SAO TOME AND PRINCIPE

ASSESSMENT OF COST-EFFECTIVE MITIGATION OPTIONS FOR NDC IMPLEMENTATION

Technology and infrastructure

CLIMATE ACTION SUPPORT

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About this document

This technical report summarises the main outcomes and findings of the assessment of cost-effectiveness of renewable energy technology options in Sao Tome and Principe and evaluates the potential to reduce greenhouse gas emissions through the implementation of different mitigation measures to inform the NDC implementation phase in the country.

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CONTENTS

FIGURES

TABLES

BOXES

EQUATIONS

ABBREVIATIONS

AGER	Sao Tome and Principe General Authority for Regulation (*Autoridade Geral de Regulação*)
BAU	business-as-usual
BECCS	bioenergy coupled with carbon capture and storage
CAPEX	capital expenditure
CCS/U	carbon capture and storage/ utilisation
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
DFO	diesel fuel oil
EC	European Commission
EMAE	Sao Tome and Principe Water and Electricity Company (*Empresa de Água e Eletricidade*)
EU TAF	European Union Global Technical Assistance Facility for Sustainable Energy
EUR	euro
GCF	Green Climate Fund
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GHI	global horizontal irradiance
GgCO_2	gigagram of carbon dioxide
GNI	gross national income
Gt	gigatonne
GtCO_2	gigatonne of carbon dioxide
GWh	gigawatt hour
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
km	kilometre
km^2	square kilometre
kt	kilotonne
kW	kilowatt
kWh	kilowatt hour
ktCO_2	kilotonne of carbon dioxide
LCOE	levelised cost of electricity
LDC	least developed country
LED	light-emitting diode
LULUCF	land use, land-use change and forestry
MACC	marginal abatement cost curve
MBtu	million British thermal units
m^2	square metre
MW	megawatt
MWh	megawatt hour
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution
NEEAP	National Energy Efficiency Action Plan (*Plano de Acção Nacional de Eficiência Energética* – PANEE)
NREAP	National Renewable Energy Action Plan (*Plano de Acção Nacional das Energias Renováveis* – PANER)
O&M	operation and maintenance
OPEX	operational expenditure
PES	planned energy scenario
PV	photovoltaic
SIDS	small island developing state
t	tonne
tCO_2	tonne of carbon dioxide
T&D	transmission and distribution
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
W	watt
Wh	watt hour

EXECUTIVE SUMMARY

The Nationally Determined Contribution (NDC) of Sao Tome and Principe, submitted in July 2021, has an economy-wide mitigation target of around 27% reduction of GHG emissions by 2030, compared to the business-as-usual (BAU) scenario.[1]

Through the small island developing states (SIDS) Lighthouses Initiative – and in support of Sao Tome and Principe's NDC implementation process – the International Renewable Energy Agency (IRENA) has conducted a cost-effectiveness analysis of mitigation options available to the country's power sector.

The overarching aim of this study is to support climate policy decision makers. The study aims to do this by providing information that can assist in the prioritisation of mitigation measures in the power sector, both for the NDC implementation phase and for long-term sectoral plans. The study can also guide decision makers on the path to a cost-effective achievement of mitigation targets.

A three-step process has been followed in evaluating power sector measures: 1) develop a baseline scenario; 2) identify and review mitigation options; 3) perform a cost-effectiveness analysis using the most recent data.

The analysis shows that efficient lighting, solar photovoltaic (PV) panels and hydropower present the highest GHG emissions reduction potential, while all the mitigation measures studied present negative abatement costs (see Figure ES 1).

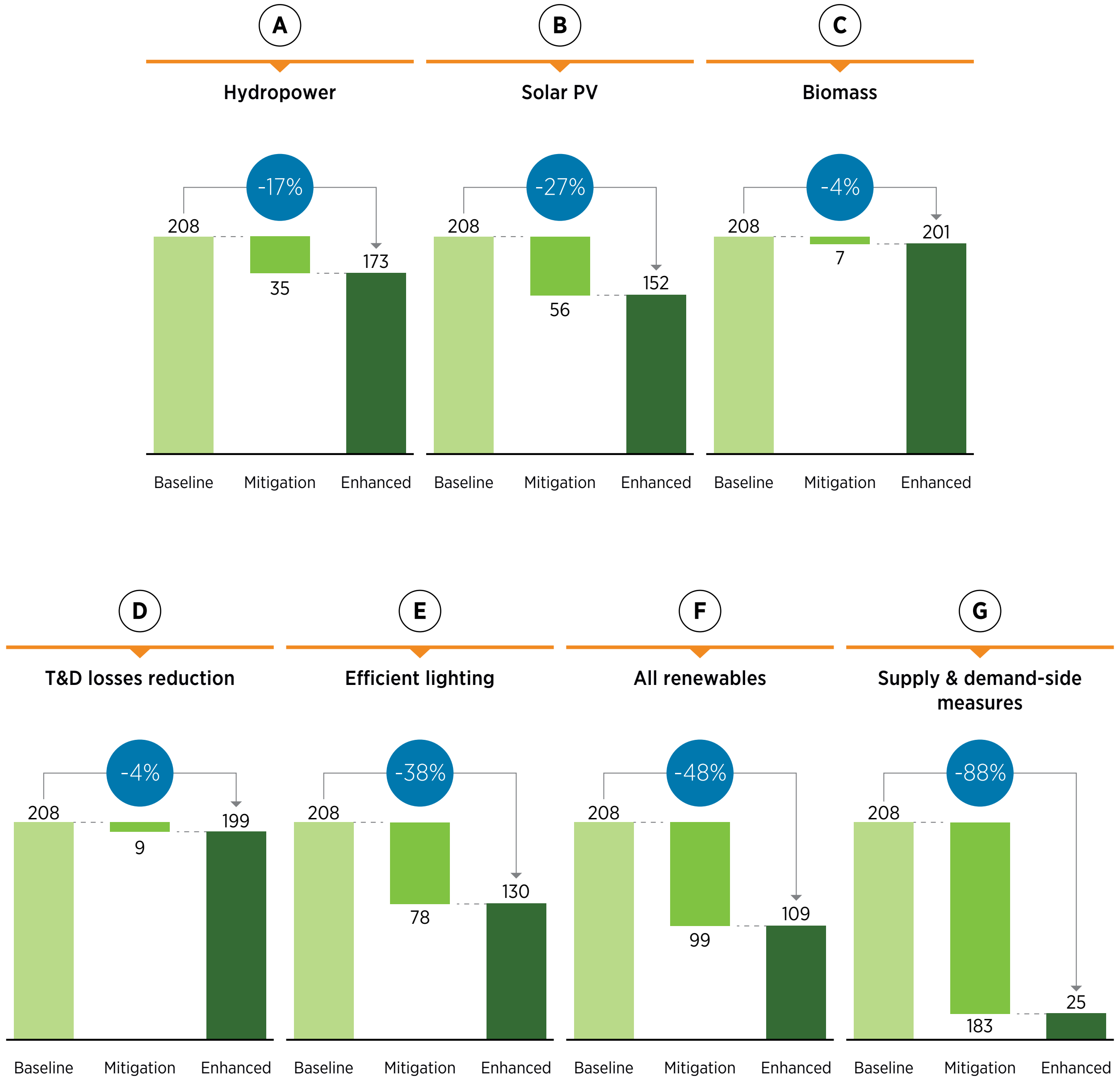
The mitigation measures allow for the following GHG emissions reductions in 2030 compared with the baseline scenario: efficient lighting, 38%; solar PV, 27%; hydropower, 17%; reduction in transmission and distribution (T&D) losses, 4%; and biomass, 4%.

As shown in Table S1, a total of five power sector mitigation measures were identified, as well as one measure for efficient cookstoves. All of these mitigation plans have been included in the National Renewable Energy Action Plan (NREAP – *Plano de Accão Nacional das Energias Renováveis* [PANER]) and/or in the National Energy Efficiency Action Plan (NEEAP – *Plano de Acção Nacional de Eficiência Energética* [PANEE]) (DGRNE, 2022a, 2022b).

Using the country's available technical and financial data, a mitigation scenario was developed for each individual power sector mitigation option. This enables a comparison to be made between the baseline scenario and both the GHG reduction potential and cost-effectiveness of each option. In addition, two more scenarios have been developed: one aggregating the renewable energy mitigation options (the "all renewables" scenario) and a second aggregating all the power sector mitigation options (the "supply and demand-side measures" scenario). For the efficient cookstoves measure, only the GHG reduction potential was calculated.

[1] *Under the BAU scenario, emissions are expected to reach 400 kilotonnes (kt) of carbon dioxide (CO_2), excluding land use, land-use change and forestry (LULUCF), by the 2030 date.*

Figure S1 GHG emissions reductions potential of power sector mitigation options by 2030 (%, $ktCO_2$)*



Notes:: * Figures calculated in comparison with the power sector baseline scenario, which is in turn based on data collected from *Renewable Energy and Energy Efficiency in Sao Tome and Principe – National Status Report* (ALER, 2020); $ktCO_2$ = thousand tonnes of CO_2.

The cost-effectiveness of the power sector mitigation options has been calculated using the marginal abatement cost curve (MACC) methodology. MACC is a useful tool in supporting climate policy decision-making as it indicates both potential GHG abatement and the associated costs of the policies and technology options assessed. The MACCs have been developed based on the power sector baseline and individual mitigation scenarios.

Although the GHG reduction potential varies significantly among the mitigation options, all the mitigation measures studied demonstrated a negative GHG abatement cost (Figure S2). This indicates that under the circumstances analysed, the measures studied were attractive both from an economic perspective and from that of GHG emissions reductions.

Table S1 Individual mitigation options identified

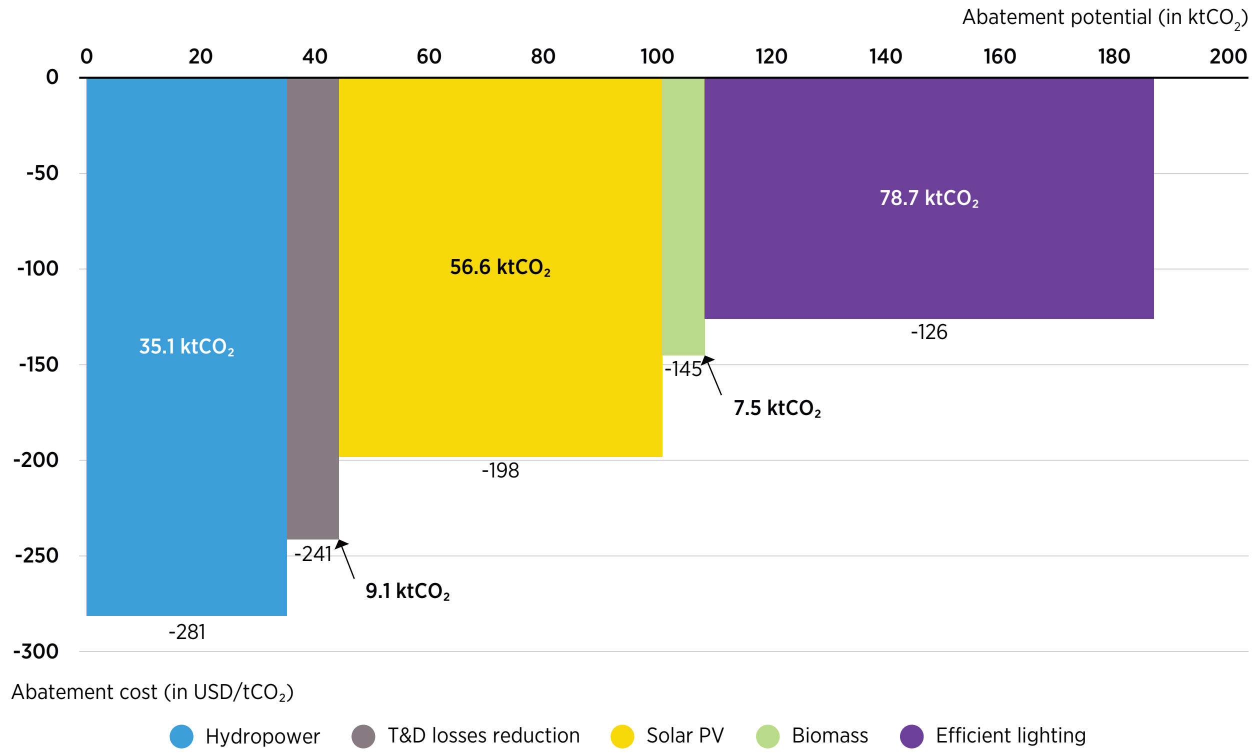
MITIGATION OPTION	DESCRIPTION	TARGET YEAR
Renewable energy technology (hydropower)	**17.3 megawatts** (MW) of **hydropower capacity** (including existing 1.8 MW) in Sao Tome	2030
Renewable energy technology (solar PV)	**46.95 MW of new utility-scale solar PV capacity:** 42.2 MW in Sao Tome and 4.75 MW in Principe	2025
Renewable energy technology (biomass)	**4.68 MW of new biomass capacity** in Sao Tome	2025
Reduced transmission and distribution losses	Reduction of transmission and distribution losses from **33%** (2019) to **30%** in Sao Tome and Principe	2030
Energy-efficient lighting	**Replacement of 611 750 incandescent lightbulbs** with LED in Sao Tome and Principe	2030
Efficient cookstoves	**Distribution of 39 600 improved cookstoves** with solid fuels in Sao Tome and Principe	2030

The mitigation measures have also been ranked according to their increasing marginal abatement cost, expressed in US dollars (USD) per tonne (t) of CO_2 reduction (USD/tCO_2). The study found the most cost-effective measure was hydropower, followed by reductions in transmission and distribution (T&D) losses, solar PV, biomass, and finally, efficient lighting.

All measures have negative abatement costs and generate revenue ranging between USD 126/tCO_2 and USD 281/tCO_2. The GHG emissions abatement cost of hydropower was -USD 281/tCO_2, followed by a reduction in T&D losses at an abatement cost of approximately -USD 241/tCO_2.

The study also includes an estimate of the total investment needs of each measure up to 2030 (see Table S2).

Figure S2 Marginal abatement cost curves for the year 2030



Notes: LED = light emitting diode; MW = megawatt; T&D = transmission and distribution.

Table S2 Estimated investment cost of each mitigation measure (USD million)

MITIGATION MEASURE	DESCRIPTION	ESTIMATED INVESTMENT NEEDS (USD MILLION)
Hydropower	15.5 MW of additional hydropower capacity	19.7
Solar PV	46.95 MW of utility-scale solar PV capacity	60.9
Biomass	4.68 MW of biomass capacity	8.9
Reduced T&D losses	Reduction of transmission and distribution losses to 30%	13.5
Energy-efficient lighting	Replacement of incandescent light bulbs with LEDs	3.0
Total		**106**

Note: T&D = transmission and distribution.

Given that the study shows that all the measures examined are both economically sound and lead to emissions reductions, IRENA recommends that Sao Tome and Principe develop a detailed implementation plan. This should include: an analysis on investment requirements across different sectors; funding sources; implementation timelines and actions; measurable milestones; responsible parties for implementation; and the opportunities and barriers to implementation that have been identified.

Furthermore, a risk assessment should be undertaken that can identify the risks and challenges to implementation and identify what factors need to be addressed to overcome these. This would include factors such as the technology and investment requirements, capacity building, organisational and regulatory requirements, supporting policies and measures, and incentive structures.

1. INTRODUCTION

Sao Tome and Principe submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. In 2021, the country submitted an updated Nationally Determined Contribution (NDC).

NDCs are national climate action plans and serve as the backbone of the Paris Agreement, which was adopted by the 197 member states of the UNFCCC in 2015. That agreement committed its signatories to undertake the steps necessary to keep global warming at 1.5°C.

NDCs include mitigation and, in most cases, steps towards adaptation that can be taken in order to stay in line with the goals of the Paris Agreement. A key principle of that agreement is that NDCs are to be revised, updated and enhanced every five years.

Analysis of the cost-effectiveness of current and future mitigation options can support countries in identifying, prioritising, selecting and quantifying mitigation measures. It can also inform the pathway to cost-efficiently reaching mitigation targets. Such analysis can therefore serve as an NDC implementation plan input and in 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 focuses on mitigation options available to the Sao Tome and Principe power sector. As an effort to support the country in the process of implementing its NDC, it has been undertaken by the International Renewable Energy Agency (IRENA) through the small island developing states (SIDS) Lighthouses Initiative and with support from the European Union Technical Assistance Facility (EU TAF).

