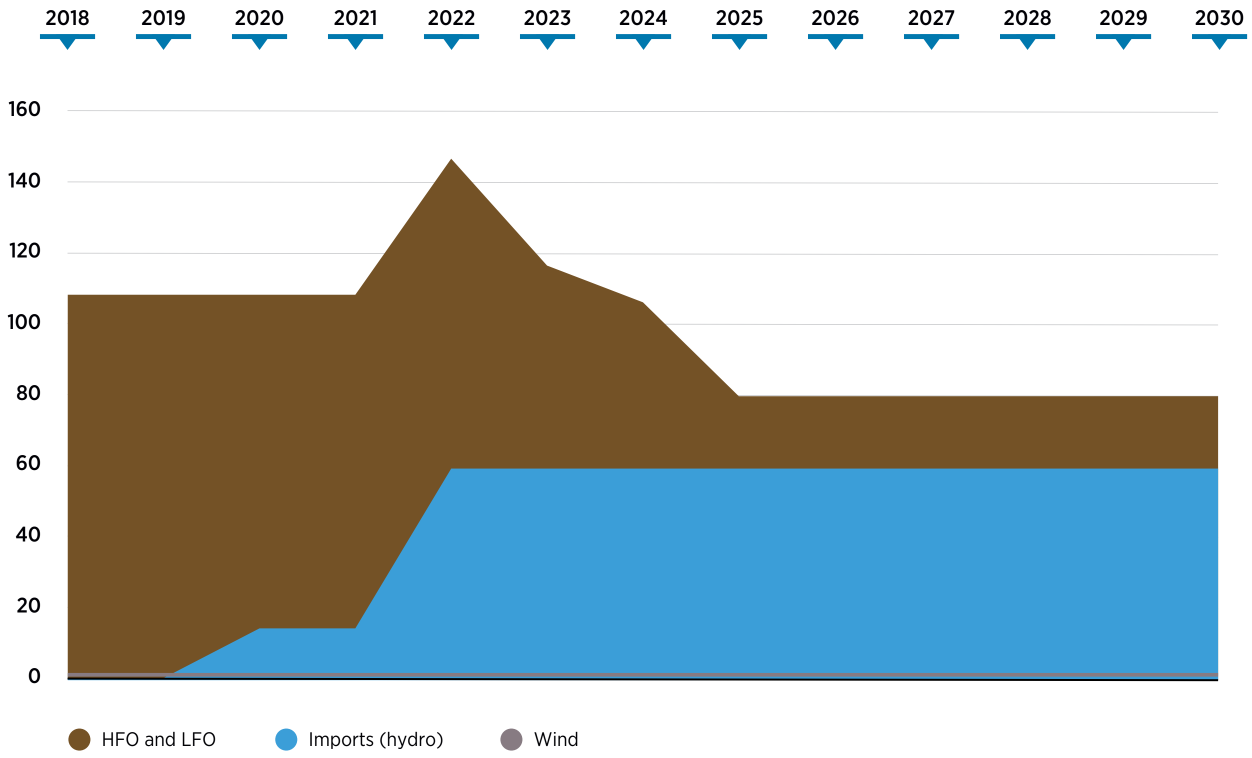
The baseline supply mix was developed using information on existing, committed and potential electricity generation capacities from the Gambia electricity roadmap update (ECA et al., 2021). The data were cross-checked against the PURA 2018 report and found to be consistent. The commissioning and decommissioning dates of each plant were considered. The on-grid capacity is estimated at 123 MW in 2021, with an additional 3.4 MW of diesel mini-grids. The following main aspects were evaluated to establish the baseline for The Gambia:

- **the commitment of Jambur solar photovoltaic (PV) project (20 MW)**
- **export of solar and wind energy**
- **imports of electricity generated by combined cycle gas turbines (CCGTs) from Senegal and Côte d'Ivoire (100 MW in 2025)**
- **a local CCGT capacity option (50 MW in 2025)**
- **hydro imports from the Gambia River Development Organisation (OMVG) (14 MW in 2020 and 59 MW in 2022).**

Several baseline supply mixes were simulated and explored, which enables the comparison of baseline emission scenarios with respect to The Gambia's future investment plans. "Appendix A – Baseline electricity generation capacities" presents the electricity generation capacities considered for the various scenarios.

Following a validation exercise with Gambian stakeholders, the baseline supply mix mainly consists of heavy fuel oil (HFO) capacity, light fuel oil (LFO) capacity and hydropower imports, as shown in Figure 7 (in MW). In this scenario, the model indicates a capacity shortage to supply the demand as of 2028. The share of non-hydro renewable energy in the total final electricity consumption is 0.2% in 2030. The Jambur solar PV project was not included in the baseline on the basis that only built assets are included; however, it is considered as a mitigation option. Although there are currently no import options for electricity, electricity imports are very likely to play a central role in The Gambia's future supply mix. As a result, it was determined that the baseline supply mix should include commissioned import capacity. Hydropower imports from the OMVG project were therefore included, but not CCGT imports from Senegal or Côte d'Ivoire since they are not yet committed. No export of solar and wind energy was foreseen.

Figure 7: Baseline electricity generation capacity



The estimated capacity factors applied for each type of plant are presented in Table 5.

Table 5: Capacity factors applied per type of power generation plant

TYPE OF POWER PLANT	CAPACITY FACTOR	SOURCE
Solar	18.8%	Solargis s.r.o., 2021; ECA et al., 2021
Wind	20%	Badger et al., 2021
Hydropower	57%	World Bank, 2015
CCGT	90%	Internal estimate

Dispatch strategy and load

Mitigation options impact either the supply side or the demand side, and the changes on either side of the supply matrix will impact the overall GHG emissions. The impact varies with the source of generation being displaced by a particular mitigation measure, and thus is dependent on the dispatch strategy. A least-cost approach was followed, based on the generation costs presented by the Least-Cost Power Development Plan developed as part of The Gambia electricity roadmap update:

- **first solar and wind production, with zero marginal cost**
- **hydro imports (if included in the baseline)**
- **CCGT imports (if included in the baseline)**
  - With cumulative hydro and CCGT supplying a maximum of 50% of demand. This requirement recognises that, while low-cost generation sources may be imported, the country is willing to maintain energy security by operating a portion of its generation domestically.
- **remaining demand is supplied by domestic capacity:**
  - Domestic CCGT capacity (if included in the baseline).
  - HFO.

As a result, each additional kilowatt hour of renewable energy displaces first HFO and subsequently domestic CCGT.

2.2 DEVELOPMENT OF MITIGATION SCENARIOS

To identify suitable mitigation measures to evaluate, the first Nationally Determined Contribution (NDC) as well as other plans, policies, ongoing projects, current investment plans and least-cost trends were reviewed. Table 6 below summarises the documents that have been reviewed to identify mitigation measures.

Table 6: Documents reviewed to identify mitigation measures in the power sector

TITLE	YEAR OF PUBLICATION
The Gambia's INDC	2016
The Gambia's Third National Communication	2020
National Energy Efficiency Action Plan (NEEAP)	2015
National Renewable Energy Action Plan (NREAP)	2015
Sustainable Energy for All (SE4All) Action Agenda and Investment Prospectus	2015

Table 6: Documents reviewed to identify mitigation measures in the power sector *(continued)*

TITLE	YEAR OF PUBLICATION
SE4All Rapid Assessment Gap Analysis	2012
Nationally Appropriate Mitigation Actions (NAMA)	2015
NAMA Design Document for Rural Electrification with Renewable Energy in The Gambia	2015
Electricity sector roadmap update	2022, forthcoming
Economic Community of West African States (ECOWAS) Renewable Energy Policy	2012
Climate change mitigation technologies in the Gambian energy, transport and waste sectors	2017
National Climate Change Policy of The Gambia	2016
Vision for the Gambia's Long-Term Climate Change Strategy	2022, forthcoming
Circular GHG mitigation opportunities: The Gambia	2021
Gap analysis of The Gambia's current NDC	2021
The Gambia National Development Plan	2018
Renewable Energy Act	2013
Gambia Strategic Programme on Climate Resilience	2017

A total of nine mitigation options were identified, as shown in Table 7. Out of these, five mitigation options were included in the first NDC and four new mitigation measures were identified, reflecting new trends emerging since the last NDC.

