IRENA
International Renewable Energy Agency

SAINT KITTS AND NEVIS

ASSESSMENT OF COST-EFFECTIVE MITIGATION OPTIONS TO INFORM THE UPDATE OF THE NDC

Technology
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CLIMATE ACTION SUPPORT

About IRENA

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About this document

This technical report summarises the main outcomes and findings of the assessment of cost-effectiveness of mitigation options in Saint Kitts and Nevis and evaluates the potential to reduce greenhouse gas emissions through the implementation of different energy sector measures to inform the update of the Nationally Determined Contribution.

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ACRONYMS AND ABBREVIATIONS

BECCS	bioenergy with carbon capture and storage
BTM	behind-the-meter
Btu	British thermal unit
CAPEX	capital expenditure
CARICOM	Caribbean Community
CCS	carbon capture and storage
CO_2	carbon dioxide
COP	Conference of the Parties
DFO	diesel fuel oil
EU TAF	European Union Technical assistance facility
EV	electric vehicle
Gg CO_2	gigagrammes of carbon dioxide
GHG	greenhouse gas
GJ	gigajoule
Gt CO_2	gigatonne of carbon dioxide
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
km	kilometre
kW	kilowatt
kWh	kilowatt hours
L	litre
MACC	marginal abatement cost curve
MBtu	million British thermal units
MW	megawatt
MWh	megawatt hours
NDC	Nationally Determined Contribution
NEVLEC	Nevis Electricity Company Limited
OPEX	operational expenditure
PV	photovoltaic
SKELEC	St Kitts Electricity Co Ltd
t CO_2	tonne of carbon dioxide
T&D	transmission and distribution
TJ	terajoule
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
V2G	vehicle-to-grid

EXECUTIVE SUMMARY

Saint Kitts and Nevis, officially the Federation of Saint Christopher and Nevis, is a two-island state in the Caribbean and the smallest country in the Americas in both land area and population, with approximately 53 000 people. Saint Kitts, the larger island, is located two miles away from Nevis across a shallow channel called The Narrows. Like many islands within the region, climate change threatens the twin islands, from rising sea levels to natural disasters and coastal erosion.

Saint Kitts and Nevis submitted its first Nationally Determined Contribution (NDC) in 2016, as a key contribution tool for the objectives of the Paris Agreement on climate change mitigation and adaptation. The country's NDC addresses all economic sectors, but focuses on energy and transportation, which account for most of the country's greenhouse gas (GHG) emissions. Measures to increase renewable energy sources and reduce energy consumption, as well as actions for water, agriculture and coastal infrastructure, are outlined in the NDC. The country has stated an emissions reduction target of 22% of Saint Kitts and Nevis GHG emissions projected in the business-as-usual scenario for 2025 and 2030, and 35% in the scenario for 2030. Saint Kitts and Nevis' NDC is conditional and based on the availability of financing and technological support.

Saint Kitts and Nevis has requested support from the International Renewable Energy Agency (IRENA) in delivering an assessment of the cost-effectiveness of mitigation options for the power and transport sectors. The analysis is based on the marginal abatement cost curve methodology, where each mitigation action is assessed based on both the GHG abatement potential and its associated costs. This technical report summarises the main outcomes and findings of the assessment and evaluates the potential to reduce GHG emissions through the implementation of different energy sector measures. This assessment aims to inform the update of the NDC, and to provide recommendations for setting GHG reduction targets.

The analysis followed established methodologies and was based on data acquired at the national level. The recommendations were validated with country officials to ensure their validity considering national climate action plans. The steps in the analysis included the following:

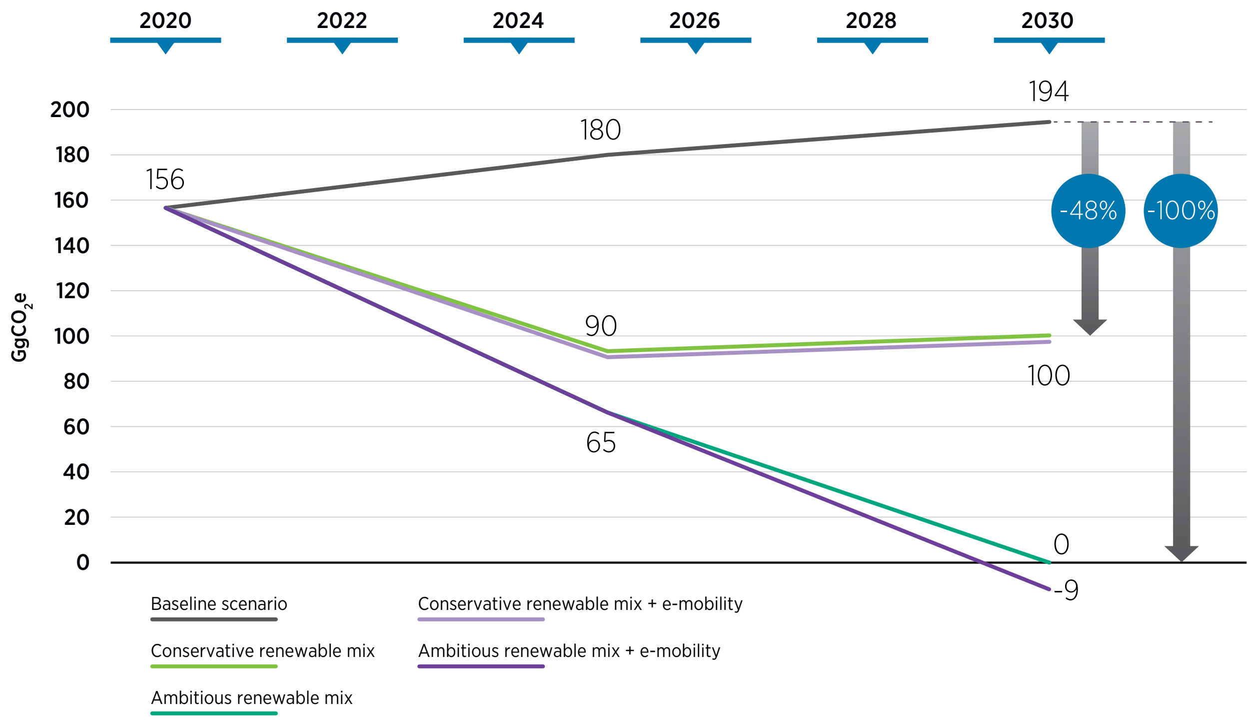
- building a set of six mitigation options for the power sector in consultation with national key stakeholders
- revising demand projections, based on the latest St Kitts Electricity Co Ltd (SKELEC) and Nevis Electricity Company Limited (NEVLEC) data and Deloitte (2017)
- developing an energy model, considering the latest data with operating capacities on both grids and information about planned decommissioning dates
- using a simplified dispatch model based on the merit-order effect
- revising emissions factors, based on the latest United Nations Framework Convention on Climate Change (UNFCCC) data, specific to each island
- analysing the electrification of the transport sector as a sector coupling option.

In the power sector, a total of six mitigation options have been identified. In addition, three aggregated alternatives were created by combining various individual mitigation options based on project maturity and potential island interconnection. Two alternatives were evaluated for the transport sector analysis, using different baselines, and analysing the subsector through the introduction of emobility via sector coupling. National plans and strategies were used to identify measures, which included a stakeholder consultation process that took place over two technical workshops between April and June 2021.

MITIGATION OPTION	DESCRIPTION	TARGET YEAR
Geothermal power plants	Installation of **25 megawatts (MW) of geothermal power capacity** additions with 10 MW in Nevis by 2025 and 15 MW in Saint Kitts by 2030.	2025 2030
Utility-scale solar PV	Installation of **35.7 MW of utility-scale solar photovoltaic (PV) capacity** additions in Saint Kitts by 2023.	2023
Grid efficiency	Transmission and distribution loss reductions of **10%** in Saint Kitts and **6%** in Nevis by 2030.	2030
Onshore wind power	Development of **6.6 MW of wind power capacity** additions in Saint Kitts by 2024.	2024
Solar water heating systems	Reduction of **5% in the electricity demand** with the introduction of solar water heating systems in Saint Kitts and Nevis by 2030.	2030
Solar PV-powered desalination plans	Additions of **two solar PV plants of 0.75 MW** each to supply two desalination plants, one in Saint Kitts and one in Nevis, by 2030.	2030
Emobility	Achieve **10% fuel savings**, compared with the baseline scenario, with the deployment of emobility in Saint Kitts and Nevis by 2030.	2030

As illustrated by Figure 1, the adoption of all mitigation options in the power sector "Ambitious renewable mix" would eliminate GHG emissions, achieving a decarbonised power mix by 2030. Furthermore, the incorporation of sector coupling alternatives in the transport subsector, the "Ambitious renewable mix with emobility" alternative, demonstrates that by substituting 10% of gasoline usage with electric vehicles, GHG emissions may be decreased by an additional 9 gigagrammes of carbon dioxide (Gg CO_2) in 2030. These emissions reductions, based on national plans and measures identified by national officials, are higher than the NDC commitments made in 2016. They thus provide a clear foundation for increasing climate change mitigation ambition in Saint Kitts and Nevis, as well as a concrete set of activities to achieve such ambition.