In addition to analysing power sector mitigation measures, this study includes a quantitative assessment of the potential for GHG reductions associated with the implementation of efficient cookstoves. Due to a scarcity of data on cookstoves, however, the results of this assessment are only indicative and should be interpreted accordingly.

A three-step process is required to evaluate the cost-effectiveness of mitigation measures: 1) develop a baseline scenario; 2) identify and review mitigation options; 3) perform a cost-effectiveness analysis using the most recent and accurate data available.

The overarching aim of this study is to support climate policy decision makers. It aims to do this by providing information useful to the prioritisation of mitigation measures in the power sector – both for the NDC implementation phase and for long-term sectoral plans.

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

- **Chapter 2 (Background)** provides the context and overview of current
- **Chapter 3 (Methodology)** describes the methodology, data and assumptions used to develop the baseline and mitigation scenarios and perform the cost analysis.
- **Chapter 4 (Validation)** summarises the validation exercise conducted as part of this study.
- **Chapter 5 (Results)** provides the baseline scenario, the GHG emissions reduction potential and the cost-effectiveness of assessed mitigation measures.
- **Chapter 6 (Discussion)** discusses the methodology and results presented in Chapter 3 and 5.
- **Chapter 7 (Conclusions and recommendations)** summarises the report's findings and provides recommendations on how these findings could be used to inform the NDC implementation phase.

2. BACKGROUND

2.1 ACHIEVING NET ZERO BY 2050: THE ROLE OF RENEWABLE ENERGY TECHNOLOGIES

Recent growth in the number of countries committing to net-zero carbon strategies indicates a significant shift in the global climate discourse. Similar trends can be found at all levels of government and in the private sector, including in the hard-to-abate and oil and gas sectors.

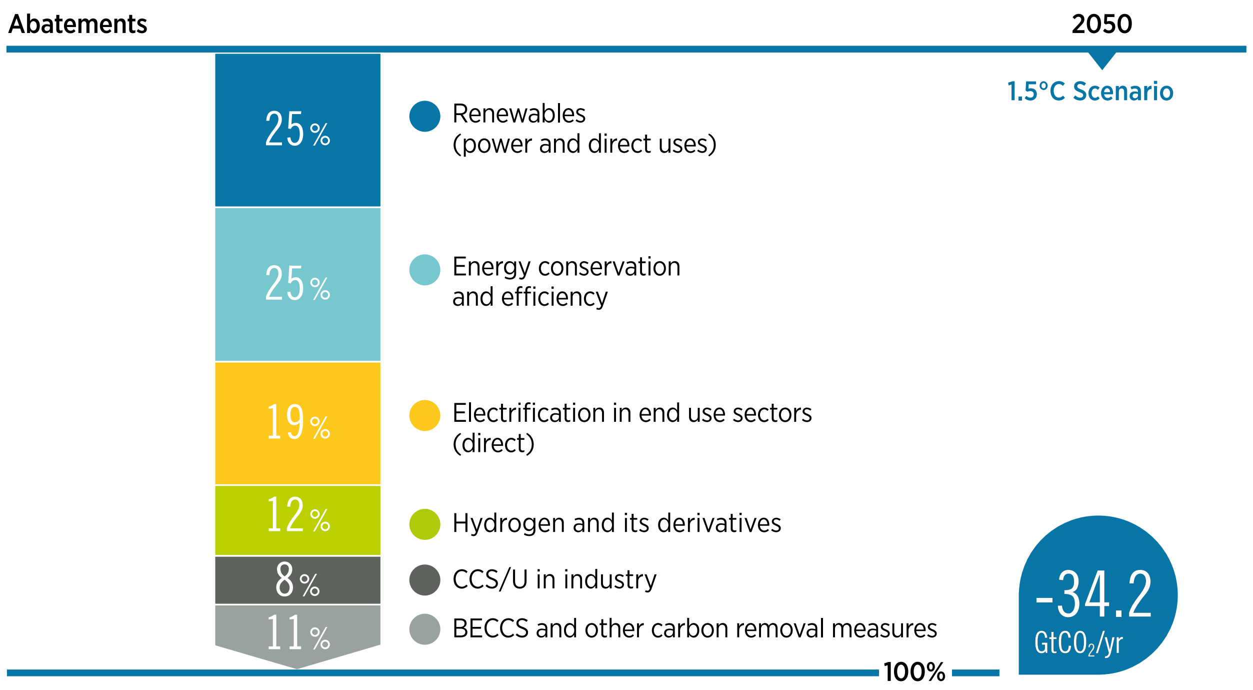
As much of the world deals with the effects of the economic downturn due to the pandemic, investments in the energy transition can help align short-term priorities with medium- and long-term development and climate goals (IRENA, 2020). Indeed, several countries have made significant commitments to dedicate public funds to these purposes and to support solutions such as electric mobility and clean hydrogen. Although more than 80% of the world's population lives in countries that are net importers of fossil fuels, every country has some renewable potential that can be used to increase energy security and independence at a lower cost (IRENA, 2019).

The analysis developed by IRENA outlines what is required for a global energy transition shift. It also presents an energy pathway that is consistent with limiting global temperature rises to 1.5°C – a pathway IRENA calls the 1.5°C Scenario. This scenario makes electrification and energy efficiency key drivers of the energy transition, enabled by renewables, hydrogen and sustainable biomass. It is also a pathway that requires a massive change in how societies produce and consume energy and would result in a cut of more than 34 gigatonnes (Gt) of annual carbon dioxide (CO_2) emissions by 2050 (IRENA, 2023a).

As depicted in Figure 1, these reductions can be achieved through: 1) significant increases in generation and direct uses of renewables-based electricity; 2) substantial improvements in energy efficiency; 3) the electrification of end-use sectors (*e.g.* electric vehicles and heat pumps); 4) clean hydrogen and its derivatives; 5) bioenergy coupled with carbon capture and storage (BECCS); and 6) last-mile use of CCS/U.

Decarbonisation of end uses is the next frontier, with many solutions provided through electrification, green hydrogen and the direct use of renewables. In end uses, deeper penetration of renewables, expanded electrification and improvements in energy efficiency can play a crucial role in alleviating concerns about prices and security of supply.

Figure 1 Carbon dioxide emissions abatement under the 1.5°C Scenario in 2050



Source: (IRENA, 2023a).

Note: BECCS = bioenergy with carbon capture and storage; CCS/U = carbon capture and storage/utilisation; $GtCO_2$/yr = gigatonne of carbon dioxide per year.

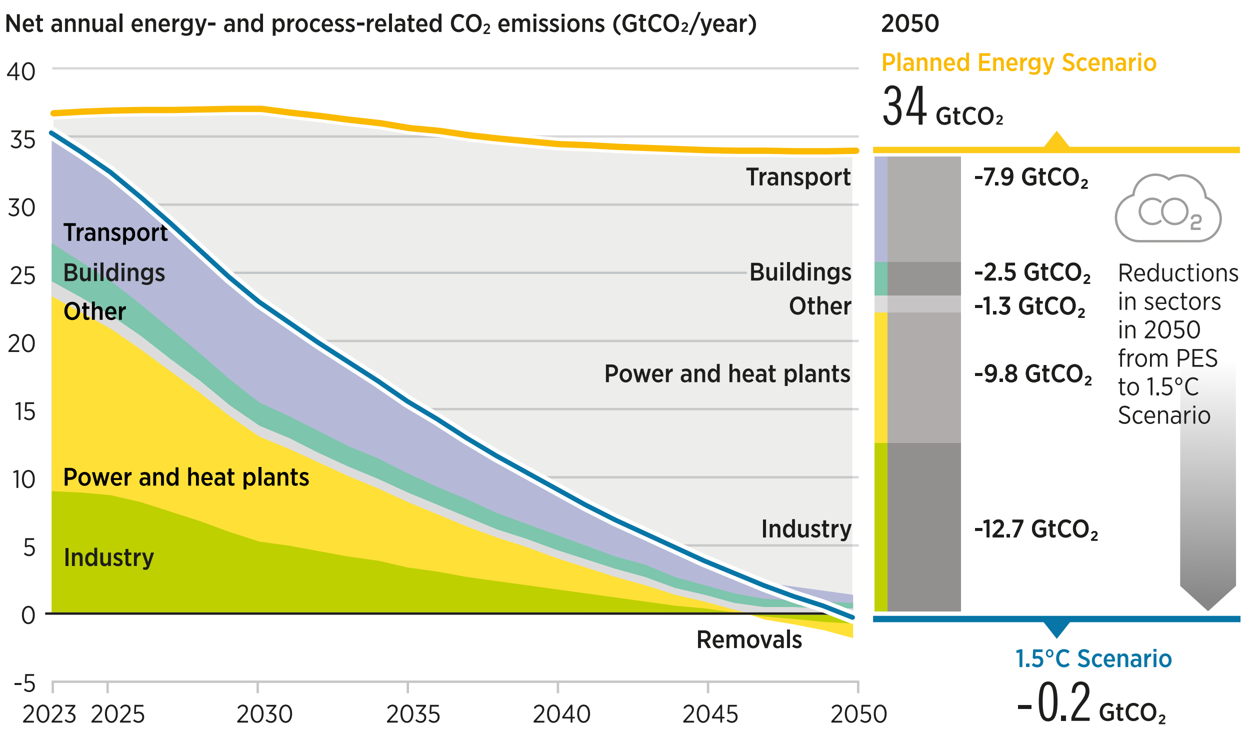
In line with the Intergovernmental Panel on Climate Change (IPCC) schedule, the IRENA analysis starts with the goal of reducing global CO_2 emissions in a steep and continuous downward trajectory from now on, finally reaching net zero by 2050. Figure 2 summarises current global shares of GHG emissions associated with energy use in the different sectors and the pathway towards the 2050 goal.

The 1.5°C Scenario shows that reaching net zero by 2050 is achievable, but extremely challenging, requiring urgent action on multiple fronts. Despite some progress, the energy transition is far from being on track, and radical action is needed to change its current trajectory. In the Planned Energy Scenario (PES)[2], annual emissions reach 34 Gt CO_2 in 2050. For the 1.5°C Scenario, emissions need to drop to net zero. Further efforts in sectors such as power, heat and industry are needed, with negative emissions delivering the necessary additional carbon reductions.

Renewable energy plays a key role in the decarbonisation effort. In the 1.5°C Scenario, in 2050, renewables account for around 77% of the total primary energy supply and 91% of electricity generation.

[2] *The PES is based on energy system developments in governments' energy plans and other plannedtargets and policies in place at the time of the analysis.*

Figure 2 Estimated trends in global CO_2 emissions under the Planned Energy Scenario and 1.5°C Scenario, 2023-2050



Source: (IRENA, 2023a).
Note: $GtCO_2$ = gigatonne of carbon dioxide; PES = Planned Energy Scenario.

Renewables for power generation have gained prominence due to cost reductions. Electricity costs from renewables have fallen sharply over the past decade (2010-2019), driven by improving technologies, economies of scale, increasingly competitive supply chains and growing developer experience.

The global weighted-average levelised cost of electricity (LCOE) from utility-scale solar PV, for example, fell by 89% between 2010 and 2022, by 13% between 2020 and 2021 and by 3% between 2021 and 2022 (IRENA, 2022; IRENA, 2023b). Reduced costs both encourage and are driven by increased uptake. As a result, renewable power generation technologies have become the least-cost option for new capacity in almost all parts of the world. This new reality has been increasingly reflected in deployment, with 2021 seeing renewables account for an unprecedented 83% of all new capacity additions worldwide (IRENA, 2023c).

With the ever-increasing deployment of renewable energy in the power sector, the shift from energy use to electricity in other sectors – including transport, buildings (heating and cooling) and industry – could make a significant contribution to decarbonisation.

Achieving the 2050 climate target depends on sufficient action by 2030, with the coming seven years being critical for accelerating the renewables-based transition. Any near-term shortfall in action will further reduce the chance of staying on path for the 1.5°C climate goal. Accelerated action is a no-regrets strategy and, when carefully implemented, allows the realisation of the benefits of a just and inclusive energy transition.

Significant progress has been made, but it has been uneven across geographies and communities. In some areas, widespread energy poverty continues to stimulate economic and social progress. In 2020, Europe, the United States and China accounted for most new renewable capacity, while Africa accounted for just 1%. This is the case even though Africa has the greatest need for expanded access to modern forms of energy, while also possessing a renewable energy potential that far exceeds projected needs.

The policies needed to advance the energy transition reinforce one another and have implications for the energy system, economy, society and the planet. A holistic global policy framework is needed to bring countries together to commit to a timely, just and fair energy transition that leaves no one behind and strengthens the international flow of finance, capacity and technologies in an equitable manner. The requisite financial resources will not always be available domestically; international collaboration and co-operation are needed to channel them, particularly to least developed countries (LDCs) and SIDS.

The *World Energy Transitions Outlook* from IRENA presents a 1.5°C Scenario compatible pathway. It also examines that pathway's socio-economic and policy implications, while providing insights on structural changes and finance. Realising the transition's far-reaching potential necessitates systemic innovation that considers both technologies and enabling frameworks.[3]

Renewable energy deployment in Africa

Renewable energy investment in Africa represents a very small share of the total invested in renewables globally. In the period 2000-2009, renewable energy investment in the continent constituted less than 1% of global renewable energy investment (USD 4.8 billion), while in 2010-2020 this share was 2.4%, representing USD 55 billion. Of the different African regions, Central Africa was the one with the lowest amount of investment in renewable energy, representing just 2% of the cumulative global investment in 2000-2020. In this region, all the investments in renewable energy – a total of USD 1.3 billion – occurred after 2010. Half of this amount was attributed to small hydropower plants, while the other half was used for the deployment of solar PV. Over the same period, investments in fossil fuels remained higher (IRENA and AfDB, 2022).

Despite the growth in renewable energy investments in Africa, countries with more advanced policy, regulatory and investment frameworks – as well as better macroeconomic conditions – attract most of the investments. Africa's LDCs need international support to attract investment and advance the energy transition, which will result in a transformative socio-economic development for these populations. Box 1 shows the results of IRENA's modelling of the socio-economic impacts of the energy transition in Africa.[4]

[3] *For a more in-depth analysis of the World Energy Transitions Outlook and its vision of the transition of the world's energy landscape aligned with the Paris Agreement goals, please refer to World Energy Transitions Outlook 2023: 1.5°C Pathway (IRENA, 2023a).*

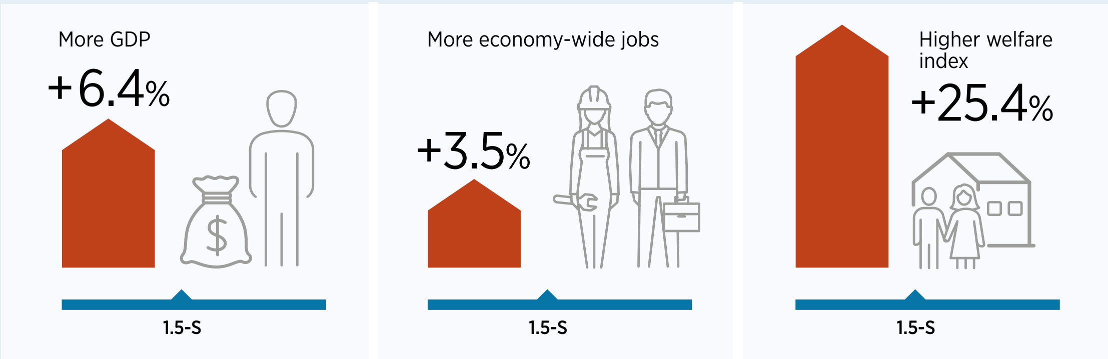
[4] *For a more in-depth analysis of this topic and the current landscape of renewable energy deployment in Africa, please see Renewable Energy Market Analysis: Africa and its Regions (IRENA and AfDB, 2022).*

Box 1 Socio-economic impacts of the energy transition in Africa

Socio-economic impacts of the energy transition in Africa

Despite the difficult shift away from carbon-intensive energy sources, the energy transition holds huge promise for Africa. On average over the period the 1.5°C Scenario predicts 6.4% higher GDP across Africa than that realised under the status quo, and a net balance of 3.5% more jobs than those predicted under current policies. IRENA analysis shows that the energy transition brings about important structural benefits for Africa, including prospering from a diversified economy, industrial development and innovation, energy access, and profound benefits for the environment, all of which are critical to more equitable socio-economic development across the continent. The energy transition is bolstered by public and private investment and targeted climate policies in addition to International co-operation, South-South co-operation, industrial policy, and the exchange of technological know-how.