Table 7: Mitigation options evaluated

MITIGATION OPTION	DESCRIPTION	TARGET YEAR	SOURCE
Renewable energy technology (utility-scale solar PV)	89 MW of utility-scale solar PV capacity (incl. Jambur solar PV project)	2030	Electricity roadmap update/NREAP
Renewable energy technology (utility-scale wind)	3.6 MW of utility-scale wind capacity	2023	Electricity roadmap update/SE4All Action Agenda/NREAP
Reduced transmission and distribution losses	Reduction of transmission and distribution losses to 17%	2030	NEEAP
Renewable energy technology (mini-grids)	25% hybridisation of diesel mini-grids with solar PV	2023	NAMA/Green mini-grid policy (under development)
Renewable energy technology (mini-grids)	Full replacement of diesel mini-grids with solar PV and battery storage systems	2023	NAMA/Green mini-grid policy (under development)
Energy-efficient lighting	Substitution of incandescent light bulbs	2030	SE4All Action Agenda
Renewable energy technology (off-grid solar home systems)	Solar home systems to supply off-grid consumption	2023	NEEAP
Renewable energy technology (rooftop solar home systems)	6 MW of solar PV rooftop systems by 2024	2024	European Commission/ European Investment Bank
Renewable energy technology (solar water heaters)	Solar water heating facilities to supply 10% of demand by 2030	2030	NREAP

For each mitigation option, a mitigation scenario was developed to evaluate its GHG reduction potential and cost-effectiveness. The methodology and assumptions behind the development of the mitigation scenarios are described in detail in this chapter. The following chapter describes the methodology, data and assumptions behind the assessment of the options' GHG reduction potential and marginal abatement costs.

In addition to the nine mitigation measures assessed in this study, two measures were identified as part of The Gambia's INDC process, namely "Energy efficiency: Appliances" and "Energy efficiency: Industrial applications and co-generation." These mitigation options could not be quantitatively evaluated due to a lack of data and information. Because the products are all imported, implementing minimum energy performance standards (MEPS) for refrigerators and air conditioners was difficult to quantify. A regional approach is also in place for all ECOWAS member states to establish and harmonise MEPS for energy appliances and equipment in the ECOWAS region. The absence of these two measures from the study does not imply that they are ineffective because they could not be quantified. However, data collection and availability are required to track the progress of mitigation measures implementation.

Utility-scale solar PV

The deployment of 89 MW of solar PV power between 2021 and 2030 has been considered as a mitigation option, as shown in Table 8 below. By 2023, the local contribution of the Jambur power plant to the national supply mix is expected to be 20 MW. An additional 69 MW of solar capacity has been considered to be gradually installed between 2025 and 2030, taking the total to 89 MW by 2030, in line with the Generation Least-Cost Power Development Plan developed as part of the Gambia electricity roadmap update (ECA et al., 2021). The capacity factor (hours/year) was multiplied by the capacity (MW) to determine the annual electricity generation (MWh). The electricity generated by solar PV replaces the electricity generated by HFO (in the baseline scenario). By multiplying the emissions factors by the respective electricity production, the GHG emissions for this scenario with on-grid solar as a mitigation option are determined. Since this mitigation option considers only grid-connected solar PV power, GHG emissions from mini-grids and off-grid electricity generation remain unchanged from the baseline scenario.

Table 8: Renewable energy technology (utility-scale solar PV) deployment schedule

YEAR	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Mitigation capacity (MW)	0	20	20	20	54	61	68	75	82	89

Utility-scale wind

In line with the Generation Least-Cost Power Development Plan developed as part of the Gambia electricity roadmap update, 3.6 MW of additional wind capacity to be operational by 2023 was investigated as a mitigation option (ECA et al., 2021). The annual electricity output is calculated by multiplying the capacity factor (hours/year) by the capacity (MW). Wind-generated electricity replaces HFO-generated electricity (in the baseline scenario). The GHG emissions for this scenario with on-grid wind as a mitigation option are calculated by multiplying the emissions factors by the respective electricity generation. GHG emissions from mini-grids and off-grid electricity generation are unchanged from the baseline scenario since this mitigation option considers only grid-connected wind capacity.

Efficient transmission and distribution networks

The INDC considered improvements in losses on the transmission network. However, the losses on the distribution network are sizeable in the Gambia, and restoration projects are ongoing to refurbish and extend the grid (World Bank, 2018). In line with the World Bank projects (World Bank, 2016; 2018) and, as indicated earlier, the baseline losses were estimated at 22% in 2017 (of which 14% technical and 8% non-technical). The mitigation option that has been evaluated for reduction of transmission and distribution losses is 17% by 2030. The mini-grid losses remain constant at 10% throughout the analysed time horizon.

Transmission and distribution losses have been linearly interpolated between the base year (22% by 2020) and the target year (17% by 2030). As a result of the reduced transmission and distribution losses, demand (i.e. annual electricity production) decreases. The GHG emissions reduction potential for this scenario is then calculated by multiplying the electricity generation savings by the corresponding emission factor. Because mini-grid transmission and distribution losses remain constant at 10%, GHG emissions from mini-grids remain unchanged from the baseline scenario.

Green mini-grids

Following the recommendations of the NAMA (Blodgett, Marett and Soezer, 2015), a fuel mix for the diesel mini-grids that includes 25% of electricity produced from solar PV has been evaluated as a mitigation option. Similar to ongoing trends in the region (e.g. Togo), a second scenario estimates GHG savings for full replacement of the diesel systems with solar PV and battery systems.

Mini-grid consumption decreases from 2023 onwards as mini-grids are gradually interconnected to the main grid from 2023 to 2030. The GHG emissions for this scenario with 25% hybridisation of mini-grids as a mitigation measure are then calculated by multiplying the electricity generation from diesel and solar PV by the respective emission factors and comparing it to the baseline scenario in which mini-grids are 100% fuelled by diesel. Since this mitigation option focuses on mini-grids, GHG emissions from on-grid and off-grid electricity generation remain constant compared with the baseline scenario.

The GHG emissions for the mitigation option that considers a full replacement of diesel mini-grids by solar PV and battery systems are calculated by multiplying the electricity generation from solar PV by the respective emission factor (i.e. zero GHG emissions from mini-grid consumption) and compared with the baseline scenario where mini-grids are 100% fuelled by diesel. Because this mitigation option focuses on mini-grids, GHG emissions from on-grid and off-grid electricity generation remain constant compared with the baseline scenario.

Efficient lighting

This mitigation scenario assumes that incandescent lights will be completely replaced by 2030. A 75% light-emitting diode (LED)/25% compact fluorescent lamp (CFL) mix to replace the incandescent lights has been validated with national stakeholders. The share of efficient lighting is interpolated linearly from 5% in 2020 to 100% in 2030. The number of lamps is determined by the number of connected users. For both urban and rural populations, the assumptions include three light bulbs per household. The number of people per household in urban areas is estimated to be 6 in urban areas and 8.4 in rural areas (GBoS, 2017). Lighting hours in urban areas are estimated to be four hours per day, while lighting hours in rural areas are estimated to be three hours per day (according to the access Tier level in each category, as defined by *Beyond Connections: Energy Access Redefined*) (Bhatia and Angelou, 2015). On-grid lighting hours increase with population, from 2.2 million in 2020 to 5.4 million in 2030, while mini-grid lighting hours vary from 17 453 in 2020 to 3 397 in 2030. The average power consumption of incandescent bulbs is estimated to be 60 watts (W), that of CFL bulbs to be 12 W (based on Clean Development Mechanism Project Design Documents for India), and that of LED bulbs to be 9 W (based on incandescent lamps with 60 W equivalent).

The electricity savings from LED/CFL light bulbs over traditional incandescent lights are deducted from the demand for electricity. The GHG emissions for this scenario with lower demand as a result of the efficient lighting measure are calculated by multiplying the electricity generation from various sources by the appropriate emission factor and comparing them with the GHG emissions for the baseline scenario with higher demand.

Solar home systems

A mitigation option of all off-grid electricity consumption to be supplied by solar home systems (SHS) by 2023 has been evaluated. This mitigation scenario assumes that all off-grid consumption will be supplied by SHS, replacing kerosene lamps and allowing for faster electricity access. According to a scenario used in the ROGEP analysis (World Bank, 2019), the electricity access rate could reach 100% as early as 2023, which entails equipping populations in rural areas with SHS while the network is being expanded and reinforced to provide grid access to all. This transition period would enable the achievement of universal electricity access as early as 2023. In this approach, the share of the population equipped with SHS will be 18% in 2023 and will decline to 0% in 2030 as the population is gradually connected to the main grid.