Figure 1: Reduction in total GHG emissions estimated from the implementation of mitigation options in 2030 compared with a baseline scenario



Box 1: Saint Kitts and Nevis' first updated NDC

On 25 October 2021, Saint Kitts and Nevis submitted its updated NDC to the United Nations Framework Convention on Climate Change. The updated NDC is significantly more ambitious than the initial. One of the most significant additions to the country's mitigation commitments is addressing CO_2 emissions from the energy sector, which accounts for most national emissions, particularly from power generation and transport sectors. By 2030, the country intends to generate 100% of its electricity from renewable sources, optimize transmission and distribution, begin electrifying its vehicle fleet, and develop electric vehicle infrastructure. IRENA collaborated with the Government to identify, quantify, and rank mitigation measures in the energy and transport sectors. The assessment's findings bolstered Saint Kitts and Nevis' case for establishing a decarbonization pathway for the power sector, as well as cross-sectoral mitigation strategies such as the introduction of electric vehicles.

1. INTRODUCTION

Saint Kitts and Nevis submitted its first Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016. Nationally Determined Contributions (NDCs) are national climate action plans and serve as the backbone of the Paris Agreement, which was adopted by 197 member states of the UNFCCC in 2015, and thereby committing to pursue the necessary efforts to keep global warming at 1.5°C. NDCs include mitigation actions and, in most cases, adaptation actions that a country takes to stay in line with the goals of the Paris Agreement. A key principle of the Paris Agreement is that NDCs are to be revised, updated and enhanced every five years. Numerous countries updated their NDCs in preparation to submit them to the UNFCCC prior to the 26th Conference of the Parties (COP) in Glasgow in November 2021.

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

This technical analysis is undertaken by the International Renewable Energy Agency (IRENA) with support from the European Union Global Technical Assistance Facility for Sustainable Energy (EU TAF) as an effort to support Saint Kitts and Nevis in the process of revising and updating its NDC.

The marginal abatement cost curve (MACC) methodology is employed to perform the cost-effectiveness assessment. MACC is a useful tool to support climate policy decision-making as it informs on the greenhouse gas (GHG) abatement potential and associated costs of the policies and technology options assessed. A three-step process is required to evaluate the cost-effectiveness of mitigation measures. The first step is the development of a baseline or "business as usual" scenario that projects emissions into the future without the implementation of any mitigation options that aim to reduce GHG emissions of the power and transport sectors of Saint Kitts and Nevis. The purpose of the baseline scenario is to act as a reference against which the GHG emissions reduction potential of mitigation options can be evaluated. The second step is the identification and revision of mitigation options. A mitigation option is a specific action undertaken in a specific GHG emission source sector with the goal of reducing GHG emissions from that sector. This step is key to be implemented and validated by national stakeholders. Finally, the third step of the cost-effectiveness analysis is to model the validated mitigation options and analyse their associated GHG emission reductions, as well as their implementation costs.

The mitigation options can provide the basis for establishing targets (conditional and unconditional) for GHG emissions reductions to inform the NDC revision. The outcomes of the cost-effectiveness analysis will provide valuable information for the identification, cost and emissions quantification, and prioritisation of the mitigation measures required to achieve the national climate goals. The analysis can become a core part of the NDC and its implementation, feed decision makers on developing plans for the power and transport sectors, and introduce a path towards the transformation of the energy sector from fossil-based to zero carbon, with the reduction in energy-related GHG emissions being central to limit climate change.

The decision as to which of these mitigation options will be the basis for Saint Kitts and Nevis' updated climate action commitment is a decision for the Ministry of Environment and Cooperatives – Department of Environment in collaboration with other key national stakeholders, such as the Ministry of Public Infrastructure – Energy Unit and national utilities, among others. The aim of this document is to provide the necessary information to inform that decision-making process. The specific aims and goals of this document are therefore to:

- present the updated estimate of GHG emissions between 2020 and 2030 (baseline scenario)
- assess the potential for GHG emissions reductions from mitigation options identified by national stakeholders in comparison with the baseline scenario
- provide preliminary cost estimates for the mitigation options
- present GHG emissions reduction potentials from aggregated mitigation options
- introduce the potentials of sector coupling through the introduction of electric vehicles in the transport sector.