Figure 3 Average differences between 1.5°C Scenario and PES in the 2021-2050 period



Source: IRENA and AfDB, 2022.
Note: 1.5-S = 1.5°C Scenario; PES = Planned Energy Scenario.

2.2 NATIONAL CONTEXT

Sao Tome and Principe is an archipelagic SIDS in Central Africa, located in the Gulf of Guinea, with a population of 215 000 (IRENA and AfDB, 2022). It consists of two main islands – Sao Tome and the Autonomous Region of Principe – and several smaller islands and islets, giving a total area of around 1 000 square kilometres (km^2). The two main islands are 160 kilometres (km) apart.

In the archipelago, 67% of the population lives in urban areas, 33% in rural areas (ALER, 2020), while the island of Sao Tome holds 95% of the population. With a per capita gross national income (GNI) of USD 1 843 in 2021 (UN, 2021), the country qualifies as an LDC. According to the World Bank, more than two-thirds of the population is poor and around one-third is below the lowest international poverty line (World Bank, 2022).

The service sector represents around 60% of gross domestic product (GDP) in Sao Tome and Principe, with the primary and secondary sectors each contributing 20% (MOPIRNA, 2019). Despite the COVID-19 pandemic, GDP increased around 3% in 2020 (World Bank, 2021).

As a SIDS, the country faces challenges related to climate change and territorial inequality. Rural areas have many inclusion challenges, such as access to electricity, drinking water and other basic services. The impact of climate change is visible through an increase in temperature and reduction in precipitation, and the country is also threatened by an increase in sea level and erosion of coastal areas.

Sao Tome and Principe's energy mix consists primarily of traditional biomass and petroleum products, with the latter by far the most used. Indeed, despite their negative environmental consequences, petroleum products play an important role in the country's energy supply because they are the primary source of fuel for transportation and electricity generation.

While all petroleum products are imported (mostly from Angola), the biomass in the energy mix is produced in-country. A small share of electricity is generated by hydropower plants – 4.6% in 2017 (AFREC, n.d.; ALER, 2020).

In 2019, approximately 87% of the population had access to electricity nationwide, with 74% access in Sao Tome and 100% in Principe. Access rates vary significantly between urban and rural areas, with 83% and 45% of the population in those areas having access to electricity, respectively (ALER, 2020). Sao Tome and Principe plans to achieve universal access to electricity by 2030, as well as universal access to clean and safe cooking, according to the National Renewable Energy Action Plan (NREAP – *Plano de Acção Nacional das Energias Renováveis* [PANER]) and the National Energy Efficiency Action Plan (NEEAP – *Plano de Acção Nacional de Eficiência Energética* [PANEE]) (DGRNE, 2022a, 2022b). These national plans, published in 2022, aim to tackle the existing barriers in the energy sector and promote investments in renewable energy and energy efficiency.

Figure 4 Map of Sao Tome and Principe

Source: ©Radzas2008/Shutterstock.com.
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.

2.3 CURRENT CLIMATE ACTION PLANS

The Nationally Determined Contribution (NDC) of Sao Tome and Principe, submitted in July 2021, has an economy-wide mitigation target of around 27% GHG emissions reduction by 2030, compared to the business-as-usual (BAU) scenario. The BAU would see those emissions reach 400 kilotonnes (kt) of CO_2 equivalent (CO_2eq) by 2030, excluding land use, land-use change and forestry (LULUCF). This mitigation goal will be met through interventions in the following industries: energy, transport, agriculture and livestock, and waste/residuals.

For the energy sector, three conditional mitigation measures have been set out, with 2030 as the target year:

1. Increase installed capacity of renewable energy up to 49 megawatts (MW), mainly from solar (32.4 MW), hydroelectric (14 MW) and biomass (2.5 MW);
2. Development of programmes promoting the implementation of an economically viable and sustainable energy model through a reduction in grid power losses and improvement of energy efficiencies;
3. Reduction of carbon intensity in the mobility sector.

The combined reduction estimated for these measures is 109 kt CO_2eq in 2030, compared to the BAU scenario.

In January 2022, the country published the NREAP and the NEEAP. These expand on the commitments and measures included in the NDC and include more quantitative targets. The power sector measures in these plans served as input for this study.

2.4 NDC IMPLEMENTATION

The NDC Sao Tome and Principe submitted in July 2021 had been updated with mitigation targets that were an enhancement of the country's earlier INDC. To reach these new targets, a sound implementation plan that considers investment needs, funding sources, financing strategy and implementation timelines is crucial.

Detailed costing estimates are essential as they can inform policy makers, strengthen the NDC implementation plan and build a financing strategy credible enough to attract possible investors or public funding sources. This is especially relevant given that the country's NDC is fully conditional.

The present study includes an investment estimate for each mitigation measure considered. This information was not detailed in the country's updated NDC, which only included a total investment cost. The assessed costing estimates show that significant financial resources will be necessary to realise the emission reduction targets.

Such funding can come from different types of sources – domestic or international, public or private. Identifying and selecting relevant sources of financing is an important step for NDC implementation. International public funding sources include climate funds, such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF). Financing can also be accessed through bilateral or multilateral channels. Private financing includes asset finance and venture capital.

3. METHODOLOGY

This analysis seeks to determine the cost-effectiveness of mitigation options in the Sao Tome and Principe power sector. Three assessments have been conducted as part of this effort, as illustrated in Figure 5.

This chapter describes in detail the methodological approaches, data and assumptions applied in these assessments. The first section (3.1) describes the development of the baseline scenario, section 3.2 describes the process of identifying mitigation options and developing mitigation scenarios, and section 3.3 describes how the GHG reduction potential and marginal abatement costs of the mitigation options were assessed.

Figure 5 Methodological process of the analysis

3.1 BASELINE SCENARIO

This section describes the methodology, data and assumptions used to develop the baseline scenario for the power sector, which served as the starting point for the analysis. A baseline scenario must be developed to serve as a benchmark against which the GHG reductions potential and the cost-effectiveness of each mitigation option can be compared.

Electricity generation

The projected baseline electricity generation for the period 2017-2030 was taken from *Renewable Energy and Energy Efficiency in Sao Tome and Principe – National Status Report*, which considers population growth, tourism growth, and a fast demand growth from large customers and institutions (ALER, 2020). Electricity generation data were provided separately for the two main islands. This analysis only considers electricity production connected to the main grid.

In Sao Tome, between 2017 and 2030, estimated electricity generation on the main grid is set to increase from 100 600 megawatt hours (MWh) to 245 900 MWh. In 2017, 5 045 MWh were generated from hydropower (ALER, 2020). In the baseline scenario, this value was assumed constant until 2030. Thus, electricity production from thermal power plants using fossil fuels was calculated as the difference between total production and hydropower production.

In Principe, all electricity is produced by fossil fuels. Electricity generation was 9 000 MWh in 2017, with this expected to grow to 16 900 MWh in 2030, whilst maintaining the same generation fleet.

T&D losses

T&D losses were assumed to be the same on both main islands. In 2017, losses on the main grid were estimated at 34% (ALER, 2020). In the NEEAP, T&D losses in 2019 were estimated at 33%, of which 11% were technical and 22% commercial (DGRNE, 2022b). Thus, in the baseline scenario, T&D losses have been set at 33% from 2019 onwards.

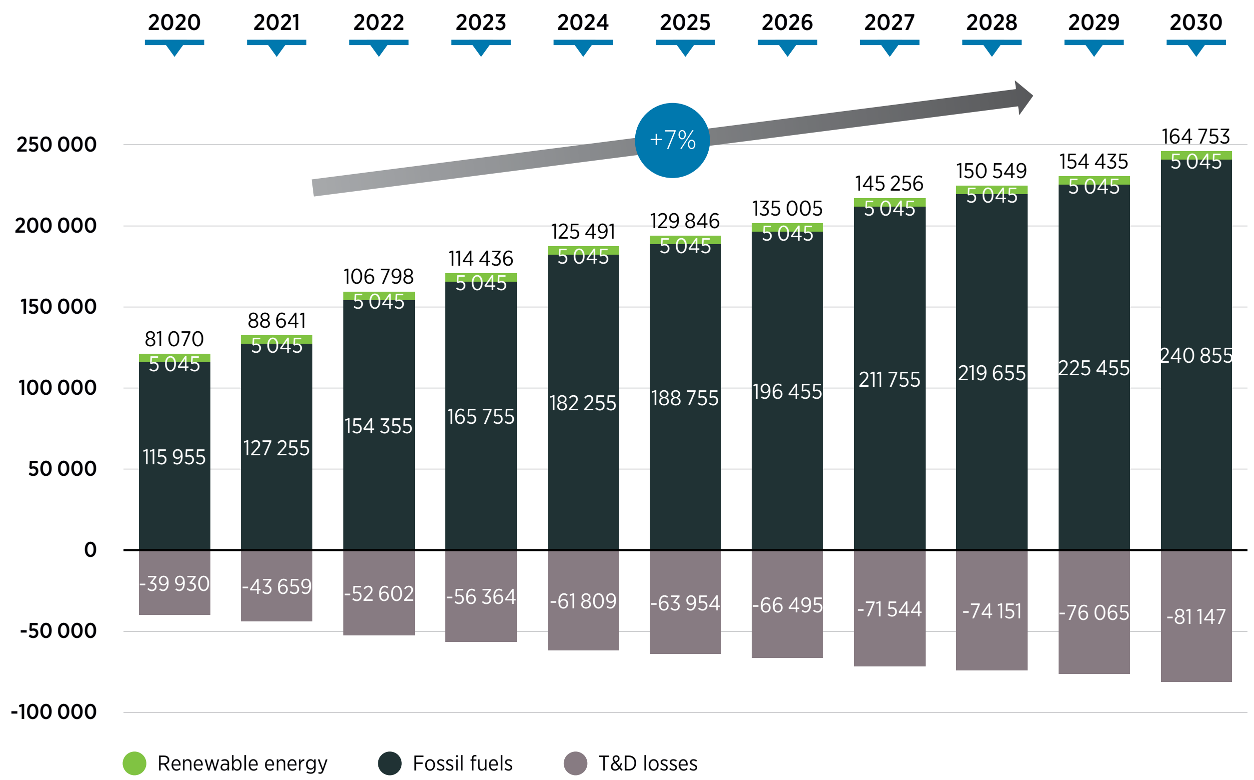
This high value of T&D losses is associated not only with the inefficiency of the T&D networks, but also theft and fraud related to electricity usage. This number has been improving, however, since higher losses were registered in previous years. In 2014, for example, T&D losses were estimated at 40.6% (DGRNE, 2022b).

Electricity demand projections

Electricity demand was calculated separately for Sao Tome and for Principe and aggregated to compute the total electricity demand for the country. T&D losses (both technical and commercial) were applied to the electricity generation dataset from ALER (2020) to estimate the demand on each island. Figure 6 and Figure 7 present electricity demand projections for the period 2020-2030 (in MWh) by type of fuel source on the islands of Sao Tome and Principe, respectively. As shown in Figure 6, in Sao Tome, hydropower generation remains constant while fossil fuel-based electricity generation progressively increases towards 2030.

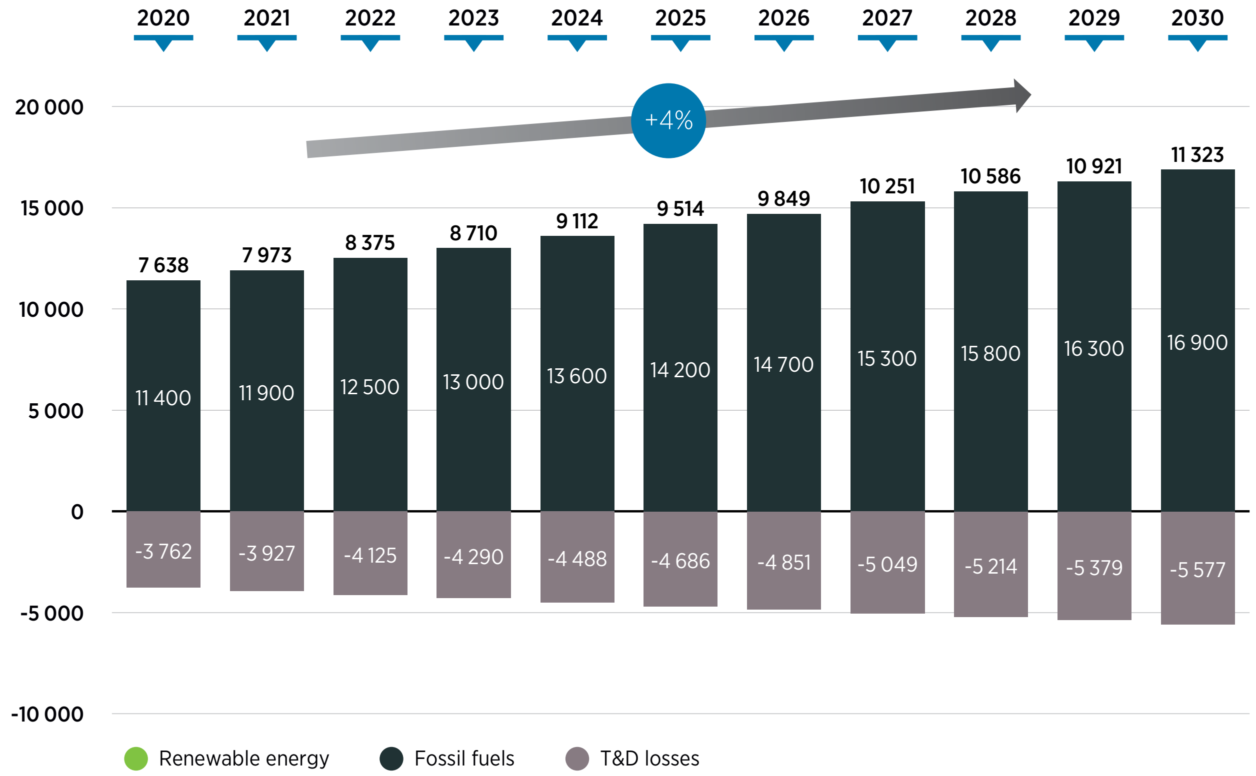
On Sao Tome, average annual electricity demand growth for 2020-2030 is 7%, while on Principe it is 4%. Demand is expected to grow due to population growth, increasing tourism and the electrification of agricultural processes (ALER, 2020).

Figure 6 Projected electricity demand in Sao Tome (MWh)



Source: ALER, 2020.
Note: MWh = megawatt hour.

Figure 7 Projected electricity demand in Principe (MWh)



Source: ALER, 2020.
Note: MWh = megawatt hour.

Electricity supply fleet

The baseline electricity supply fleet shown in Table 1 was compiled from power generation capacity and commissioning date data provided in *Renewable Energy and Energy Efficiency in Sao Tome and Principe – National Status Report* (ALER, 2020). The fleet is relatively modern, with new capacities added since 2000 in Santo Amaro – Santo Amaro 1 (2010), Santo Amaro 2 (2016) and Santo Amaro 3 (2020) – and in Bobo Forro, with Bobo Forro 1 (2008) and Bobo Forro 2 (2015). These facilities complement older generator groups in Sao Tome. According to ALER (2020), only 59% part of the fleet is operational, however, with 59.68 MW of installed capacity listed, but only 35.22 MW available. Table 3 only includes those assets that have available capacity.