The SHS displace the off-grid consumption which is supplied by kerosene lamps in the baseline scenario. Since all population is gradually connected to the main grid, off-grid systems are gradually being interconnected to the main grid from 2023 onwards, hence the consumption decreases from 2023 onwards. The GHG emissions for this scenario with SHS as a mitigation measure is determined by multiplying the electricity generation from the SHS with the respective emission factor (i.e. zero GHG emissions from SHS) and compared with the baseline scenario where the off-grid demand is supplied by kerosene lamps. Since this mitigation option targets off-grid systems, the GHG emissions from on-grid and mini-grid electricity generation are unchanged from the baseline scenario.

SHS demand is estimated to be 4 195 MWh, which could represent 50 000 to 100 000 systems of 1-2 kilowatt (kW) users per day for four hours. If production data and the number of connections for off-grid systems were available, the scenario could be refined.

Solar PV rooftop applications in schools and hospitals

The European Investment Bank-funded programme (European Investment Bank, 2018; D'Addario et al., 2018) seeking to equip 1 100 schools and hospitals with solar PV rooftop applications has been considered as a mitigation option. The mitigation scenario assumes that 6 MW of grid-connected rooftop solar PV will be gradually deployed between 2020 and 2024. The deployment was linearly interpolated between these years, and a capacity factor of 1 650 hour per year (18.8%) was used.

The annual electricity output is calculated by multiplying the capacity factor by the installed capacity. In the baseline scenario, electricity generated by solar PV rooftops replaces electricity generated by HFO. This scenario's GHG emissions are calculated by multiplying the electricity generated by the various energy sources by the respective emission factor (zero GHG emissions from solar PV) and compared with the baseline scenario, which does not include solar PV. Because the solar rooftop applications are linked to the main grid, the GHG emissions from mini-grid and off-grid consumptions are the same as in the baseline scenario.

Solar water heating

A mitigation option of solar water heating to supply 10% of total demand by 2030 has been evaluated, with 50% of total demand saved by 2030. A linear interpolation raises the share of solar water heating to this level between 2020 and 2030.

This scenario's GHG emissions are calculated by multiplying the electricity generated by the various energy sources by the respective emission factor (zero GHG emissions from solar water heating) and compared with the baseline scenario, which does not include solar water heating.

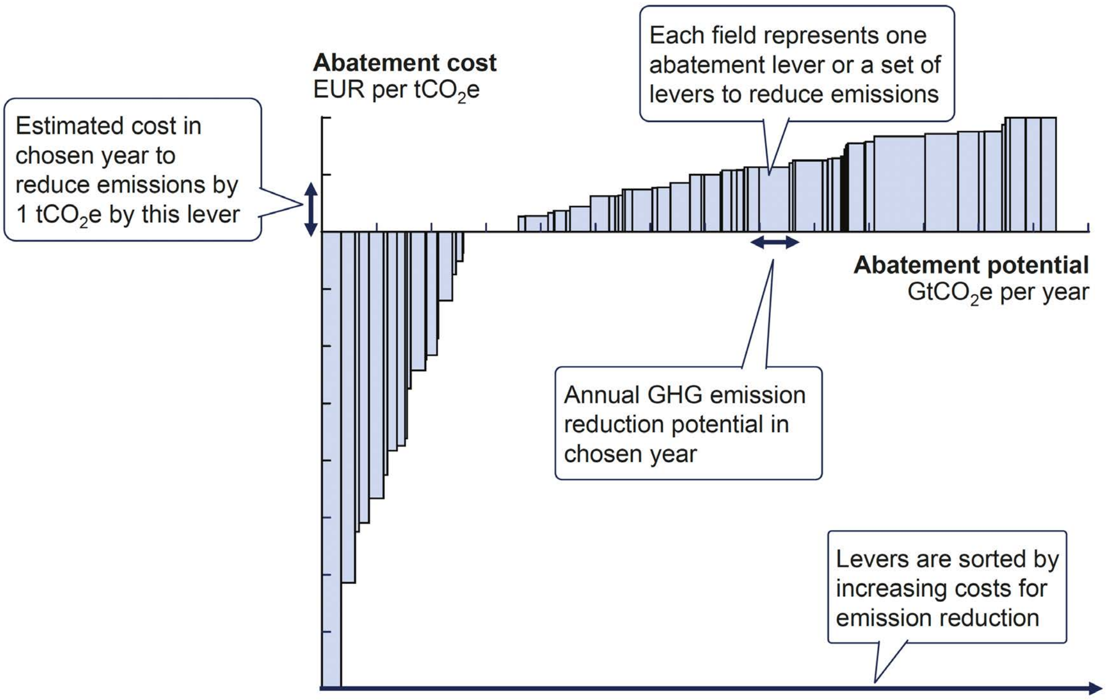
2.3 MARGINAL ABATEMENT COSTS AND GHG REDUCTION POTENTIALS

Following the development of the baseline scenario, identification of mitigation options and development of mitigation scenarios, as defined previously, it was necessary to assess the cost-effectiveness of mitigation options. This section explains the methodologies and assumptions used to calculate the cost-effectiveness of mitigation solutions by assessing their GHG reduction potential and marginal abatement costs.

The methodology of marginal abatement cost curves

The cost-effectiveness analysis is performed based on the marginal abatement cost curve (MACC) methodology. As shown in Figure 8, the MACC is a two-axis graph: the horizontal axis indicates the GHG abatement potential, typically in gigatonnes of carbon dioxide equivalent (Gt CO_2-e) per year, and the width of each bar indicates the abatement potential to reduce annual GHG emissions for a particular option; and the vertical axis displays the abatement cost, in for example USD per tonne of CO_2 equivalent (t CO_2-e), which is the cost to reduce or offset one unit of GHG emissions, and it is indicated by the height of the bar.

Figure 8: Example of MACCs



Source: Nauclér and Enkvist, 2009.

Greenhouse gas emissions reduction potential

As explained in the previous section, GHG emissions have been calculated for each mitigation scenario by multiplying the emission factor for each fuel type by the respective electricity production and then compared with the baseline scenario emissions, to estimate the GHG reduction potential for each mitigation option. The emissions factors that have been applied for each fuel type are presented in Table 9. Emissions associated with manufacturing, installation, operation and decommissioning have not been considered, and it is therefore assumed that the renewable energy options present zero emissions. The emissions have been calculated for every year of analysis based on the estimated abatement potential.

Table 9: Emission factors for each fuel type considered

FUEL	EMISSION FACTOR (T CO_2-E /MWH)	SOURCE
Renewables	0	INDC
LFO (Diesel)	0.80	Standardised baseline project
HFO	0.66	Standardised baseline project, World Bank guidelines
CCGT	0.50	US Environmental Protection Agency database, Clean Development Mechanism Beijing Caoqiao Natural Gas CCGT Project
Kerosene	0.5	Stakeholder workshops
Imports (CCGT, hydro)	0	Stakeholder workshops

Table 10 summarises the reference solutions used to evaluate the mitigation measures in terms of cost-effectiveness and GHG reduction potential. HFO-generated electricity has been applied as a reference solution for the mitigation measures that displace electricity generated from the main grid since it is currently supplying most of the electricity in the grid (100% in 2017). The operation of diesel-powered gensets is used as a reference solution for mitigation measures considering mini-grids. SHS have been assumed to cover the lighting demand and are thus evaluated using kerosene as a reference solution. Finally, incandescent bulbs are the reference solution applied to evaluate the mitigation option of efficient lighting.

Table 10: Reference solutions considered for the evaluation of each mitigation option

MITIGATION OPTION	DESCRIPTION	REFERENCE SOLUTION
Renewable energy technology (utility-scale solar PV)	89 MW of utility-scale solar PV capacity	HFO
Renewable energy technology (utility-scale wind)	3.6 MW of utility-scale wind capacity	HFO
Reduced transmission and distribution losses	Reduction of transmission and distribution losses to 17%	HFO
Renewable energy technology (mini-grids)	25% hybridisation of diesel mini-grids with solar PV	Diesel

Table 10: Reference solutions considered for the evaluation of each mitigation option *(continued)*

MITIGATION OPTION	DESCRIPTION	REFERENCE SOLUTION
Renewable energy technology (mini-grids)	Full replacement of diesel mini-grids with solar PV and battery storage systems	Diesel
Energy-efficient lighting	Substitution of incandescent light bulbs	Incandescent light bulbs
Renewable energy technology (off-grid SHS)	SHS to supply off-grid consumption	Kerosene
Renewable energy technology (rooftop SHS)	6 MW of solar PV rooftop systems by 2024	HFO
Renewable energy technology (solar water heaters)	Solar water heating facilities to supply 10% of demand by 2030	HFO

Abatement costs

The abatement costs estimate the incremental cost, in USD per t CO_2-e, associated with the implementation of a low-emission technology (i.e. mitigation measure) compared with a reference scenario. As described by McKinsey & Company (Nauclér and Enkvist, 2009), the abatement cost of each individual mitigation option can be calculated as follows:

Equation 1: Abatement cost of each individual mitigation option

$$\text{Abatement cost} = \frac{(\text{Full cost of low emission solution} - \text{Full cost of reference solution})}{(\text{Emissions from reference solution} - \text{Emissions from low emission solution})}$$

The full cost of low-emission and reference solutions includes the annual repayment of the capital expenditure (CAPEX), operational expenditure (OPEX), and costs associated with the usage of fuel or savings (e.g. energy savings in the case of energy efficiency solutions). Finance availability is not considered a constraint, and full costs do not include transaction expenditure, subsidies or taxes (Nauclér and Enkvist, 2009). No decommissioning costs are considered. Abatement costs can be calculated for each year, and in this study, abatement costs were calculated for the years 2021 to 2030. The following sections outline the cost assumptions, as well as technical assumptions affecting costs, that were used to evaluate each mitigation option. For the evaluation of each mitigation option, a linear learning curve of 3% was considered to adjust both CAPEX and OPEX of mitigation measures and reference solutions in the 2021-30 period. Furthermore, a 3% annual cost increase is considered for the fossil fuel-based reference solutions, that is, HFO, diesel and kerosene. OPEX figures presented for reference and mitigation measures are indicated as a percentage of the respective CAPEX.

HFO and diesel technologies

Table 11 presents the financial and technical assumptions taken for reference solutions HFO and diesel, including system availability, costs, generation efficiency, fuel prices and lifetime. Identical CAPEX and OPEX have been assumed for generation units running with HFO and diesel.

Table 11: Financial and technical assumptions considered for reference solutions HFO and diesel

VARIABLE	VALUE	UNITS	SOURCE
System availability	80%		AF-Mercados EMI, 2013
CAPEX	1.6	Million USD/MW	Government of The Gambia, 2017
OPEX	2% of CAPEX	Million USD/MW	World Bank, 2018
Consumption HFO	0.3	Tonne HFO/MWh	World Bank, 2018
Efficiency diesel genset	35%		Shakti Sustainable Energy Foundation, 2017
HFO price	400	USD/tonne	Government of The Gambia, 2017
Diesel price	1	USD/litre	ESMAP, 2019
Lifetime	20	Years	Internal estimate

Renewable energy technologies

Table 12 lists the financial and lifetime assumptions for the mitigation measures considering on-grid solar, on-grid wind, green mini-grids 25%, green mini-grids 100% and solar PV rooftop applications. The CAPEX of SHS includes the cost of the CFL light bulbs, which are typically included in the system. Additionally, no CAPEX for kerosene lamps was considered, as this cost is considered negligible in comparison with the actual cost of kerosene, and kerosene lamps are considered to have a long lifetime. The cost of kerosene in Sierra Leone has been considered in this analysis.

Table 12: Financial and lifetime assumptions considered for renewable energy technologies

RENEWABLE ENERGY TECHNOLOGY	CAPEX (MILLION USD/MW)	OPEX (% OF CAPEX)	LIFETIME (YEARS)	SOURCE
Utility-scale solar PV	1.3	1	20	World Bank, 2018; internal estimate
Utility-scale wind	1.4	2	20	ECA et al., 2021; Stehly, Beiter and Duffy, 2020
Green mini-grids 25%	1.9	3	20	D'Addario et al., 2018; World Bank, 2020; internal estimate
Green mini-grids 100%	1.9	3	20	D'Addario et al., 2018, The World Bank, 2020, internal estimate
SHS	4.65	3	5	D'Addario et al., 2018; World Bank, 2020; internal estimate
Solar PV rooftop applications	3.1	3	20	D'Addario et al., 2018; World Bank, 2020; internal estimate

Source: Sunshine Seeds / Shutterstock.com.

Table 13 lists the main technical assumptions considered for the assessment of SHS.

Table 13: Technical assumptions considered for the evaluation of solar home systems and its reference solution kerosene

VARIABLE	VALUE	UNITS	SOURCE
Luminous efficacy CFL	70	Lumen (Lm)/W	Energypedia, 2021
Luminous efficacy lamp kerosene	0.13	Lm/W	Energypedia, 2021
Fuel cost	0.83	USD/litre	GlobalPetrolPrices, 2021

Table 14 presents the main financial and technical assumptions considered in the evaluation of solar water heating as a mitigation measure. In this case, the CAPEX is indicated per household solar water heater system, consisting of one flat solar collector, water tank and additional required equipment. Solar fraction accounts for domestic hot water consumption covered by solar water heating, taking into account the mismatch between demand and supply and volume finiteness of water storage.

Table 14: Financial and technical assumptions considered for the evaluation of solar water heating

VARIABLE	VALUE	UNITS	SOURCE
Lifetime	20	Years	Internal estimate
CAPEX	400	USD/system	UNDP, 2012
OPEX	2% of CAPEX		Internal estimate
Size solar collector	1.4	Square metres	Maldonado et al., 2014
Efficiency system	30%		Maldonado et al., 2014
Solar fraction	60%		Rodríguez-Hidalgo et al., 2012

Transmission and distribution network

Table 15 shows the financial assumptions applied for the improvements on the transmission and distribution network. CAPEX cost is indicated as the total cost of the project equivalent to a reduction in transmission and distribution losses of 3% (World Bank, 2018).

Table 15: Financial and lifetime assumptions considered for reduction of transmission and distribution losses

MITIGATION OPTION	CAPEX (MILLION USD PER 3% REDUCTION)	OPEX (% OF CAPEX PER 3% REDUCTION)	LIFETIME (YEARS)	SOURCE
Reduced transmission and distribution losses	77.3	1	40	World Bank, 2018; Hernàndez et al., 2020, internal estimate

Efficient lighting

Table 16 shows the financial and technical assumptions considered in the evaluation of the mitigation measure efficient lighting. For the assessment of efficient lighting solutions, the reference solution includes the usage of incandescent bulbs, and cost savings are computed based on the estimated average cost of electricity service, which was USD 320/MWh in 2017 (World Bank, 2018).

Table 16: Financial and technical assumptions considered for the evaluation of mitigation measure efficient lighting

TYPE OF LIGHTING	CAPEX (USD/BULB)	LIFETIME (HOURS/BULB)	POWER (W/BULB)	SOURCE
Incandescent bulb	1	1 000	60	Eartheasy, 2021; US Department of Energy, 2021
CFL	2	10 000	12	Eartheasy, 2021; US Department of Energy, 2021
LED	5	25 000	9	Eartheasy, 2021; US Department of Energy, 2021

3. VALIDATION

This chapter describes the validation exercises conducted as part of this study and the main outcomes from them.

Two technical validation workshops were organised to discuss and validate the data, assumptions and mitigation measures used in the technical analysis with key stakeholders and collect their feedback. The overall objective of the validation exercise was to ensure that accurate data and assumptions as well as mitigation measures in line with national plans and priorities were considered in the analysis. The workshops' key outcomes included the validation of the proposed mitigation model, either through acceptance of the proposed mitigation options and data or by incorporating options and data acceptable to the participants. This resulted in a final version of the model aiming to support the revision of the energy component of the country's Nationally Determined Contribution.

Source: Elizabethras / Shutterstock.com.

4. RESULTS

This chapter presents the results of the analysis applying the methodologies and assumptions described in the previous chapter. The first section (4.1) describes the baseline emissions scenarios and the second section (4.2) describes the greenhouse gas (GHG) reduction potential of the mitigation options analysed. Lastly, the cost-effectiveness of the mitigation options analysed are presented in the third section (4.3).