Table 1 Baseline capacity assets

TECHNOLOGY	LOCATION /SYSTEM	GENERATOR	COMMISSIONING	LIFETIME	DECOMMISSIONING	TOTAL AVAILABLE CAPACITY (MW)
Sao Tome						
Diesel fuel oil	Sao Tome	ABC 3	1996	35	2031	0.9
		Deutz 1	2000	35	2035	1.23
		Deutz 3	2000	35	2035	1.23
		Caterpillar	2009	35	2044	1.5
		Perkins	2015	12	2027	0.0
	Santo Amaro 1	Him Sem 1	2010	35	2045	1.626
		Him Sem 2	2010	35	2045	1.626
		Him Sem 3	2010	35	2045	1.626
		Him Sem 4	2010	35	2045	1.626
		Him Sem 5	2010	35	2045	1.626
	Santo Amaro 2	ABC 1	2016	35	2051	2.0
		ABC 2	2016	35	2051	2.0
		ABC 3	2016	35	2051	2.0
	Santo Amaro 3	Caterpillar	2020	35	2055	1.8
		Caterpillar	2020	35	2055	1.8
		Caterpillar	2020	35	2055	1.8
		Caterpillar	2020	35	2055	1.8
		Caterpillar	2020	35	2055	1.8

Table 1 Baseline capacity assets (continued)

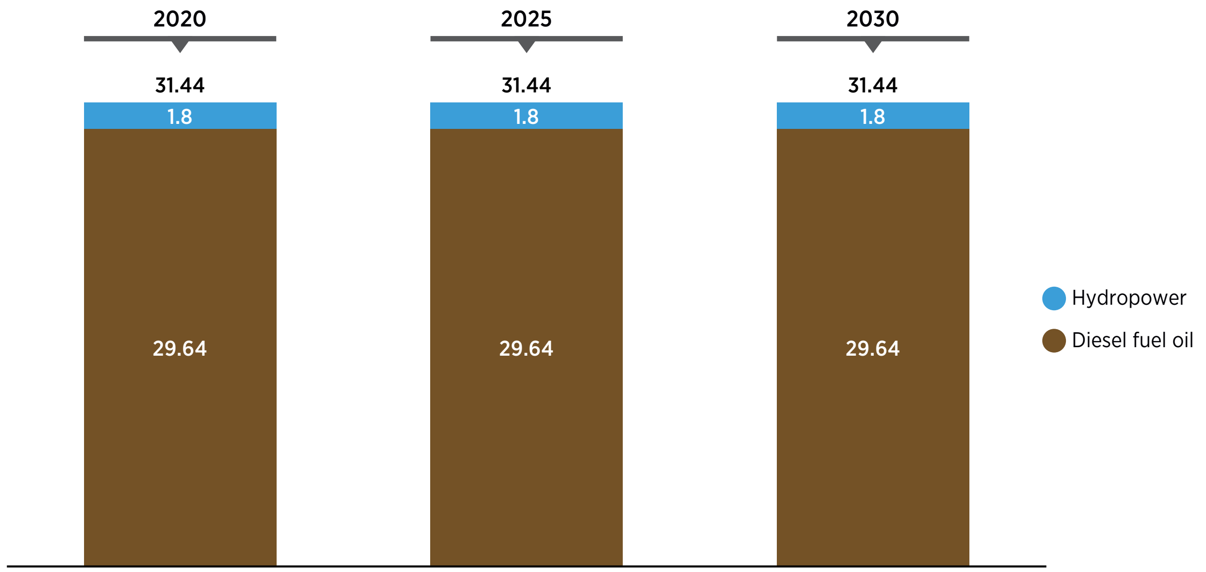
TECHNOLOGY	LOCATION /SYSTEM	GENERATOR	COMMISSIONING	LIFETIME	DECOMMISSIONING	TOTAL AVAILABLE CAPACITY (MW)
Diesel fuel oil	Bobo Forro 1	Pramac	2008	35	2043	0.55
		Pramac	2008	35	2043	0.55
		Pramac	2008	35	2043	0.55
	Total					**29.64**
Hydro	Contador	Leroy Somer	1967	65	2032	0.9
		Leroy Somer	1967	65	2032	0.9
	Total					**1.8**
Principe						
Diesel fuel oil		Caterpillar	2014	35	2049	0.72
		Caterpillar	2014	35	2049	0.72
		Caterpillar	2014	35	2049	0.72
		Caterpillar	2000	35	2035	0.72
		Caterpillar	2000	35	2035	0.9
	Total					**3.78**

Source: ALER, 2020.
Note: MW = megawatt.

To take into account potential decommissioning of assets in the model, a lifetime period was applied to determine the availability of the capacity at each date. For fuel-based assets, the lifetime expectancy was set at 35 years and for hydropower assets 65 years. The total baseline capacities per fuel source are presented in Figure 8 and Figure 9. None of the operational generators is being decommissioned before 2030, which leads to a constant baseline capacity throughout the period 2017-2030.

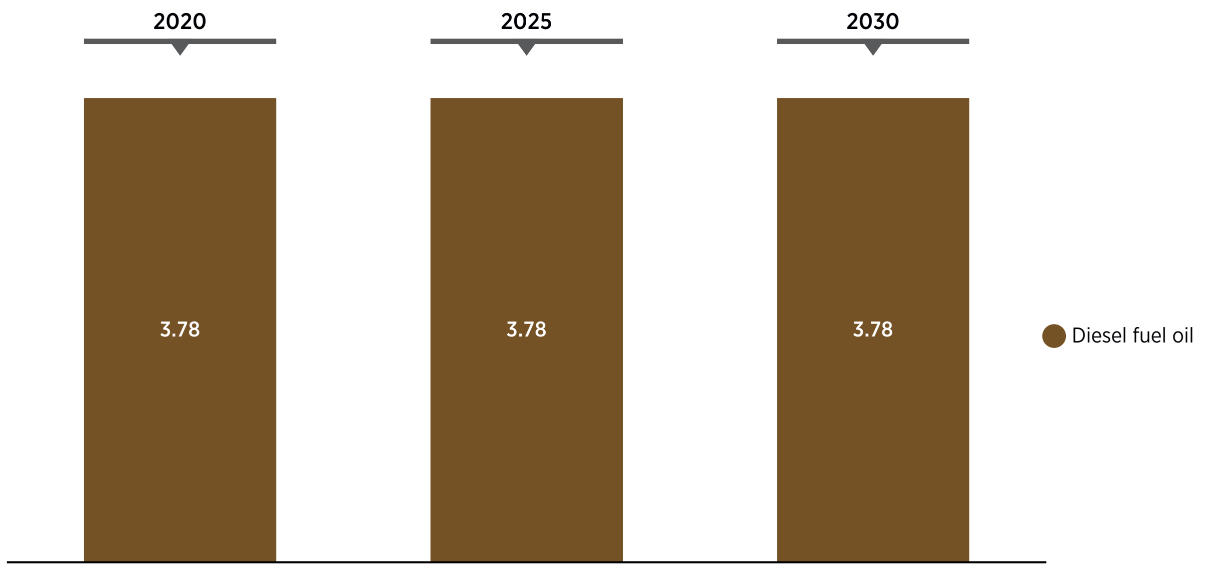
In Sao Tome, the electricity generation fleet consists of 29.64 MW of diesel fuel oil (DFO)-based capacity and 1.8 MW of hydropower capacity, while the electricity generation fleet in Principe consists of 3.78 MW of DFO-based capacity (ALER, 2020).

Figure 8 Baseline capacities, Sao Tome (MW)



Source: ALER, 2020.
Note: MW = megawatt.

Figure 9 Baseline capacities, Principe (MW)



Source: ALER, 2020.
Note: MW = megawatt.

Currently, DFO capacities are running at moderate levels (estimated at 49% in Sao Tome and 36% in Principe for 2021). In the baseline scenario, the capacity factor (*i.e.* the load) increases to 93% in Sao Tome and 51% in Principe by 2030. These side calculations tend to show that Sao Tome might be at risk of facing a shortage of capacity in the short to medium term, as the electricity demand is projected to increase. Also, the drivers for adding renewable energy generation rely on a lower marginal cost of generation with stable prices over time, coupled with GHG emissions reductions.

Dispatch strategy and load

Across the model, a dispatch model is included in order to factor in the merit-order effect of renewable energy, leading to a reduction in emissions. This simplified dispatch model ranks the supply sources according to their marginal cost of operations. The following order was considered: 1) hydropower, 2) solar PV, 3) biomass, 4) DFO. As a result, each additional kilowatt hour of renewable energy displaces DFO.

The estimated capacity factors applied for each type of plant are presented in Table 2. For hydropower, the capacity factor was calculated using the actual values of installed capacities and generation (ALER, 2020), leading to 2 803 hours per year (corresponding to a capacity factor of 32%). The capacity factors for solar and biomass were calculated based on the average installed capacities and generation estimated in the NREAP for 2030 and 2050.

Table 2 Capacity factors applied per type of power generation plant

TYPE OF POWER PLANT	CAPACITY FACTOR	HOURS/YEAR
Hydropower	32%	2 803
Solar PV	16%	1 437
Biomass	23%	1 987

3.2 ANALYSIS OF MITIGATION SCENARIOS

To identify those mitigation measures suitable for evaluation, Sao Tome and Principe's NDC, NREAP and NEEAP were reviewed, along with other relevant plans, policies, ongoing projects, current investment plans and least-cost trends. Appendix A summarises the documents that were reviewed.

A total of five power sector mitigation options were identified for this study, as shown in Table 3, plus one for efficient cookstoves. All of them were included in the NREAP (DGRNE, 2022a) and/or NEEAP (DGRNE, 2022b).

Table 3 Individual mitigation options identified

MITIGATION OPTION	DESCRIPTION	TARGET YEAR
Renewable energy technology (hydropower)	17.3 MW of hydropower capacity (including existing 1.8 MW) in Sao Tome	2030
Renewable energy technology (solar PV)	46.95 MW of new utility-scale solar PV capacity: 42.2 MW in Sao Tome and 4.75 MW in Principe	2025
Renewable energy technology (biomass)	4.68 MW of new biomass capacity in Sao Tome	2025
Reduced T&D losses	Reduction of T&D losses from 33% (2019) to 30% in Sao Tome and Principe	2030
Energy-efficient lighting	Replacement of 611 750 incandescent lightbulbs with LED in Sao Tome and Principe	2030
Efficient cookstoves	Distribution of 39 600 improved cookstoves with solid fuels in Sao Tome and Principe	2030

Notes: LED = light emitting diode; MW = megawatt; T&D = transmission and distribution.

For each individual power sector mitigation option, a mitigation scenario was developed to evaluate its GHG reduction potential and cost-effectiveness. Two other mitigation scenarios were created for the power sector: one aggregating all the renewable energy measures (supply-side mitigation options), and one combining all measures (supply and demand-side).

All the mitigation scenarios for the power sector are presented in Table 4. For the efficient cookstoves measure, the study includes a quantitative assessment of the potential for GHG emissions reduction.

Table 4 Description of mitigation scenarios for the power sector

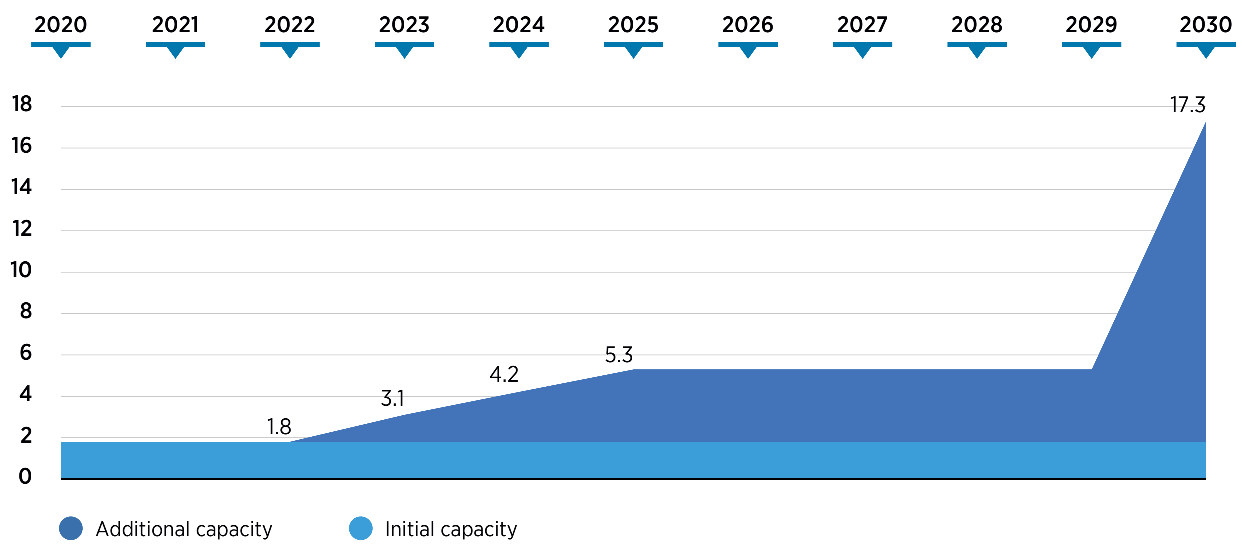
	REFERENCE	MITIGATION SCENARIO	DESCRIPTION
Supply-side mitigation options	A	Hydropower	17.3 MW by 2030
	B	Solar PV	46.95 MW by 2025
	C	Biomass	4.68 MW by 2025
Demand-side mitigation options	D	T&D loss reduction	Reduction of T&D losses to 30% by 2030
	E	Efficient lighting	611 750 LEDs to replace incandescent lightbulbs by 2030
Aggregated scenarios	F	All renewables	68.93 MW of renewable capacity by 2030
	G	Supply and demand-side measures	Combined mitigation options from the supply and demand sides

Notes: LED = light emitting diode; MW = megawatt; T&D = transmission and distribution.

Hydropower

The island of Sao Tome already has installed hydropower capacity of 1.8 MW. According to national documents, due to its many rivers and regular precipitation, the country has huge hydroelectric potential and there are plans to build more hydropower plants in the future. In line with the NREAP, the deployment of an additional 15.5 MW of hydropower in Sao Tome between 2021 and 2030 has been investigated as a mitigation option, as shown in Figure 10 below.

Figure 10 Renewable energy technology (hydropower) deployment schedule (MW)



Source: DGRNE, 2022a.
Note: MW = megawatt.

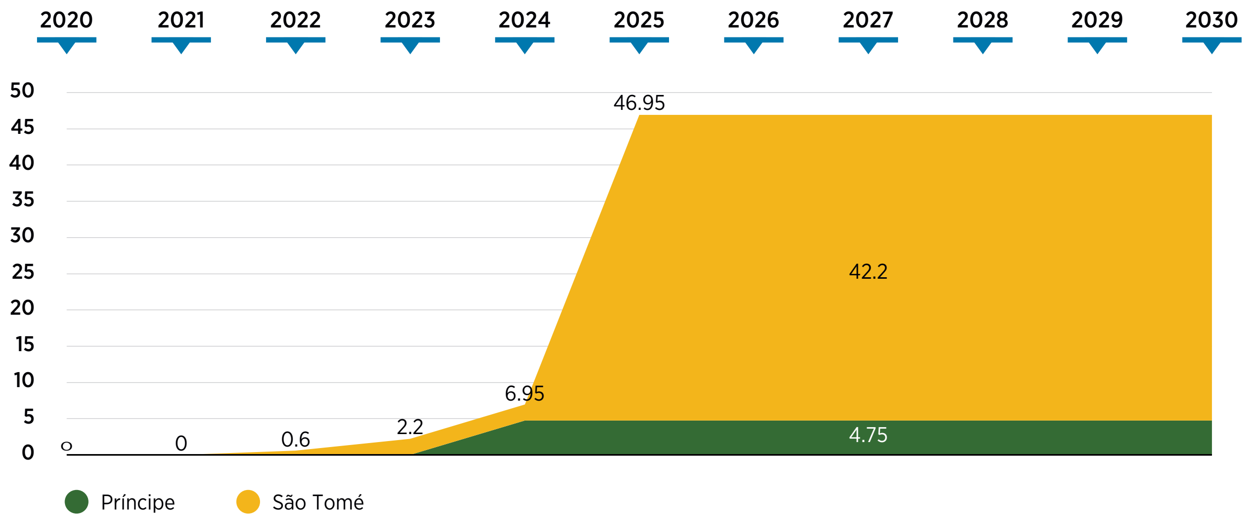
The capacity factor (hours/year) was multiplied by the capacity (MW) to determine annual electricity generation (MWh). In this mitigation scenario, hydro generated electricity replaces electricity generated by DFO in the baseline scenario. The GHG emissions were calculated by multiplying the emissions factor by the respective level of electricity production.

Solar PV

The country has good solar potential. The coastal area in the northeast of Sao Tome island has a global horizontal irradiance (GHI) of 4.35 kilowatt hours (kWh) per square metre (m^2) per day and in Principe this value is estimated at 4.43 kWh/m^2/day. Therefore, solar PV deployment is relevant to consider as a mitigation option. The NREAP lists several solar PV projects in the planning phase, as well as some in the implementation phase.

The deployment of 46.95 MW of utility-scale solar PV power, split between Sao Tome and Principe, between 2021 and 2030 has been considered as a mitigation option, as shown in Figure 11 below.

Figure 11 Renewable energy technology (solar PV) deployment schedule (MW)



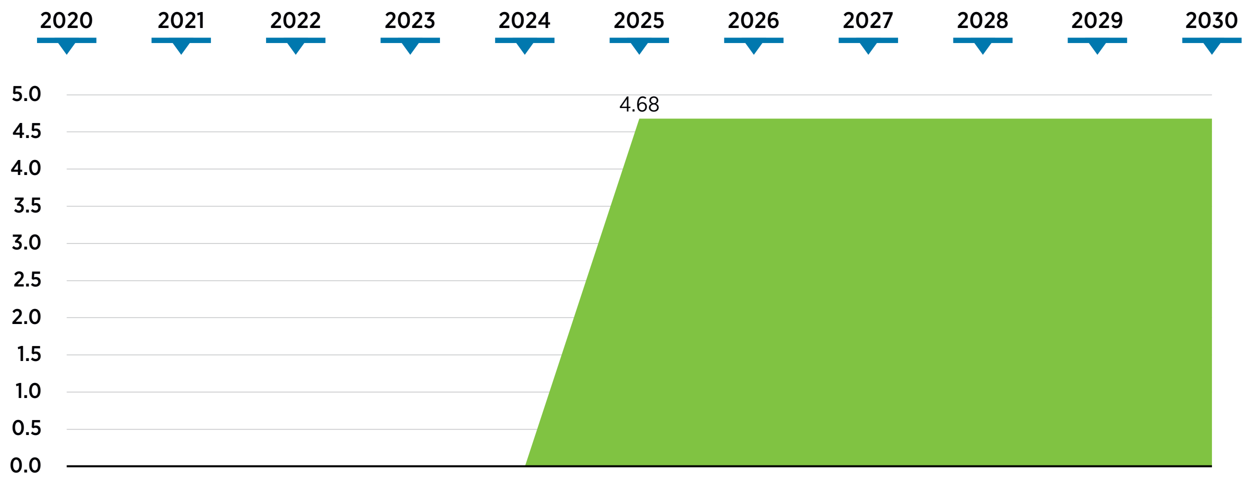
Source: DGRNE, 2022a.
Note: MW = megawatt.

The capacity factor (hours/year) was multiplied by the capacity (MW) to determine the annual electricity generation (MWh). In this mitigation scenario, the electricity generated by solar PV replaces electricity generated by DFO in the baseline scenario. By multiplying the emissions factors by the respective electricity production levels, the GHG emissions for this scenario, with solar PV as a mitigation option, were determined.

Biomass

The deployment of 4.68 MW of biomass in Sao Tome in 2025 thanks to a new biomass power plant has also been considered as a mitigation option (Figure 12). This power plant will use solid urban, plant and industrial waste (DGRNE, 2022a).[5]

Figure 12 Renewable energy technology (biomass) deployment schedule (MW)



Source: DGRNE, 2022a.
Note: MW = megawatt.

[5] *This mitigation option assumes sustainably sourced biomass. The NREAP mentions programmes for guaranteeing sustainable usage of biomass.*

Annual electricity generation (MWh) was determined by multiplying the capacity factor (hours/year) by the installed capacity (MW). In this mitigation scenario, electricity generated with biomass replaces DFO generated electricity. The GHG emissions were calculated by multiplying the emissions factor by the respective level of electricity production.

T&D networks

The NEEAP considered improvements in losses in the T&D network. Baseline losses were estimated at 33% in 2019 (of which 11% were technical and 22% nontechnical). The mitigation option that has been evaluated for reduction of T&D losses is 30% by 2030.

These losses have been linearly interpolated between the base year (33% by 2019) and the target year (30% by 2030). As a result of the reduced T&D losses, demand (*i.e.* annual electricity production) decreases. The reduction in demand will displace electricity production from DFO. For this scenario, the GHG emissions reduction potential was calculated by multiplying the electricity generation savings by the corresponding emissions factor of DFO.

Efficient lighting

This mitigation scenario assumes that 611 750 incandescent lights will be replaced with LEDs by 2030, in line with the NEEAP. The number of lightbulbs replaced in public lighting will be 13 750, while the remaining 598 000 lightbulbs will be replaced in the residential and commercial sectors. The targets for 2030 are split into different sub-measures, as shown in Table 5.

Table 5 Sub-measures considered for the efficient lighting measure

MEASURE	IMPLEMENTATION PERIOD
Replacement of 300 000 incandescent lightbulbs with LEDs in 60 000 households	2020-2024
Replacement of 100 000 incandescent lightbulbs with LEDs in 20 000 poor households	2021-2030
Replacement of 198 000 incandescent lightbulbs with LEDs in commercial buildings	2021-2030
Replacement of 13 750 incandescent lightbulbs with LEDs in public lighting	2021-2030

Source: DGRNE, 2022b.
Note: LED = light emitting diode.

The growth in the number of lightbulbs replaced was considered to be linear throughout the implementation period of each measure. Lighting hours in all houses were estimated at four hours per day, according to the access tier level in each category (Bhatia and Angelou, 2015). In public buildings and street lighting, lighting hours were estimated at nine hours per day (Bhatia and Angelou, 2015). The average power consumption of incandescent bulbs was estimated at 60 watts (W), and that of LED bulbs 9 W, based on incandescent lamps with a 60 W equivalent.

The electricity savings from LED light bulbs over traditional incandescent lights were calculated from the demand for electricity. The demand reduction will displace electricity generated by DFO. For this scenario, with lower demand as a result of the efficient lighting measure, GHG emissions reductions were calculated by multiplying electricity generation savings by the appropriate emission factor.

Improved cookstoves with solid fuels

This mitigation scenario assumes that 39 600 improved cookstoves using solid fuels (firewood and charcoal) will be distributed and in use by 2030, in line with the NEEAP. Considering a useful lifetime of five years, this involves distributing 7 920 cookstoves annually.

The GHG emissions reduction potential for this scenario was calculated using the Emissions Reduction Calculation Tool for the "Simplified Methodology for Efficient Cookstoves" version 2.1, distributed by The Gold Standard.[6] Due to a lack of national data on cookstoves, model default values were used; hence, the results of this mitigation option assessment should be considered with great caution. This model only considers firewood as a fuel.

3.3 MARGINAL ABATEMENT COSTS AND GHG REDUCTION POTENTIALS

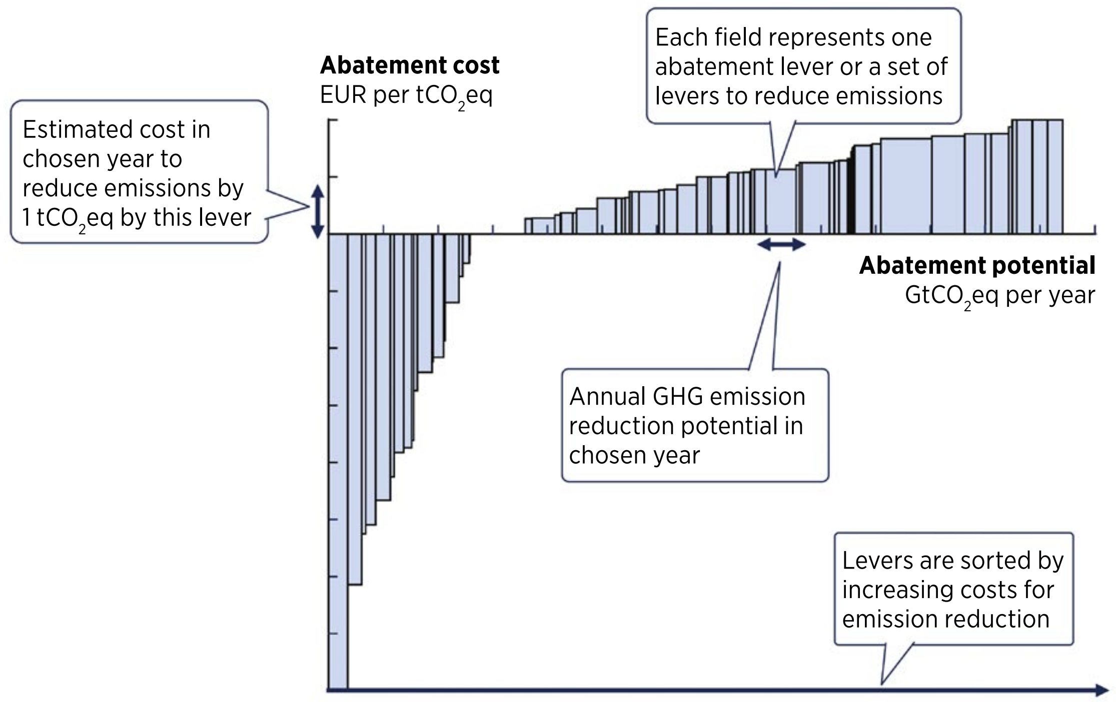
Following the evaluation of the baseline scenario, the identification of mitigation options and the development of mitigation scenarios, a cost-effectiveness analysis of the mitigation options was conducted. This section explains the methodologies and assumptions used to calculate the cost-effectiveness of those mitigation solutions by assessing their GHG reduction potential and marginal abatement costs.

The methodology of MACC

This cost-effectiveness analysis has been performed using a marginal abatement costs curve (MACC) methodology. As shown in Figure 13, the MACC is a two-axis graph. The horizontal axis indicates the GHG abatement potential – typically in $GtCO_2$/year – with the width of each bar indicating the abatement potential for reducing annual GHG emissions for a particular option. The vertical axis displays the abatement cost, expressed in the below example in euros (EUR) per tonne of CO_2 equivalent (EUR/tCO_2eq). This is the cost of reducing or offsetting one unit of GHG emissions and is indicated by the height of the bar.

[6] See *https://globalgoals.goldstandard.org/408-ee-ics-smics-er-tool/* accessed 5 October 2023.

Figure 13 Example of marginal abatement cost curves (MACCs)



Source: Nauclér and Enkvist, 2009.

GHG reduction potential

For each mitigation scenario, GHG emissions have been calculated by multiplying the emissions factor for each fuel type by the respective level of electricity production. This is then compared to the baseline scenario emissions level in order to estimate the GHG reduction potential of each mitigation option.

The emissions factors that have been applied for each fuel type are presented in Table 6. 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.

Emissions levels have been calculated for every year of analysis based on the estimated abatement potential.

Table 6 Emission factors for each fuel type considered

FUEL	EMISSION FACTOR (tCO_2/MWh)	SOURCE
Renewables	0	Own assumption (based on power plant operational emissions)
DFO	0.81	IPCC, 2006

Note: tCO_2/MWh = tonnes of CO_2 per megawatt hour.

Table 7 summarises the reference solutions considered in order to evaluate the mitigation options in terms of cost-effectiveness and GHG reduction potential. For the assessment of solutions associated with electricity generation (*i.e.* biomass, solar PV and hydro), DFO has been applied as a reference solution, since biomass, solar PV and hydropower are dispatched before DFO and thus displace DFO-generated electricity. DFO is also used for the analysis of the T&D upgrade mitigation option. Finally, incandescent bulbs are the reference solution applied to evaluate the mitigation option of efficient lighting.

Table 7 Reference solutions considered for the evaluation of each mitigation option in the power sector

MITIGATION OPTION	DESCRIPTION	REFERENCE SOLUTION
Sao Tome		
Hydropower	17.3 MW of hydropower capacity (including existing 1.8 MW)	DFO
Solar PV	42.2 MW of new installed utility-scale solar PV capacity	DFO
Biomass	4.68 MW of new installed biomass capacity	DFO
Principe		
Solar PV	4.75 MW of new installed utility-scale solar PV capacity	DFO
Sao Tome and Principe		
Reduced T&D losses	Reduction of transmission and distribution losses to 30%	DFO
Energy-efficient lighting	Replacement of incandescent light bulbs with LEDs	Incandescent light bulbs

Notes: LED = light emitting diode; MW = megawatt; T&D = transmission and distribution.

Cookstoves

The GHG emissions reduction resulting from improved cookstoves was calculated using the Emissions Reduction Calculation Tool for the "Simplified Methodology for Efficient Cookstoves" version 2.1, distributed by The Gold Standard.[7]

[7] See https://globalgoals.goldstandard.org/408-ee-ics-smics-er-tool/ accessed 5 October 2023.

Table 8 shows the assumptions considered in the evaluation of the improved cookstoves mitigation measure. The efficiency of the improved cookstoves was assumed to decrease 1% per year until 2029, starting at 94% in 2021, reaching 86% in 2029 and remaining at that level in 2030.

Table 8 Assumptions considered for the improved cookstoves mitigation measure

VARIABLE	VALUE	UNIT	SOURCE
Number of cookstoves	1	Cookstove/household	
CO_2 emissions factor of firewood that is substituted or reduced	1.75	tCO_2/tonne of wood	Model default assumption
Non-CO_2 emission factor of firewood that is substituted or reduced.	0.53	tCO_2/tonne of wood	Model default assumption
Adjustment factor to account for uncertainty related to project cookstove efficiency test	0.94	n/a	Model default assumption
Baseline firewood consumption	2.5	tonnes/household/year	Model default assumption
Firewood savings[8]	2.23	tonnes/household/year (tonnes/cookstove/year)	Model default assumption
Efficiency of baseline cookstove being replaced	10	%	Model default assumption

Note: tCO_2 = tonne of CO_2.

Abatement cost methodology and assumptions

Abatement costs estimate the incremental cost, in USD/tCO_2, associated with the implementation of a low-emissions technology (*i.e.* a mitigation measure) compared with a reference scenario. The abatement cost of each individual mitigation option can be calculated as follows (Nauclér and Enkvist, 2009):

Equation 1 Abatement cost of each individual mitigation option

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

[8] *The model estimates only firewood use, although there is some consumption of charcoal in the country.*

The full costs of low-emission and reference solutions include the annual repayment of 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). The availability of finance is not considered a constraint, and full costs do not include transaction expenditure, subsidies or taxes (Nauclér and Enkvist, 2009). In addition, no decommissioning costs are considered.

Abatement costs can be calculated for each year, with this study calculating them for the years 2020-2030. The following sections outline the cost assumptions – as well as the technical assumptions affecting the costs – that were used to evaluate each mitigation option. For this evaluation, a linear learning curve of 3% was considered and used to adjust both the CAPEX and OPEX of all the mitigation measures (except for hydropower) and to adjust the reference solutions in the 2020-2030 period. Furthermore, a 2% annual cost increase was considered for the DFO reference solution. OPEX figures presented for the mitigation measures are indicated as a percentage of the respective CAPEX.

The investment needs of each mitigation option were calculated considering the total CAPEX of additional renewable energy capacity, reducing grid losses and new LED lamps, respectively, and the learning curves of the period under consideration.

DFO

Table 9 presents the financial and technical assumptions made for the DFO reference solution. These included system availability, costs, generation efficiency and lifetime.

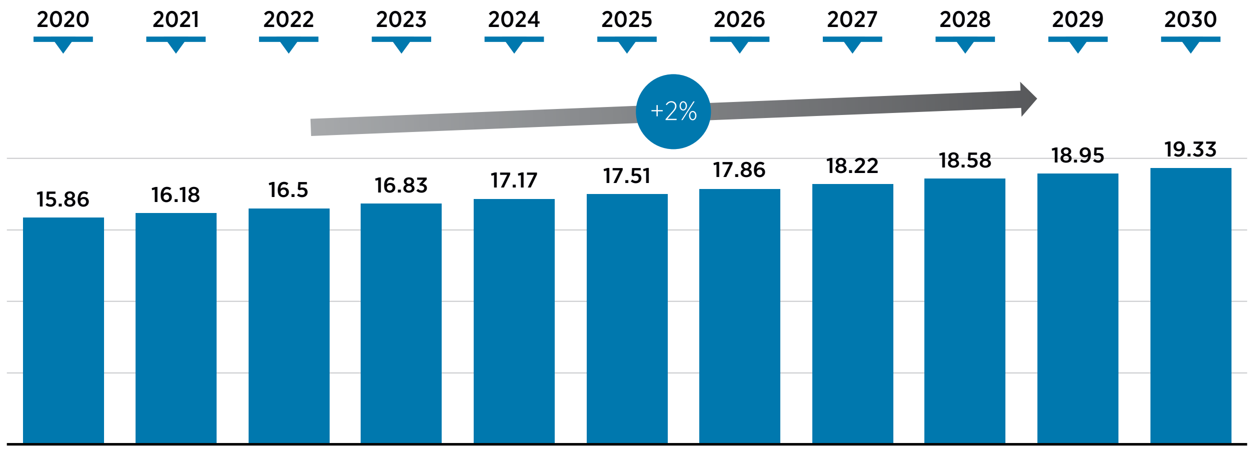
Table 9 Financial and technical assumptions considered for the DFO reference solution

VARIABLE	VALUE	UNITS	SOURCE
System availability	90	%	NDC background information
Estimated CAPEX	1 200	USD/kW	Own assumption
Variable O&M cost	30	USD/MWh	Own assumption
Heat rate	9 000	Btu/kWh	Own assumption
Efficiency	33	%	NDC background information
Lifetime	20	Years	Own assumption

Note: Btu = British thermal units; CAPEX = capital expenditure; kW = kilowatt; NDC = Nationally Determined Contribution; O&M = operations and maintenance; USD = US dollars.