4.1 BASELINE EMISSIONS

As described in Chapter 2, five baseline scenarios were developed, each with a different mix of generation, before a single scenario was chosen following a validation exercise with national stakeholders. The different baseline scenarios explored are described in Table 17, and the projected GHG emissions per scenario are shown in Figure 9. Including electricity imports and domestic renewable energy capacity in the baseline has sizeable impacts on GHG emissions; for example, emissions in the baseline scenario with combined effects are 48% lower in 2030 compared with the selected baseline scenario. The baseline scenario with new combined cycle gas turbines (CCGTs) and the baseline scenario with combined effects represent the lowest GHG emissions and both include imports of CCGT-generated electricity. It is worth noting that GHG emissions from imported electricity are not included in The Gambia's GHG emissions inventory, which means that imported electricity, regardless of whether it is generated from CCGT or hydropower, indicates zero emissions in this analysis. While emissions from imported electricity are not represented in this analysis, they are still emitted in the country of origin and contribute to global warming. The projected emissions for the selected baseline scenario are estimated to reach 330 kilotonnes of CO_2 equivalent (kt CO_2-e) in 2025 and 535 kt CO_2-e in 2030.

Figure 9: Greenhouse gas emissions per baseline scenario in the period 2018-30

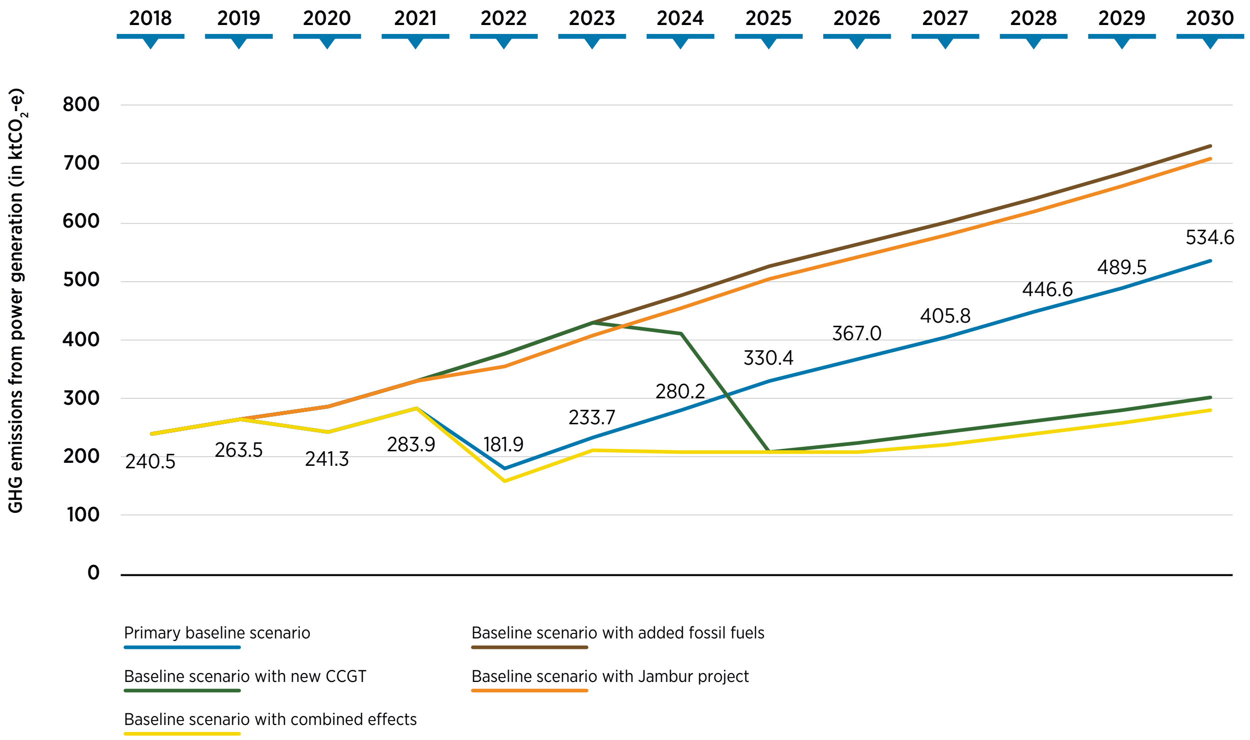


Table 17: Descriptions of baseline scenarios

BASELINE SCENARIO	DESCRIPTION
Primary baseline	In addition to HFO capacity, this scenario also includes hydropower imports from the Gambia River Development Organisation (OMVG) project
Fossil fuels	Includes only HFO capacity
New CCGT	In addition to HFO capacity, this scenario also includes domestically produced as well as imported CCGT-generated electricity
Jambur project	In addition to HFO capacity, this scenario also includes the solar photovoltaic (PV) project Jambur
Combined effects	In addition to HFO capacity, this scenario also includes hydropower imports from the OMVG project, the solar PV project Jambur, and domestically produced as well as imported CCGT-generated electricity

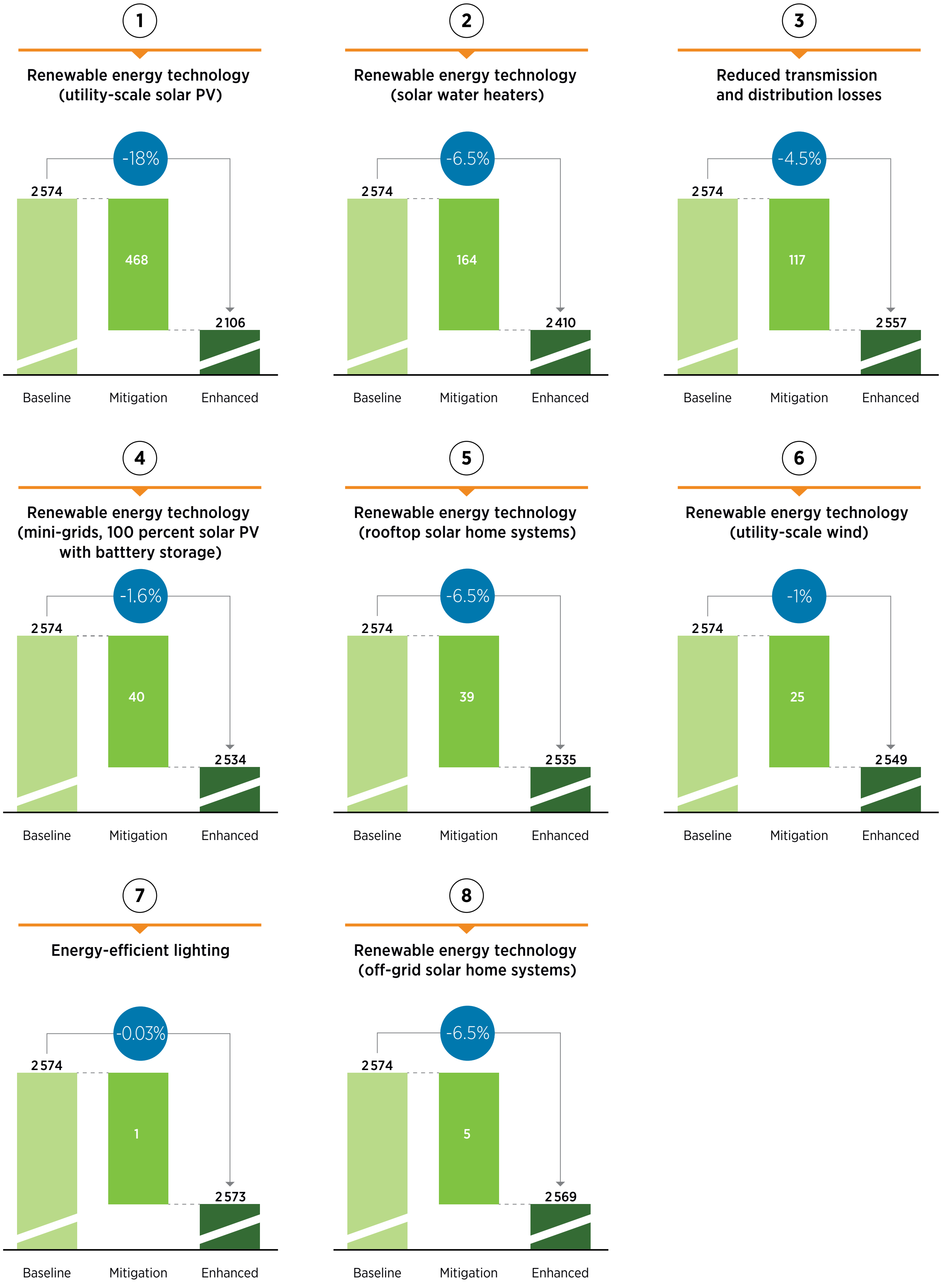
4.2 MITIGATION POTENTIAL IN THE POWER SECTOR

The GHG reduction potentials of the analysed mitigation options are presented in Figure 10 (in % and kt CO_2 e). Utility-scale solar PV has the largest GHG mitigation potential with average savings of up to 18% compared with the baseline scenario over the period 2025-30, followed by solar water heating (6% over period 2025-30 compared with baseline); reductions in transmission and distribution losses (5% over period 2025-30 compared with baseline); and additional smaller-scale PV capacity (solar PV rooftop systems and hybridisation of mini-grids), up to 3% savings averaged over 2025-30 compared with the baseline scenario.