Figure 14 presents the forecasted trend of fuel costs between 2020 and 2030, based on the study's own assumptions.

Figure 14 Fuel cost projections in USD/MBtu*



Note: * MBtu = million British thermal units.

Renewable energy technologies

Table 10 lists the estimated CAPEX and OPEX costs and the lifetime considered for the power sector mitigation measures with renewable energy. These include hydropower, solar PV and biomass.

Table 10 Financial and lifetime assumptions considered for renewable energy technologies

RENEWABLE ENERGY TECHNOLOGY	ESTIMATED CAPEX (USD/kW)	OPEX (% OF ESTIMATED CAPEX)	LIFETIME (YEARS)	SOURCE
Hydropower	1 138.1	0.5 %	25	NDC background information; own assumption
Solar PV (utility-scale)	1 500	1 %	20	NDC background information
Biomass	1 910	5 %	20	Own assumption

Considering the capacity factor and CAPEX of each renewable energy technology, the OPEX values translate into USD 2.03/MWh, USD 10.44/MWh and USD 48.06/MWh for hydropower, solar PV and biomass, respectively.

T&D network

The financial and lifetime assumptions applied to enable improvements in the T&D network are outlined in Table 11.

For the mitigation option addressing the T&D grid upgrade, this analysis considered cost and technical data from the *International Development Association Project Appraisal Document – Power Sector Recovery* (World Bank, 2016). The cost of the T&D component was USD 18.4 million. This was mostly for reductions in commercial losses, the improvement of medium and distribution lines, and the introduction of metering systems. A 40-year lifetime and a 1% OPEX were also considered (Hernández, C., *et al.*, 2020).

Table 11 Financial and lifetime assumptions considered for the reduction of T&D losses

MITIGATION OPTION	ESTIMATED CAPEX (USD MILLION)	OPEX (% OF ESTIMATED CAPEX)	LIFETIME (YEARS)	SOURCE
Reduced T&D losses	18.4	1	40	(World Bank, 2016; Hernández *et al.*, 2020; own assumption)

Note: T&D = transmission and distribution.

Efficient lighting

For the efficient lighting mitigation measure, Table 12 shows the financial and technical assumptions considered. The reference solution includes the usage of incandescent bulbs, with cost savings computed based on the estimated average cost of the electricity service supplied by DFO. This was USD 54.13/MWh in 2020.

Table 12 Efficient lighting mitigation measure: Financial and technical assumptions considered

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

Note: LED = light emitting diode.

4. VALIDATION

In collaboration with the General Directorate of Natural Resources and Energy of Sao Tome and Principe, two technical sessions were held, in 2021 and 2022. At these, the methodology used in the technical analysis, the datasets used, the key assumptions and the mitigation options were presented, discussed and validated. These technical sessions also gathered together key national stakeholders to receive feedback, ensure that the data were accurate and that the analysis aligned with national plans and priorities. Participants included energy and power sector stakeholders from public organisations, such as the General Directorate of Environment, the National Water and Electricity Company (*Empresa de Água e Eletricidade* – EMAE) and the General Authority for Regulation (*Autoridade Geral de Regulação* – AGER). Representatives from academia, non-governmental organisations (NGOs), the private sector and other relevant policy makers were also included.

The kick-off meeting, held in October 2021, saw IRENA present the scope of the work in detail and the objectives of the mitigation analysis. The underlying methodology for analysing the selected mitigation measures was also presented, and the availability of energy and cost datasets was clarified.

The second meeting was a validation session held in February 2022, at which IRENA presented the preliminary results and findings of the modelling exercise. Before this session, IRENA shared a technical memorandum with key national stakeholders. This presented the information, data and assumptions for the development of the cost-effectiveness analysis to support the implementation of Sao Tome and Principe's NDC. The validation session included a discussion with the national stakeholders, and their feedback was collected. As a result, given the methodology behind the analysis, IRENA updated some assumptions and incorporated the session inputs to the greatest extent possible. The revisions and updates have already been reflected in the report's results.

In collaboration with the Directorate of Natural Resources and Energy, a final close-out technical session was held in April 2022 to present the findings and overall results of the technical study, as well as provide insights and recommendations for the implementation phase of the country's NDC.

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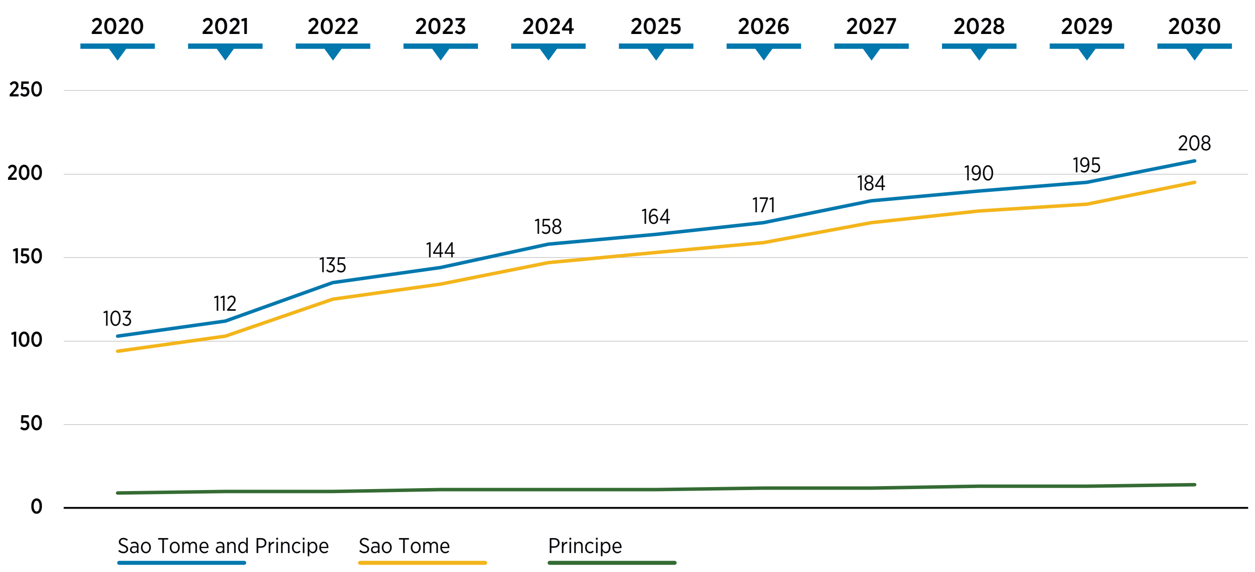
5. RESULTS

This chapter presents the results of the analysis, after the methodologies and assumptions described in the previous chapter have been applied. The first section (5.1) describes the baseline emissions scenarios and the second section (5.2) describes the GHG reduction potential of the mitigation options analysed. Lastly, the cost-effectiveness of those options is presented (5.3).

5.1 BASELINE EMISSIONS

As described in Chapter 2, the baseline scenario for the power sector was developed after considering the current generation mix in Sao Tome and Principe. The projected power sector GHG emissions in the baseline scenario are shown in Figure 15. By 2025, those emissions are estimated to have reached 164 ktCO_2 and by 2030, 208 kt CO_2.

Figure 15 Projected baseline emissions in the power sector (ktCO_2)



5.2 MITIGATION POTENTIAL IN THE POWER SECTOR

The GHG reductions resulting from the power sector mitigation options that have been analysed are presented in Figure 16. Compared to the power sector baseline, the mitigation option with the highest reduction potential for 2030 is efficient lighting (38%), followed by solar PV (27%) and hydropower (17%). Biomass and the reduction of T&D losses each resulted in a 4% GHG emissions reduction. All of these mitigation options have a high economic potential, with negative GHG emissions abatement costs, as is shown in the following section (5.3).

Taking all the renewable energy technology mitigation options together – solar PV, hydropower and biomass – there is a potential reduction of 48%, from 208 kt CO_2 to 109 kt CO_2, in 2030, compared to the baseline. Additionally, if the energy efficiency mitigation options are added to the renewable energy ones, the reduction potential would be 88% in 2030, compared to the baseline, which corresponds to a reduction in GHG emissions from 208 kt CO_2 to 25 kt CO_2.

5.3 MITIGATION POTENTIAL OF IMPROVED COOKSTOVES

The improved cookstoves measure has the largest GHG mitigation potential, with average savings of up to 192% in 2030, compared to the baseline scenario. This measure's emissions reductions increase steadily, from 40 ktCO_2/year in 2021 to 401 ktCO_2/year in 2030. These values lead to very large CO_2 savings – higher than the savings achieved by the power system measures. With the Gold Standard model default values, the annual firewood savings could amount to 88 308 tonnes, annually.

It should be noted, however, that no detailed technical information on the type of cookstoves and their use was available for this study, so those preliminary results should be taken with great caution. Additionally, the current assumptions consider the full replacement of current cooking practices by the improved cookstoves, thus assuming there is no 'fuel stacking,' *i.e.* some continuing to use their old cookstove, despite having an improved one. Field surveys could help estimate the usage rate of cookstoves, which could then impact the results.

Figure 16 Potential GHG reductions from different mitigation options, 2030 (%, kt CO_2)*

Note: *All reductions calculated in comparison to the baseline scenario.

5.4 MARGINAL ABATEMENT COST CURVES

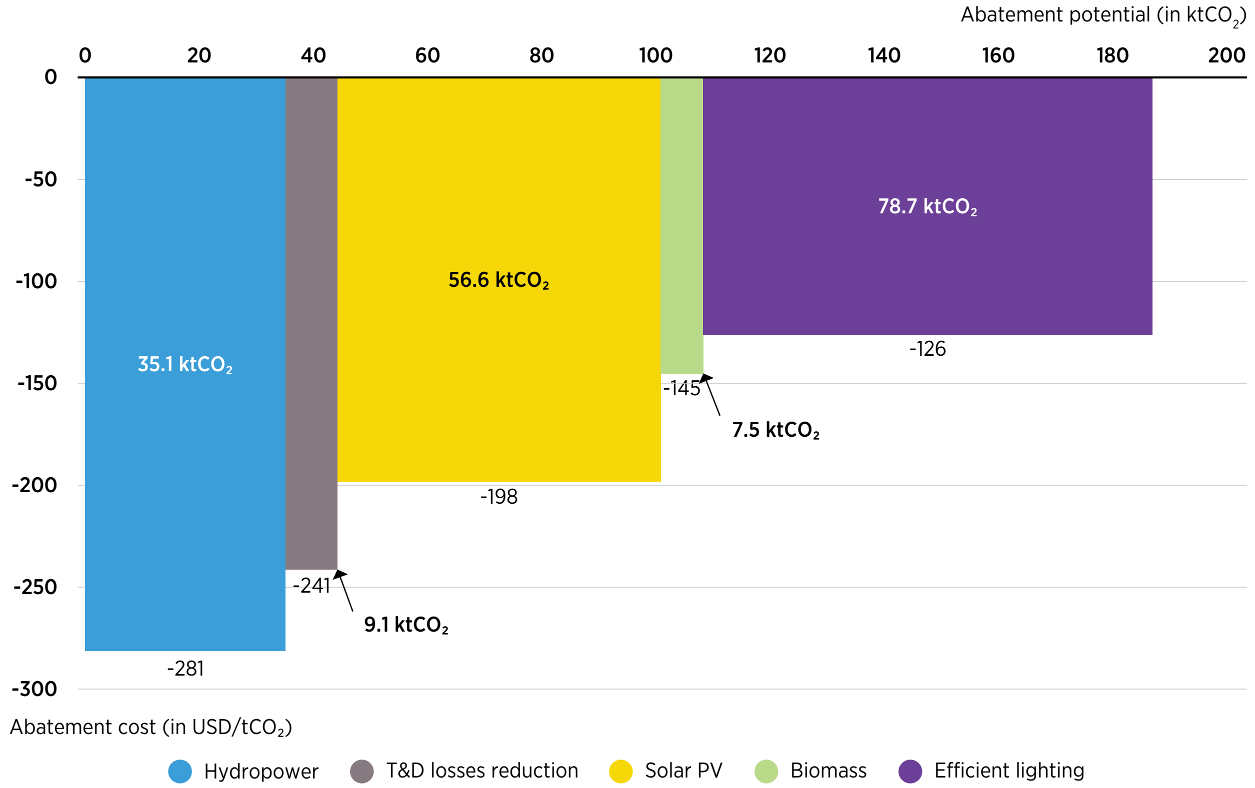
As shown in section 5.2, estimated GHG emissions reduction potential vary greatly among the mitigation options as presented in the previous section.

In Figure 17, the results of the mitigation options assessment for the year 2030 are presented using MACCs. The mitigation measures are ranked according to an increasing marginal abatement cost per tCO_2 reduction (USD/tCO_2). It is important to note, however, that the MACCs represent a visual representation of each choice being evaluated. As a result, the analysis disregards potential interactions between the options considered, as well as their probable effects on the calculated abated level of GHG emissions and its cost.

All the mitigation measures studied demonstrate a negative GHG emissions abatement cost, implying that the initial investment is converted into financial savings. The most cost-effective measure is hydropower, followed by reductions in T&D losses, solar PV capacity deployment, biomass and efficient lighting.

The GHG emissions abatement cost of hydropower is a negative USD 281/t CO_2. This is slightly lower than the second lowest-cost measure, which is reductions in T&D losses, which has an abatement cost of approximately -USD 241/t CO_2. All measures have an abatement cost ranging between -USD 126/t CO_2 and -USD 281/t CO_2, with efficient lighting having the highest cost.

Figure 17 MACCs for the year 2030



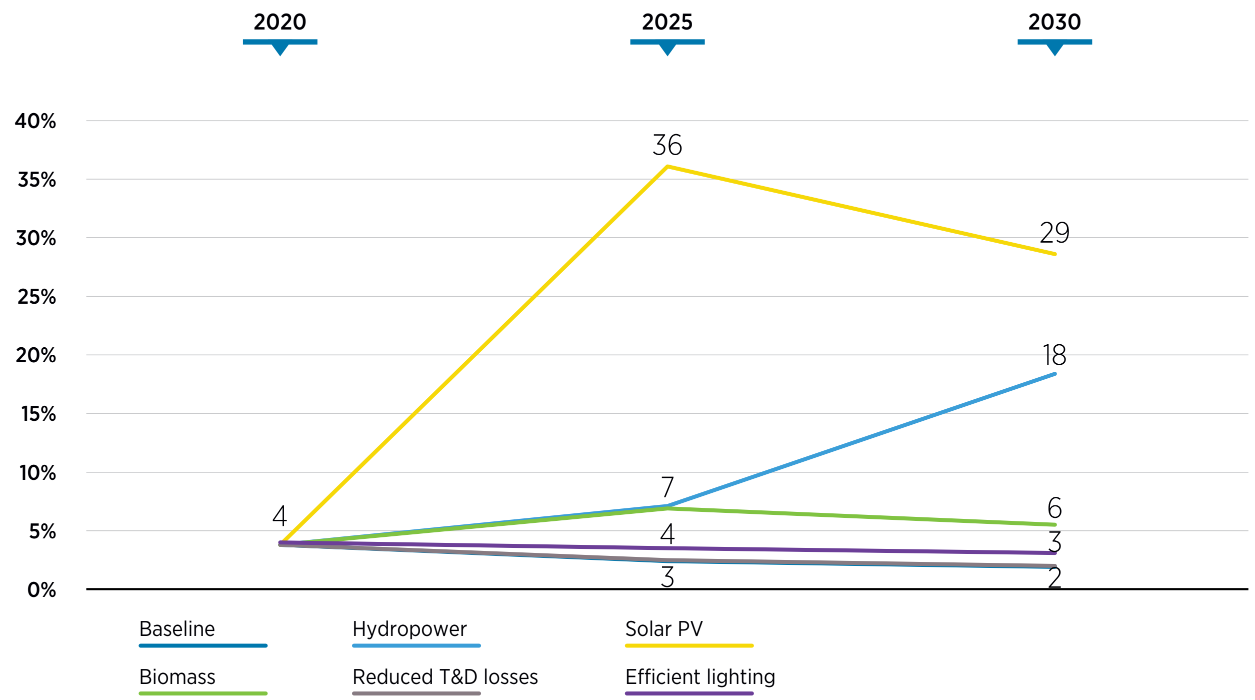
Note: T&D = transmission and distribution.