The mitigation options considering solar home systems and efficient lighting do not have significant impacts on GHG emissions, although these mitigation options have a high economic potential, i.e. negative GHG emissions abatement costs, as will be presented in the following section (4.3). These mitigation options should be viewed from a broader perspective and considered in a social, environmental and economic context.

Source: Lidia Daskalova / Shutterstock.com.

Figure 10: Greenhouse gas reduction potential of mitigation options over the period 2025-30 compared with the baseline scenario



Note: kt CO_2-e = kilotonnes of carbon dioxide equivalent.

4.3 MARGINAL ABATEMENT COST CURVES

This section presents the outcomes of the cost-effectiveness analysis of mitigation options, which is presented as marginal abatement costs curves (MACCs), as described in section 2.3.

Figure 11 presents the results of the assessed mitigation options for the year 2030. The estimated GHG reduction potential varies greatly among the mitigation options as presented in the previous section.

The mitigation measures are ranked according to the increasing marginal abatement cost per kt CO_2-e reduction (USD/kt CO_2-e). However, it is important to note that the MACCs represent a visual representation of the various choices being evaluated. As a result, the analysis conducts an individual evaluation and disregards potential interactions between the options considered, as well as their probable effects on the calculated abated GHG and cost.

All studied mitigation measures demonstrate a negative GHG abatement cost, implying that the initial investment is converted into financial savings. The most cost-effective measure is efficient lighting, followed by the hybridisation and substitution of mini-grids with solar PV, reductions in transmission and distribution losses, solar home systems, utility-scale solar PV capacity deployment, solar water heating systems, utility-scale wind capacity deployment, and the solar PV rooftop systems.

The GHG emissions abatement cost of efficient lighting is USD -580/kt CO_2-e, less than half the cost of the second lowest-cost measure, which is the substitution and hybridisation of mini-grids at an abatement cost of approximately USD -270/kt CO_2-e. All measures except efficient lighting and solar rooftops have an abatement cost ranging between USD -145/kt CO_2-e and USD -270/kt CO_2-e, while solar rooftops have the highest cost at USD -5/kt CO_2-e.

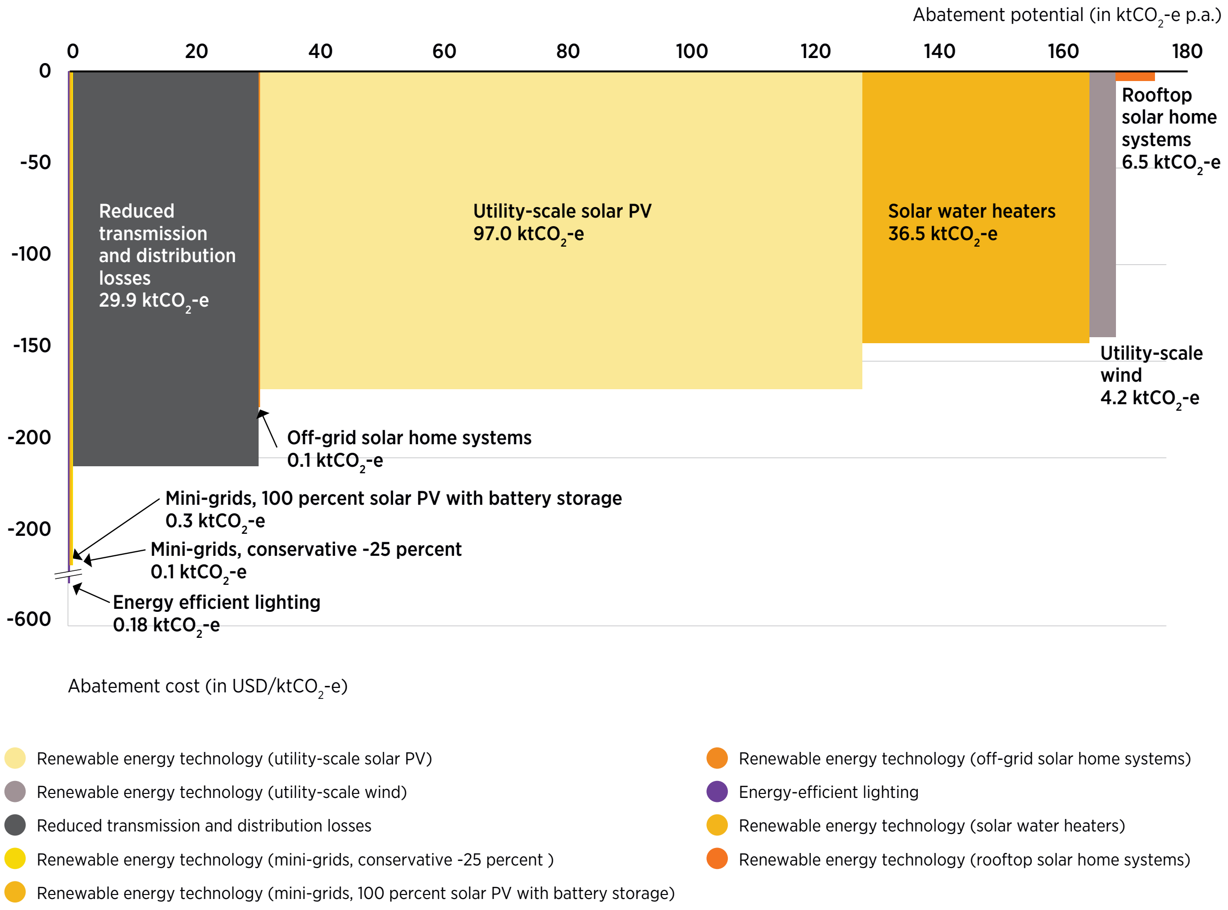


Figure 11: Marginal abatement cost curves for year 2030

4.4 SENSITIVITY ANALYSIS

The results of the cost-effectiveness analysis of mitigation options are highly dependent on the cost assumptions applied. Five mitigation options are compared with a heavy fuel oil (HFO) reference scenario, indicating that a decrease in the fuel price of HFO would make these mitigation options less cost-effective. Sensitivity analyses with lower fuel prices of HFO were therefore conducted.

As explained in the Methodology chapter, the fuel price for HFO was estimated at USD 400/tonne using a technology learning curve cost adjustment coefficient of 3% per year. In comparison with the fuel price used in the analysis (USD 400/litre), the HFO price was reduced by 62.5% (USD 150/tonne), 50% (USD 200/tonne), and 25% (USD 300/tonne). Table 18 summarises the abatement costs as a result of the sensitivity analyses. The results indicate that, despite a 62.5% decrease in HFO fuel prices, all mitigation options are cost-effective, with the exception of solar PV rooftop mitigation.

Table 18: Sensitivity analyses of mitigation options with HFO-generated electricity as reference solution

MITIGATION OPTION	ABATEMENT COST (USD/KT CO_2-E) AT HFO FUEL PRICE OF USD 150/TONNE	ABATEMENT COST (USD/KT CO_2-E) AT HFO FUEL PRICE OF USD 200/TONNE	ABATEMENT COST (USD/KT CO_2-E) AT HFO FUEL PRICE OF USD 300/TONNE
89 megawatts (MW) of utility-scale solar PV capacity	-40	-67	-121
3.6 MW of utility-scale wind capacity	-21	-46	-96
Reduction of transmission and distribution losses to 17%	-78	-106	-161
6 MW of solar PV rooftop systems by 2024	117	93	44
Solar water heating facilities to supply 10% of demand by 2030	-15	-42	-95

Sensitivity analyses of mitigation options using reference scenarios other than HFO (mini-grids, efficient lighting and solar home systems) were conducted following the same approach as for mitigation options using HFO as the reference scenario. For the mini-grid mitigation options, that includes substituting diesel capacity for solar PV and batteries; the diesel price was reduced by 62.5% (USD 0.375/litre), 50% (USD 0.5/litre), and 25% (USD 0.75/litre), compared with the diesel fuel price used in the analysis (USD 1/litre). The results are shown in Table 19.

Table 19: Sensitivity analyses of the mitigation options hybridisation and full substitution of diesel mini-grids

MITIGATION OPTION	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.375/LITRE	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.5/LITRE	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.75/LITRE
25% hybridisation of diesel mini-grids with solar PV	-43	-89	-180
Full replacement of diesel mini-grids with solar PV and battery storage systems	-43	-89	-180

For the mitigation option of replacing all incandescent light bulbs with compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs), the cost per incandescent light bulb was set to USD 1. Sensitivity analyses were conducted using costs per light bulb that were 62.5%, 50% and 25% lower. The results are shown in Table 20.

Table 20: Sensitivity analyses of the mitigation option of substituting light bulbs

MITIGATION OPTION	ABATEMENT COST (USD/KT CO_2-E) AT INCANDESCENT LIGHT BULBS COST OF USD 0.375/BULB	ABATEMENT COST (USD/KT CO_2-E) AT INCANDESCENT LIGHT BULBS COST OF USD 0.50/BULB	ABATEMENT COST (USD/KT CO_2-E) AT INCANDESCENT LIGHT BULBS COST OF USD 0.75/BULB
Substitution of incandescent light bulbs	-505	-520	-550

Solar home systems were estimated to supply The Gambia's off-grid demand and replace the usage of kerosene. Kerosene was estimated to cost USD 0.833 per litre. Sensitivity analyses were conducted using 62.5%, 50% and 25% lower kerosene fuel costs. Table 21 presents the results of the sensitivity analyses.

Table 21: Sensitivity analyses of the mitigation option of installation of solar home systems

MITIGATION OPTION	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.312/LITRE	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.417/LITRE	ABATEMENT COST (USD/KT CO_2-E) AT DIESEL FUEL PRICE OF USD 0.625/LITRE
Solar home systems to supply off-grid consumption	-67	-90	-137

The sensitivity analyses demonstrate that the results regarding the cost-effectiveness of mitigation options are robust, as all but one retain negative abatement costs even when cost parameters in the reference scenarios are significantly reduced (up to 65%).

5. DISCUSSION

This study provides a cost-effectiveness analysis of identified mitigation measures in The Gambia's power sector, as part of the country's Nationally Determined Contribution (NDC) revision process. The cost-effectiveness analysis was conducted using the marginal abatement cost curve (MACC) methodology, and the report details all technological and financial assumptions used. This methodology can be an effective tool for assisting in climate policy decision-making because it provides information on the greenhouse gas (GHG) abatement potential and associated costs of the policies and technology options evaluated, and the results of this analysis provide valuable information for identifying, quantifying and selecting suitable mitigation measures to achieve targets set by the country. Such analysis can play a critical role in the development and implementation of the new NDC, while also informing decision makers about possible pathways to increase renewable energy deployment and energy access. However, the MACC methodology has some drawbacks and should be used in conjunction with other cost-benefit analyses to aid in climate policy decision-making.

All mitigation measures considered have a negative cost of GHG abatement, indicating that emissions can be reduced while achieving economic benefits. The MACCs provide a visual representation and must be updated to reflect future policy adjustments, since they evaluate each solution separately and do not account for potential interactions or their likely impact on the abated GHG emissions and costs measured.

Source: Hanyu Qiu / Shutterstock.com.

A baseline and a mitigation scenario were established to perform the cost-effectiveness analysis. The demand estimation methodology was revised using best practices, and all data were benchmarked against available local or regional sources. The generation capacity and timeline were compared with official Gambian sources, and a least-cost dispatch approach has been used. Mitigation options were defined through revisions to the Intended Nationally Determined Contribution and other national plans and programmes, as well as through the incorporation of the most recent data available. Individual mitigation measures were evaluated using available technical and financial data from the country. Following a thorough analysis of the available literature, the revised hypotheses were discussed with national stakeholders during two workshop sessions on 23-24 February 2021 and 18 March 2021.

In terms of GHG emissions reductions, utility-scale solar photovoltaic (PV) offers the greatest potential, owing to The Gambia's scale of ambition. On average, utility-scale PV energy saves up to 18% of total GHG emissions in the baseline scenario for the period 2025-30. The second significant opportunity is solar water heating (6% savings averaged over the period 2025-30), followed by reductions in transmission and distribution losses (5% savings averaged over the period 2025-30), and increased small-scale PV power (the current rooftop solar programme and hybridisation of mini-grids), which could save up to 3% on average over the period 2025-30. The most cost-effective measure is efficient lighting, followed by mini-grid hybridisation, grid efficiency upgrades, solar home systems, utility-scale solar PV, solar water heaters, utility-scale wind and solar PV rooftop systems.

It is worth noting in this context that the total mitigation potential does not equal the sum of the mitigation potentials of all individual measures. Mitigation measures in the power sector affect either total demand or the source of supply. Between demand and supply is a dispatch model that determines which supply sources to activate based on their marginal production cost. Thus, the model output would differ depending on whether each measure is considered individually or collectively, with the latter expected to result in a significant decline in demand and a less carbon-intensive fuel mix.

Furthermore, it is worth mentioning that MACCs typically do not account for ancillary benefits, i.e. those associated with improved social, environmental and other conditions, such as improved health, local job creation, energy independency and increased resilience, to name a few, nor indirect costs (Ibrahim and Kennedy, 2016). Only direct costs associated with infrastructure investment and operational aspects are included in this analysis. This aspect may be important for the implementation phase of the NDC process.

6. CONCLUSIONS AND RECOMMENDATIONS

This study has supported the quantification of the potential of mitigation measures to reduce greenhouse gas (GHG) emissions and their cost-effectiveness. The analysis indicates that utility-scale solar photovoltaic (PV) is the most effective mitigation option for reducing GHG emissions, followed by solar water heaters and transmission and distribution loss reduction. These measures have the potential to reduce GHG emissions by 18% (utility-scale solar PV), 6% (solar water heaters) and 5% (transmission and distribution loss reduction), between 2025 and 2030, as compared with the baseline scenario. The remaining measures have a potential to reduce GHG emissions by less than 5% over the same period. All mitigation measures have negative abatement costs, indicating that they are both economically and environmentally attractive in the circumstances examined.

Table 22: Recommended mitigation measures for inclusion in the Nationally Determined Contribution update

MITIGATION OPTION	DESCRIPTION	TARGET YEAR
Renewable energy technology (utility-scale solar PV) ●	**89 megawatts** (MW) of utility-scale solar PV capacity	2030
Renewable energy technology (utility-scale wind) ●	**3.6 MW** of utility-scale wind capacity	2023
Reduced transmission and distribution losses ●	Reduction of transmission and distribution losses to **17%**	2030
Renewable energy technology (mini-grids) ●	Replacement of diesel mini-grids with **solar PV and battery storage systems**	2023
Energy-efficient lighting ●	Substitution of incandescent **light bulbs**	2030
Renewable energy technology (off-grid solar home systems) ●	**Solar home systems** to supply off-grid consumption	2023
Renewable energy technology (rooftop solar home systems) ●	**6 MW** of solar PV rooftop systems by 2024	2024
Renewable energy technology (solar water heaters) ●	Solar water heating facilities to supply **10% of** demand by 2030	2030