5.5 SHARE OF RENEWABLE ENERGY

This section presents the share of the electricity mix taken by renewable energy in each mitigation scenario. This study estimates that in the baseline scenario, this share would be 1.9% in 2030. This contrasts with 49% with the renewable energy options, of which 48% would be in Sao Tome and 56% in Principe.

Figure 18 presents the shares of renewable energy in the electricity generation of individual mitigation scenarios (with data points for 2020, 2025 and 2030). Figure 19 shows the shares taken by renewable energy in the aggregated mitigation scenarios “All renewables” and “Supply and demand side measures”.

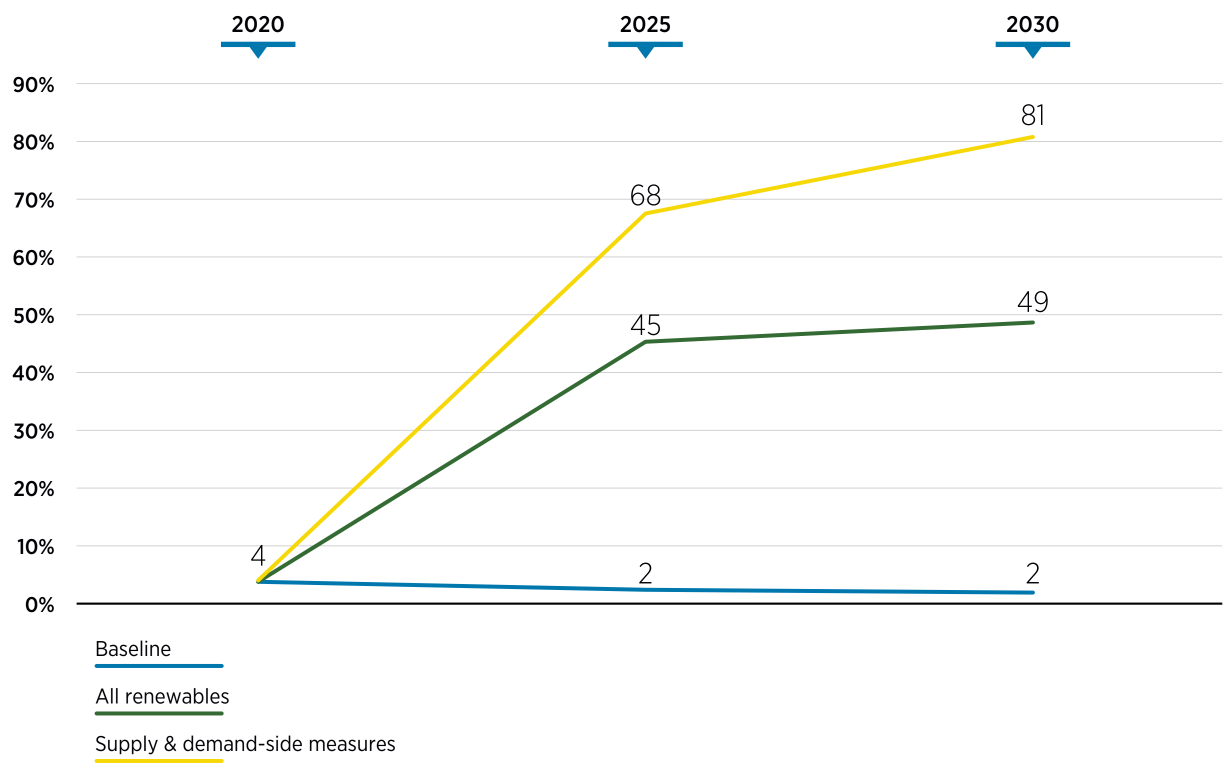
Figure 18 Share of renewable energy in electricity generation for each mitigation measure, 2020-2030 (%)



Note: T&D = transmission and distribution.

The measure with highest contribution to an increased renewable energy share, compared to the baseline, is solar PV (29% in 2030), followed by hydropower (18% in 2030). Combining energy efficiency measures (reduction in T&D losses and efficient lighting) with an increase in installed renewables allows for the highest renewable energy share in electricity generation – 81% – due to a decrease in demand.

Figure 19 Share of renewable energy in the electricity generation mix for aggregated mitigation scenarios, 2020-2030 (%)



5.6 INVESTMENT NEEDS

Today, renewable energy technologies are often the least expensive forms of new electricity generation. Since 2013, a total of 1 805 GW of renewable energy capacity has been added globally, with estimated costs lower than those of the lowest fossil fuel-fired options, including diesel fuel.

Recent fossil fuel price volatility serves as a reminder that the majority of renewables have an inherent benefit for consumers, as their production can be purchased at a fixed price for the asset's entire life. Thus, the deployment of renewable energy can help mitigate the risk of fuel price hikes, so benefiting consumers.

Generally, power generated by diesel generators costs three to four times as much as electricity supplied by the grid. This makes it unaffordable to many, including the majority of the rural population and the urban poor. These groups thus often find themselves reliant on a fuel that is not always accessible. Local renewable energy sources, however – such as solar, hydro, or biomass – can be used in place of diesel, thereby reducing negative environmental and health impacts while also stimulating local economic development. Renewable energy advances, combined with a dramatic drop in the cost of components such as solar PV panels, have enabled renewable energy-powered systems to compete with diesel on price, while also providing cleaner, more reliable and quieter operation.

Regarding the efficient lighting measure, the investment costs for LED lightbulbs are higher than incandescent light bulbs, but due to the significant reduction in electricity demand that results from replacing incandescent lightbulbs with LED lightbulbs, this mitigation option still generates cost savings. Additionally, LED lightbulbs have a higher lifetime than incandescent ones. Consequently, significantly more incandescent light bulbs are required to deliver the same number of lighting hours, as they need to be replaced more often.

The investment needs up to 2030 associated with each mitigation option are presented in Table 13.

Table 13 Estimated investment costs of mitigation measures

REFERENCE	MITIGATION MEASURE	DESCRIPTION	ESTIMATED INVESTMENT NEEDS (USD MILLION)
A	Hydropower	15.5 MW of additional hydropower capacity	19.7
B	Solar PV	46.95 MW of utility-scale solar PV capacity	60.9
C	Biomass	4.68 MW of biomass capacity	8.9
D	Reduced T&D losses	Reduction of transmission and distribution losses to 30%	13.5
E	Energy-efficient lighting	Replacement of incandescent light bulbs with LEDs	3.0
	Total		**106**

Notes: LED = light emitting diode; MW = megawatt; T&D = transmission and distribution.

The mitigation option that requires the highest investment is solar PV, at around USD 60.9 million, followed by hydropower and biomass. The total investment estimate is approximately USD 106 million.

5.7 SENSITIVITY ANALYSIS

Consisting of a 'what if?' analysis of all important assumptions, uncertain model parameters and inputs, sensitivity analysis is a crucial component of quantitative and qualitative risk assessment. Its goal is to determine how sensitive model outputs are to changes in inputs and how that sensitivity may alter decisions. In the context of this study, the cost-effectiveness analysis of each mitigation option is highly dependent on the assumptions made about cost and other parameters. Thus, sensitivity analyses were conducted on those key assumptions.

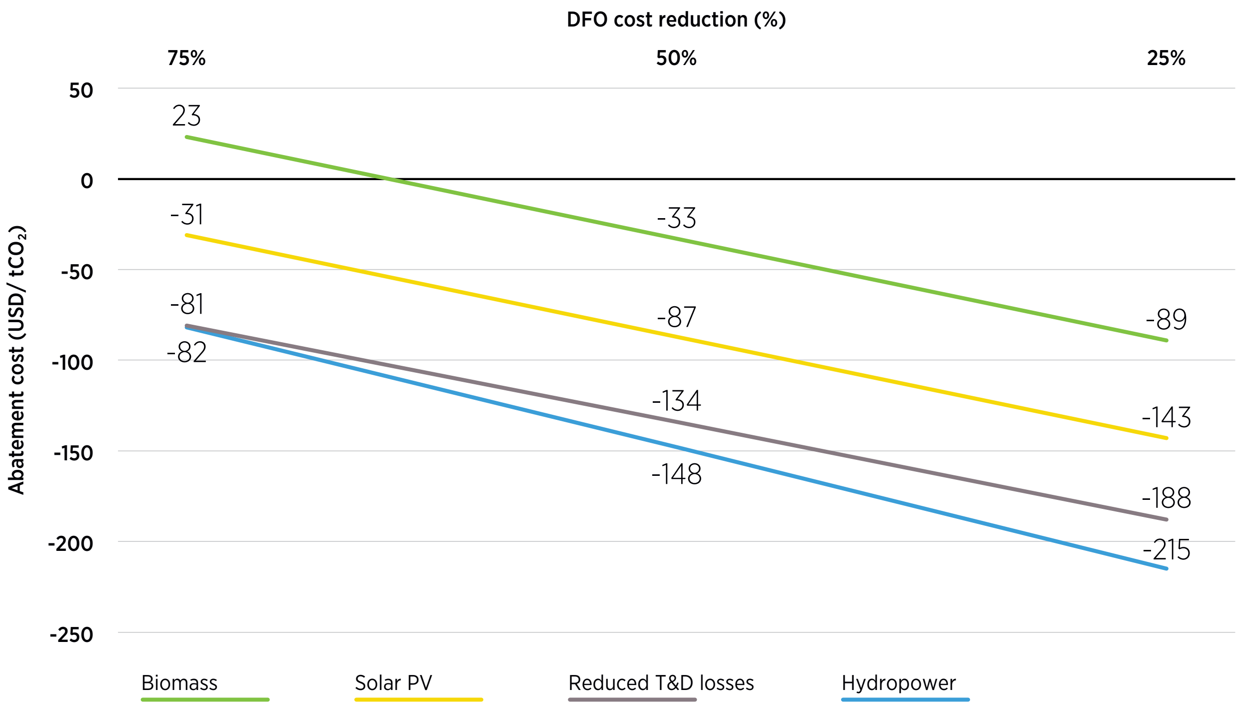
Reference options assumptions

DFO cost

Four mitigation options are based on comparisons with the DFO reference scenario. This indicates that a decrease in the price of DFO would make those options less cost-effective. On the other hand, if the DFO price increases, those mitigation options would present even lower abatement costs (*i.e.* higher savings). Sensitivity analyses with lower fuel prices of DFO were therefore conducted, to assess if the measures would remain cost-effective.

As explained in the methodology chapter, the fuel price for DFO was estimated at USD 15.86/MBtu in 2020, using a cost trend curve with a growth of 2% per year. The DFO price was therefore reduced by 75% (to USD 3.97/MBtu), 50% (USD 7.93/MBtu), and 25% (USD 11.90/MBtu). Figure 20 summarises the abatement costs in 2030 as a result of this sensitivity analysis. The results indicate that even with a 75% decrease in DFO prices, all the mitigation options remain cost-effective, with the exception of the biomass option.

Figure 20 Sensitivity analyses of mitigation options with DFO-generated electricity as reference solution



Incandescent light bulb cost

For the mitigation option of replacing all incandescent light bulbs with LEDs, a sensitivity analysis was performed on the incandescent light bulb cost, which was set at a base rate of USD 1.00. Sensitivity analyses were conducted using costs per light bulb that were 75%, 50% and 25% lower, to assess if this would result in the option having positive abatement costs in 2030, or would remain cost-effective. The results are shown in Table 14.

Table 14 Sensitivity analysis of the efficient lighting mitigation option

MITIGATION OPTION	ABATEMENT COST (USD/tCO_2) AT INCANDESCENT LIGHT BULB COST OF USD 0.25/BULB	ABATEMENT COST (USD/tCO_2) AT INCANDESCENT LIGHT BULB COST OF USD 0.50/BULB	ABATEMENT COST (USD/tCO_2) AT INCANDESCENT LIGHT BULB COST OF USD 0.75/BULB
Efficient lighting	-59	-82	-104

These sensitivity analyses show that the results regarding the cost-effectiveness of mitigation option are robust. In all but one measure (biomass), they retain negative abatement costs, even when the cost parameters in the reference scenarios are significantly reduced.

Renewable energy technology assumptions

Hydropower costs and capacity factors

The costs for hydropower validated by the country are significantly lower than the costs in IRENA's *Renewable Power Generation Costs in 2021* (IRENA, 2022). Additionally, the capacity factor considered in the analysis is lower than the values in the same IRENA report. Thus, a sensitivity analysis was conducted on these parameters, to assess the influence of different costs and capacity factors in the abatement cost of the hydropower measure.

As described in the methodology chapter, the CAPEX for hydropower was estimated at USD 1 138.1/kW, the OPEX at 0.5% of estimated CAPEX and the capacity factor at 32%. The abatement cost of this measure is a negative USD 281/t CO_2.

In the IRENA database, small hydropower projects in Africa during the period 20162021 presented weightedaverage installed costs of USD 3 514/kW. The 5th percentile presents total installed costs of USD 2 580/kW and the 95th, USD 5 028/kW. For the same type of projects in Africa, the weighted average of capacity factors was 55%. The 5th percentile presents a capacity factor of 51% and the 95th of 65%. Regarding the OPEX of hydropower projects, global values range from 1% to 4% of installed costs (IRENA, 2022). Thus, sensitivity analyses with these values were conducted, to assess their impact on the abatement cost of the hydropower mitigation option for 2030 (Table 15).

Table 15 Sensitivity analyses of the hydropower mitigation option with CAPEX, OPEX and capacity factor changes

PARAMETER ANALYSED	UNIT	PARAMETER VALUES	ABATEMENT COST (USD/tCO_2)
CAPEX	USD/kW	2 580	-249
		3 514	-228
		5 028	-194
OPEX	% of estimated CAPEX	1	-278
		2.5	-269
		4	-261
Capacity factor	%	51	-278
		55	-278
		65	-277

Furthermore, two sensitivity analyses with simultaneous changes in more than one variable were performed (Table 16). The first considered variations in CAPEX and OPEX, with values of USD 3 514/kW and 2.5% respectively, while the second considered variations in CAPEX, OPEX and the capacity factor, with values of USD 3 514/kW, 2.5% and 55% respectively.

Table 16 Sensitivity analyses of the hydropower mitigation option with multiple variable changes

PARAMETER ANALYSED	PARAMETER VALUES			
	ESTIMATED CAPEX (USD/kW)	OPEX (% OF ESTIMATED CAPEX)	CAPACITY FACTOR (%)	ABATEMENT COST (USD/tCO_2)
CAPEX and OPEX	3 514	2.5	32	-193
CAPEX, OPEX and capacity factor	3 514	2.5	55	-229

As shown in Table 15, the changes in OPEX and in capacity factor values do not significantly impact the abatement cost of the hydropower option. The CAPEX variations would, however, result in considerably lower abatement costs. The impact would be even greater in the case of a simultaneous increase of CAPEX and OPEX, as seen in Table 16.

Yet, despite some significant impact on the abatement cost of the hydropower measure, all changes to the CAPEX, OPEX and capacity factor values still result in negative abatement costs – proving that the measure is robust.

Biomass capacity factor

The biomass capacity factor considered in this study was 23%, with the biomass mitigation measure presenting a 2030 abatement cost of -USD 145/t CO_2. The capacity factors for bioenergy fired power generation projects in 20002021 recorded in IRENA's database (IRENA, 2022) present a significant range and are higher than the estimate in this study. IRENA (2022) presents specific values for China, Europe, India, North America and the 'rest of the world'. Sensitivity analyses were conducted using the 'rest of the world' values that correspond with the 5th percentile (35%), the weighted average (67%) and the 95th percentile (92%). The results are shown in Table 17.

Table 17 Sensitivity analyses of the biomass mitigation option

MITIGATION OPTION	ABATEMENT COST (USD/tCO_2) AT A CAPACITY FACTOR OF 35%	ABATEMENT COST (USD/tCO_2) AT A CAPACITY FACTOR OF 67%	ABATEMENT COST (USD/tCO_2) AT A CAPACITY FACTOR OF 92%
Biomass	-187	-224	-235

Source: ©Xinovap/Shutterstock.com

An increase in the biomass capacity factor would result in lower abatement costs in 2030 – *i.e.*, in higher cost savings.

Demand-side options assumptions

Cost of electricity service

The cost savings of the efficient lighting option were calculated based on the average cost of the electricity service, which was estimated at USD 54.13/MWh in 2020. Table 18 shows the results of a sensitivity analysis conducted on this cost, considering the higher values for household and commercial buildings (EMAE, 2022).

Table 18 Sensitivity analyses of the efficient lighting mitigation option with rising electricity costs

MITIGATION OPTION	ABATEMENT COST (USD/tCO_2) AT AN ELECTRICITY COST OF USD 72.40/MWh	ABATEMENT COST (USD/tCO_2) AT AN ELECTRICITY COST OF USD 106.21/MWh	ABATEMENT COST (USD/tCO_2) AT AN ELECTRICITY COST OF USD 166.47/MWh
Efficient lighting	-145	-179	-240

Notes: MWh = megawatt hour; tCO_2 = tonne of CO_2.

As expected, a higher cost of electricity services results in higher cost savings, which then translates into lower abatement costs.

6. DISCUSSION

The cost-effectiveness analysis was conducted using the MACC methodology, with this document including the relevant technological, economic and financial assumptions used. This methodology can be an effective tool in assisting with climate policy decision-making because it provides information on the potential for GHG abatement and the associated costs of the policies and technology options evaluated. The results of this analysis provide valuable information for prioritising appropriate mitigation measures to meet the country's targets. This type of analysis can be critical in the implementation of the new NDC, as well as informing decision makers about potential pathways to increase renewable energy deployment and energy access.

Yet, the MACC methodology does have some limitations and should be used in conjunction with other cost-benefit analyses to assist in climate policy decision-making. MACCs also serve as a visual representation and must be updated to reflect future policy adjustments, as they evaluate each solution independently and do not account for potential interactions or their likely impact on the abated GHG emissions and costs.

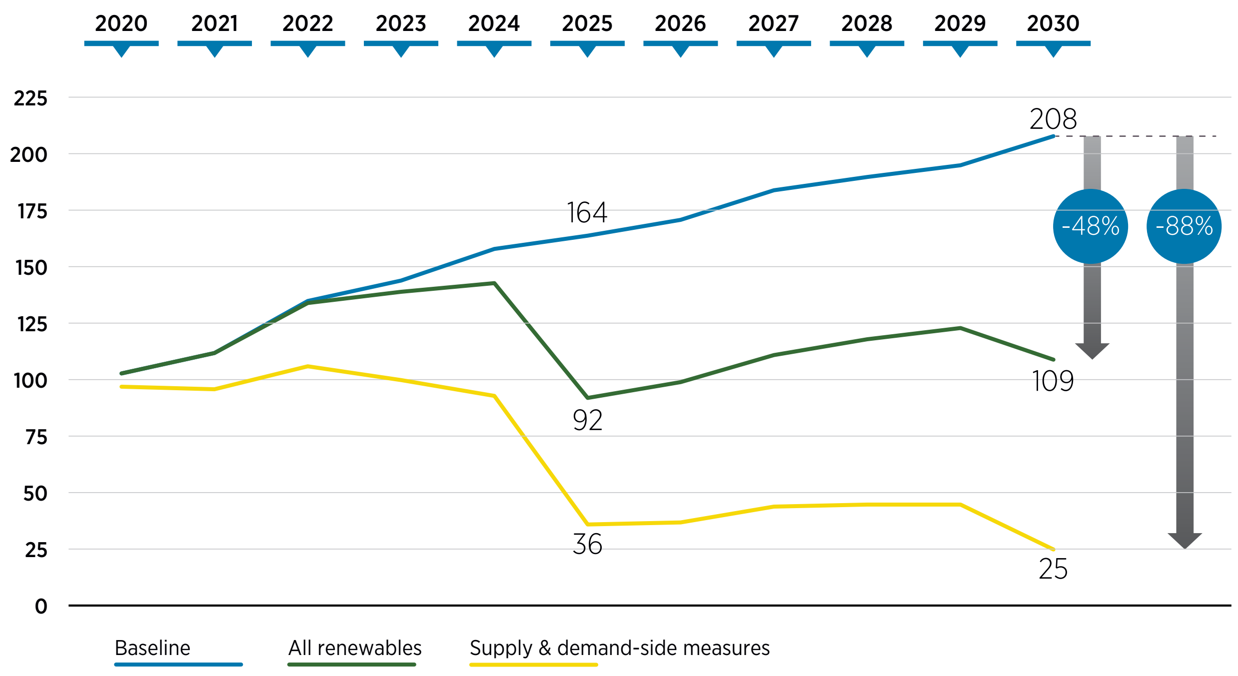
All the mitigation measures considered have a negative GHG abatement cost, indicating that emissions can be reduced while generating economic benefits.

To conduct the cost-effectiveness analysis, a baseline and a mitigation scenario were established. The demand estimation methodology was revised using best practices, and the data were benchmarked against local sources. The generation capacity and timeline were compared to those provided by official sources in the country, and a least-cost dispatch strategy was used. Mitigation options were chosen from the NREAP and NEEAP, as well as from other national plans and programmes, along with the most recent available data. Individual mitigation measures were evaluated using country-specific technical and financial data, with all data compared to available local or regional sources. The revised hypotheses were discussed with national stakeholders during a workshop session in February 2022, following a thorough analysis of the available literature.

Cookstoves have the greatest potential for reducing GHG emissions. Given the scarcity of available data, however, these findings should be interpreted cautiously. In the power sector, hydropower is the most cost-effective measure, followed by reductions in T&D losses, solar PV, biomass and efficient lighting. The aggregated scenario ("Supply & demand-side measures") allows a GHG emissions reduction of up to 88% in 2030 compared to the baseline scenario, which is significantly higher than the aggregated scenario, "All Renewables", due to savings on the demand-side (Figure 21).

It is worth noting in this context that the total mitigation potential does not equal the sum of the mitigation potentials of all the individual measures. Mitigation measures in the power sector have an effect on 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 costs of production. Thus, the model output varies depending on whether each measure is considered separately or in aggregate, with the latter expected to result in a significant decline in demand and a less carbon-intensive fuel mix.

Figure 21 Projected emissions in the baseline and aggregated scenarios (kt CO_2)



Note: $ktCO_2$ = kilotonne of CO_2.

Additionally, it is worth noting that MACCs typically do not account for ancillary benefits. These include improved social, environmental and other conditions, such as improved health, local job creation, energy independence and increased resilience. MACCs also do not typically account for indirect costs (Ibrahim and Kennedy, 2016). This analysis considers only the direct costs associated with infrastructure investment and operations. This aspect may be critical for the NDC's implementation phase.

The study also includes an estimate of the investment required to implement each mitigation measure considered. This information was omitted from the country's updated NDC, which contained only an estimate of the total investment cost. Detailed costing is critical for determining the funding requirements for meeting the NDC commitments and achieving Sao Tome and Principe's climate targets. Cost estimates can assist policy makers in making informed decisions and strengthening the NDC implementation plan. They can also assist in developing a credible financing strategy that will attract potential investors and/or public funding sources. This is particularly relevant in light of the fact that Sao Tome and Principe's NDC is fully conditional.

The assessed costing estimates indicate that significant financial resources will be required to achieve the emission reduction targets. This funding can come from a variety of sources: public and private, domestic and international. Identifying and selecting relevant financing sources is a critical step in implementing the NDC. Climate funds such as the GCF and the GEF are international public funding sources. Financing can also be obtained through bilateral or multilateral channels. Private financing includes asset finance and venture capital.

Sensitivity analyses were conducted on the different assumptions used in the study in order to assess their impact on the abatement costs of the different mitigation measures. For some renewable energy technology assumptions, the estimates in this study were significantly different from the data in IRENA (2022). In these instances, sensitivity analyses were performed, evaluating the impact of using IRENA's cost data on the cost-effectiveness of measures. It is worth noting that the data retrieved from IRENA (2022) is regional or global and comes from projects commissioned from 2016 (for hydropower) and 2000 (for bioenergy). These data are therefore not specific to Sao Tome and Principe. Additionally, the cost assumptions used in the analysis were validated by the country. Nevertheless, all changes considered in the sensitivity analyses resulted in negative abatement costs for these mitigation options.

7. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to evaluate the mitigation measures communicated by Sao Tome and Principe in their NDC, NREAP and NEEAP in terms of their cost-effectiveness, investment costs and potential to reduce GHG emissions.

The study concluded that all the mitigation measures examined have a negative abatement cost, implying that if implemented, they would result in cost savings relative to the baseline scenario. The aggregated scenario that considers all power mitigation measures in this study presents a GHG emissions reduction potential of up to 88% in 2030, compared with the baseline. The total investment required to implement all measures is estimated to be USD 106 million.

According to the analysis, the most cost-effective measure (*i.e.* the measure with the highest cost savings per abated kt of GHG emissions) is hydropower, followed by a reduction of T&D losses, solar PV, biomass and finally, efficient lighting. This is illustrated in Table 19, along with the estimated investment costs for each measure.

Table 19 Abatement and investment costs of the mitigation measures analysed

MITIGATION OPTION	ABATEMENT COST (USD/ktCO_2)	INVESTMENT COST (USD MILLION)
Hydropower	-281	19.7
Reduced T&D losses	-241	13.5
Utility-scale solar PV	-198	60.9
Biomass	-145	8.9
Energy-efficient lighting	-126	3.0

Notes: ktCO_2 = kilotonne of CO_2; T&D = transmission and distribution.

The most effective mitigation option for reducing GHG emissions is efficient lighting, followed by solar PV and hydropower. These measures have the potential to cut GHG emissions by 38% (efficient lighting), 27% (solar PV) and 17% (hydropower), respectively, in 2030, when compared to the baseline scenario. The remaining mitigation measures (biomass and reduction of T&D losses) have the potential to reduce GHG emissions by less than 5% each over the same time period. Additionally, the study concludes that implementing all the renewable energy technology measures could result in a reduction of up to 48% in GHG emissions in 2030, when compared to the baseline scenario.

Source: Vladimka production/Shutterstock.com

Concerning the mitigation measure of improved cookstoves, the analysis indicates that implementing improved cookstoves could result in a significant reduction in GHG emissions (up to 192% of power sector emissions by 2030, when compared to the baseline). It is critical to note, however, that due to the lack of detailed technical information on the type of cookstoves and their uses, these results should be interpreted with extreme caution. Similarly, cost data for cookstoves were unavailable and thus no cost estimations were conducted for this measure.

IRENA recommends that Sao Tome and Principe implement a strategy based on Nationally Appropriate Mitigation Actions (NAMAs) to further investigate the mitigation potential that improved cookstoves could bring to the country. NAMAs refer to any action that reduces emissions in developing countries that is undertaken as part of a national government initiative. They can be policies aimed at transforming an economic sector or cross-sectoral actions with a broader national scope. NAMAs are backed and enabled by technology, financing and capacity building, and they aim to achieve a reduction in emissions in 2020 relative to 'business as usual' emissions (UNFCCC, n.d).

Given that the study demonstrates that all measures are economically and environmentally viable, it is suggested that Sao Tome and Principe produce a detailed implementation plan. This should include an analysis of the investment requirements across various sectors, funding sources, implementation timelines and actions, measurable milestones, responsible parties for implementation, opportunities identified and barriers to implementation.

A risk assessment that identifies implementation risks and roadblocks is also recommended. This assessment should also assist in identifying implementation requirements, such as technology and investment needs, capacity building, organisational and regulatory requirements, supporting policies and measures, and incentive structures. Because Sao Tome and Principe is vulnerable to climate change, it is suggested that the risk of extreme weather events and their impact on electrical infrastructure also be assessed. Droughts, for example, have an impact on electricity generation, while T&D equipment can be harmed by rising sea levels, greater precipitation and flooding, as well as by rising temperatures. Increasing climate resilience by assessing the risks of implementing these measures and determining the needs needed to reduce those risks may result in future savings.

During the development of a formal NDC implementation plan, there are a number of steps that are recommended. It can be beneficial, for example, to assess human and technical capacity needs and do a stocktake of existing capacity gaps that must be addressed to meet the capacity requirements for each activity involved in implementing the NDC.

It is also worth noting the importance of having a co-ordination body to lead the process of overseeing the NDC, as well as to manage and enhance co-operation within the government. Another important step involves reviewing the current institutional framework within the country and addressing necessary changes in responsibilities or roles to strengthen the existing institutional structures. This is a responsibility that can fall under the co-ordination body, which can include mapping existing structures that are critical for NDC implementation and identifying current responsibilities and co-ordination mechanisms among them, followed by assessing the need to enhance these structures.

The institutional framework created should include: a focus on establishing procedures to engage public and external stakeholders and facilitate dialogue; the creation of accountability mechanisms to facilitate co-operation and the participation of governmental and nongovernmental stakeholders; and the involvement of the perspectives of women and minorities.

Additionally, the legal and regulatory framework should be reviewed to ensure that the current mechanisms and instruments can help support and advance NDC implementation. This includes reviewing laws, acts and administrative rulings related to public policy on climate change. It may be necessary to adopt new regulations, pass new laws or implement new measures to attract financing.

All of the actions described above, as well as stakeholder engagement activities, and the identification and prioritisation of specific adaptation and mitigation measures, lay the ground for the development of an NDC implementation plan. Once this plan is created, monitoring its progress constitutes an essential step that may include strengthening data collection practices and ensuring transparency throughout the reporting of progress. For mitigation measures specifically, this process could include updating national GHG inventories and BAU scenarios regularly, in order to assess the need of additional GHG emissions reductions to meet climate targets and analyse the impacts of implementing policies.

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9. APPENDICES

APPENDIX A: DOCUMENTS REVIEWED

Table 20 Documents reviewed to identify mitigation measures in the power sector

TITLE	YEAR OF PUBLICATION
Sao Tome and Principe's INDC	2015
Sao Tome and Principe's NDC	2021
National Renewable Energy Action Plan (NREAP)	2022
National Energy Efficiency Action Plan (NEEAP)	2022
Sao Tome and Principe's Third National Communication	2019
Inventory Report on Greenhouse Gases in the Energy Sector for the Period 2010-2019	2021
Renewable Energy and Energy Efficiency in Sao Tome and Principe – National Status Report	2020
Energy Policy and Data Gaps Analysis Report	2021
Energy Access Diagnostic Report Based on the Multi-Tier Framework	2019
EMAE report, balance and accounts	2019
EMAE report, balance and accounts	2020
Least Cost Development Plan for Sao Tome and Principe	2018
Strategic Environmental Evaluation of the hydropower potential in Sao Tome	2021
Technology Action Plan for Mitigation	2021
Technology Needs Assessment Report on Barrier Analysis & EnablingFramework (Ba&Sf) for Mitigation (*Relatório De Avaliação Das Necessidades Tecnológicas Sobre Análise Das Barreiras & O Enquadramento Estrutural (Ba&Ef) Para A Mitigação*)	2020
Sao Tome and Principe NDC Implementation Plan	2020

APPENDIX B: MITIGATION ANALYSIS

Table 21 GHG reduction potential of mitigation options

MITIGATION OPTION	DESCRIPTION	SOURCE	GHG EMISSIONS REDUCTION POTENTIAL (KT CO_2) 2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	TOTAL ABSOLUTE GHG EMISSIONS REDUCTIONS 2020-2030 VERSUS BASELINE
Hydropower	17.3 MW of hydropower capacity deploymefiguregurent by 2030	NREAP	0	0	0	2.9	5.4	7.9	7.9	7.9	7.9	7.9	35.1	83.2
Solar PV	46.98 MW of utility-scale PV capacity deployment by 2030	NREAP	0	0	0.7	2.6	10.2	56.6	56.6	56.6	56.6	56.6	56.6	353.3
Biomass	4.68 MW of biomass capacity deployment by 2030	NREAP	0	0	0	0	0	7.5	7.5	7.5	7.5	7.5	7.5	45.1
All renewables	Aggregated renewables capacity	NREAP	0	0	0.7	5.5	15.6	72.1	72.1	72.1	72.1	72.1	99.3	481.5
T&D losses reduction	Grid losses reduction to 30% by 2030	NEEAP	0.4	0.9	1.6	2.3	3.2	.0	4.8	5.9	6.9	7.8	9.1	46.9

MITIGATION OPTION	DESCRIPTION	SOURCE	GHG EMISSIONS REDUCTION POTENTIAL (KT CO_2) 2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	TOTAL ABSOLUTE GHG EMISSIONS REDUCTIONS 2020-2030 VERSUS BASELINE
Efficient lighting	Substitute incandescent light bulbs by 2030	NEEAP	5.4	16.0	26.5	37.1	47.6	52.8	58	63.1	68.3	73.5	78.7	527.0
Supply and demand-side measures	Aggregated renewables and energy efficiency options (excluding cookstoves)	NREAP/ NEEAP	5.8	16.8	28.6	44.4	65.5	127.6	133.3	139.2	144.9	150.5	183.7	1 040.2
Cookstoves	Distribute 39 600 improved cookstoves by 2030	NEEAP		40.3	80.5	120.7	160.8	200.9	241	280.9	320.9	360.7	400.6	2 207.4

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