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7.1 APPENDIX A – BASELINE ELECTRICITY GENERATION CAPACITIES

Table 23: Primary baseline electricity generation capacities

FUEL	NAME	UNIT	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Heavy fuel oil (HFO)	Kotu	Megawatts (MW)	5.5	5.5	5.5							
HFO	Kotu	MW	11	11	11	11	11	11	11	11	11	11
HFO	Kotu	MW	5	5	5							
HFO	Kotu	MW	5	5	5	5						
HFO	Kotu	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama I	MW	5	5	5	5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama II	MW	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
HFO	Karpower	MW	15	15								
HFO	Karpower	MW	15	15								
Light fuel oil (LFO)	Farafenni	MW	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
LFO	Bansang	MW	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
HFO	Basse	MW	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
HFO	Kaur	MW	0.12	0.12								
HFO	Brikama III	MW		18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
HFO	ICE	MW		20	20	20	20	20	20	20	20	20
Hydro	Imports	MW	14	59	59	59	59	59	59	59	59	59
Wind		MW	1	1	1	1	1	1	1	1	1	1
Total capacity		**MW**	**123.12**	**206.52**	**176.4**	**165.9**	**139.4**	**139.4**	**139.4**	**139.4**	**139.4**	**139.4**

Table 24: Electricity generation capacities – baseline scenario with fossil fuels

FUEL	NAME	UNIT	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
HFO	Kotu	MW	5.5	5.5	5.5							
HFO	Kotu	MW	11	11	11	11	11	11	11	11	11	11
HFO	Kotu	MW	5	5	5							
HFO	Kotu	MW	5	5	5	5						
HFO	Kotu	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama I	MW	5	5	5	5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama II	MW	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
HFO	Karpower	MW	15	15								
HFO	Karpower	MW	15	15								
LFO	Farafenni	MW	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
LFO	Bansang	MW	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
HFO	Basse	MW	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
HFO	Kaur	MW	0.12	0.12								
HFO	Brikama III	MW		18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
HFO	ICE	MW		20	20	20	20	20	20	20	20	20
Wind		MW	1	1	1	1	1	1	1	1	1	1
Total capacity		**MW**	**109.12**	**147.52**	**117.4**	**106.9**	**80.4**	**80.4**	**80.4**	**80.4**	**80.4**	**80.4**

Table 25: Electricity generation capacities – baseline scenario with new combined cycle gas turbines (CCGTs)

FUEL	NAME	UNIT	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
HFO	Kotu	MW	5.5	5.5	5.5							
HFO	Kotu	MW	11	11	11	11	11	11	11	11	11	11
HFO	Kotu	MW	5	5	5							
HFO	Kotu	MW	5	5	5	5						
HFO	Kotu	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama I	MW	5	5	5	5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama II	MW	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
HFO	Karpower	MW	15	15								
HFO	Karpower	MW	15	15								
LFO	Farafenni	MW	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
LFO	Bansang	MW	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
HFO	Basse	MW	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
HFO	Kaur	MW	0.12	0.12								
HFO	Brikama III	MW		18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
HFO	ICE	MW		20	20	20	20	20	20	20	20	20
Wind		MW	1	1	1	1	1	1	1	1	1	1
CCGT	Imports (Senegal and Côte d'Ivoire)	MW					100	100	100	100	100	120
CCGT	Committed	MW				50	50	50	50	50	50	50
Total capacity		**MW**	**109.12**	**147.52**	**117.4**	**156.9**	**230.4**	**230.4**	**230.4**	**230.4**	**230.4**	**250.4**

Table 26: Electricity generation capacities – baseline scenario with Jambur project

FUEL	NAME	UNIT	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
HFO	Kotu	MW	5.5	5.5	5.5							
HFO	Kotu	MW	11	11	11	11	11	11	11	11	11	11
HFO	Kotu	MW	5	5	5							
HFO	Kotu	MW	5	5	5	5						
HFO	Kotu	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama I	MW	5	5	5	5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama II	MW	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
HFO	Karpower	MW	15	15								
HFO	Karpower	MW	15	15								
LFO	Farafenni	MW	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
LFO	Bansang	MW	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
HFO	Basse	MW	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
HFO	Kaur	MW	0.12	0.12								
HFO	Brikama III	MW		18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
HFO	ICE	MW		20	20	20	20	20	20	20	20	20
Wind		MW	1	1	1	1	1	1	1	1	1	1
Solar	Jambur	MW		20	20	20	20	20	20	20	20	20
Total capacity		**MW**	**109.12**	**167.52**	**137.4**	**126.9**	**100.4**	**100.4**	**100.4**	**100.4**	**100.4**	**100.4**

Table 27: Electricity generation capacities – baseline scenario with combined effects

FUEL	NAME	UNIT	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
HFO	Kotu	MW	5.5	5.5	5.5							
HFO	Kotu	MW	11	11	11	11	11	11	11	11	11	11
HFO	Kotu	MW	5	5	5							
HFO	Kotu	MW	5	5	5	5						
HFO	Kotu	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama I	MW	5	5	5	5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5						
HFO	Brikama I	MW	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
HFO	Brikama II	MW	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
HFO	Karpower	MW	15	15								
HFO	Karpower	MW	15	15								
LFO	Farafenni	MW	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
LFO	Bansang	MW	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
HFO	Basse	MW	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
HFO	Kaur	MW	0.12	0.12								
HFO	Brikama III	MW		18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
HFO	ICE	MW		20	20	20	20	20	20	20	20	20
Hydro	Imports	MW	14	59	59	59	59	59	59	59	59	59
Wind		MW	1	1	1	1	1	1	1	1	1	1
CCGT	Imports (Senegal and Côte d'Ivoire)	MW					100	100	100	100	100	120
CCGT	Committed	MW				50	50	50	50	50	50	50
Solar	Jambur	MW		20	20	20	20	20	20	20	20	20
Total capacity		**MW**	**123.12**	**226.52**	**196.4**	**235.9**	**309.4**	**309.4**	**309.4**	**309.4**	**309.4**	**329.4**

7.2 APPENDIX B – MITIGATION ANALYSIS

Table 28: Greenhouse gas reduction potential of mitigation options

MITIGATION OPTION	DESCRIPTION	SOURCE	GHG EMISSIONS REDUCTIONS (KT CO_2-E)										
			2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	ABSOLUTE GHG EMISSIONS REDUCTIONS 2030 VERSUS BASELINE
Renewable energy technology (utility-scale solar PV)	89 MW of utility-scale solar PV capacity deployment by 2030	INDC/Electricity roadmap update/ NREAP	0	22	22	22	59	67	74	82	89	97	533.25
Renewable energy technology (utility-scale wind)	3.6 MW of utility-scale wind capacity deployment by 2023	INDC/Electricity roadmap update/ SE4All Action Agenda/ NREAP	0	0	4	4	4	4	4	4	4	4	33.35
Reduced transmission and distribution losses	Reduce transmission and distribution losses to 17% by 2030	INDC/NEEAP	1	3	5	8	11	14	17	21	25	30	134.07
Renewable energy technology (mini-grids)	25% of mini-grid consumption to be supplied by solar PV by 2023	NAMA/Green mini-grid policy (under development)	2.0	2.1	2.7	2.6	2.5	2.4	2.2	1.8	1.0	0.1	19.42
Renewable energy technology (mini-grids)	100% of mini-grid consumption to be supplied by solar PV and battery systems by 2023	Regional target	8.0	8.4	10.7	10.5	10.2	9.6	8.7	7.3	4.0	0.3	77.69
Renewable energy technology (off-grid solar home systems)	100% of off-grid consumption to be supplied by Solar home systems by 2023	INDC/SE4All Action Agenda	0	0	2.1	1.9	1.6	1.3	1.0	0.7	0.4	0.1	9.18
Energy-efficient lighting	Substitute incandescent light bulbs by 2030	INDC/NEEAP	0.02	0.03	0.04	0.06	0.07	0.09	0.11	0.13	0.15	0.18	0.90
Renewable energy technology (solar water heaters)	Install solar water heating facilities to supply 10% of demand by 2030	INDC/NREAP	3.7	7.3	11.0	14.6	18.3	21.9	25.6	19.2	32.9	36.5	200.94
Renewable energy technology (rooftop solar home systems)	Install 6 MW of solar PV rooftop systems by 2024	EC/EIB	1.6	3.3	4.9	6.5	6.5	6.5	6.5	6.5	6.5	6.5	55.61

Note: GHG = greenhouse gas; kt CO_2-e = kilotonnes of carbon dioxide equivalent; PV = photovoltaic; MW = megawatt; INDC = Intended Nationally Determined Contribution; NREAP = National Renewable Energy Action Plan; SE4All = Sustainable Energy for All; NEEAP = National Energy Efficiency Action Plan; NAMA = Nationally Appropriate Mitigation Actions; EC = European Commission; EIB = European Investment Bank.

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