The report is structured as follows:

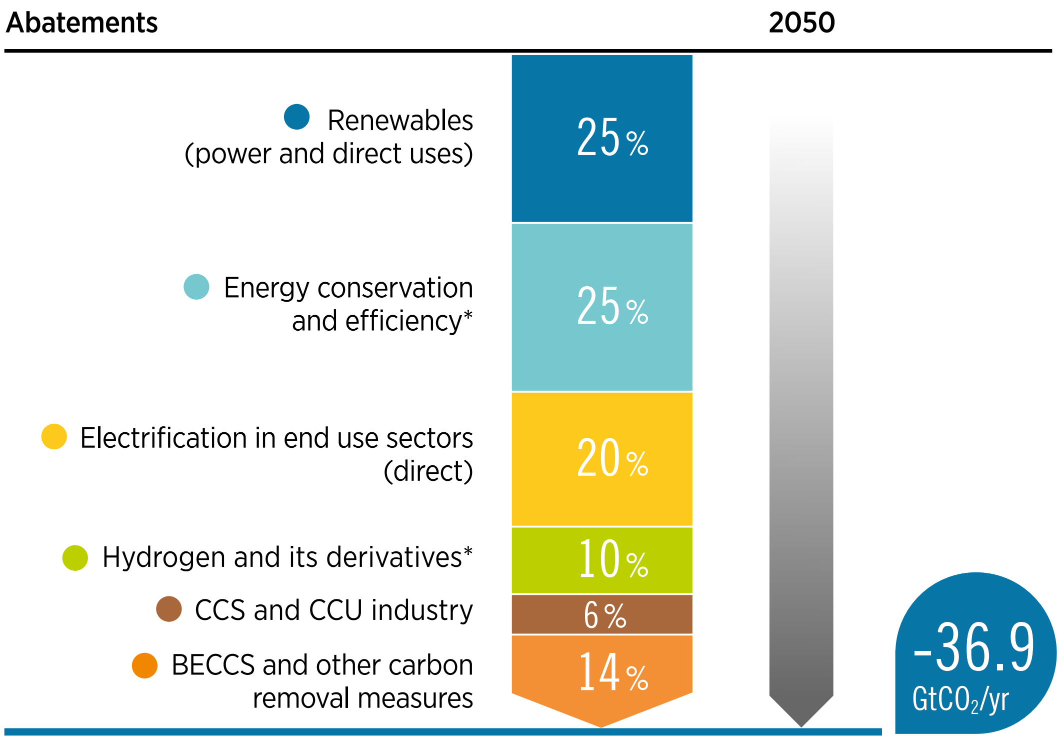
- **Chapter 2** provides context for the technical analysis, which is based on the findings of IRENA's *World Energy Transitions Outlook*, which describes a roadmap for the world to meet the Paris Agreement's goals and slow the rate of climate change through a transformation of the global energy sector. Additionally, it discusses the country's current climate targets in relation to the submitted INDC.
- **Chapter 3** describes the methodology used to determine the cost-effectiveness of mitigation solutions, including the baseline scenario, mitigation choices, and methodology used to calculate marginal abatement costs and GHG reduction potential. Additionally, this chapter discusses the assumptions made for electricity demand and generation, energy generation technologies, associated costs, aggregated mitigation measures, and the analysis for transport electrification.
- **Chapter 4** discusses the validation exercises that were undertaken as part of this study and the primary findings.
- **Chapter 5** contains the results of the MACC model for the electricity sector, the aggregated mitigation solutions and the study of the transport sector under the examined assumptions.
- **Chapter 6** provides some insights and recommendations for the NDC revision and implementation process. Recommended mitigation options for the NDC update are summarised.

2. BACKGROUND

2.1 WORLD ENERGY TRANSITIONS OUTLOOK

The increasing number of countries committing to net zero carbon strategies indicates a significant shift in 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, 2020b). 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. More than 80% of the world's population lives in countries that are net importers of fossil fuels. In contrast, every country has some renewable potential that can be used to increase energy security and independence at a lower cost (IRENA, 2019b).

Figure 2: Carbon emissions abatements under the IRENA 1.5°C Scenario (%)



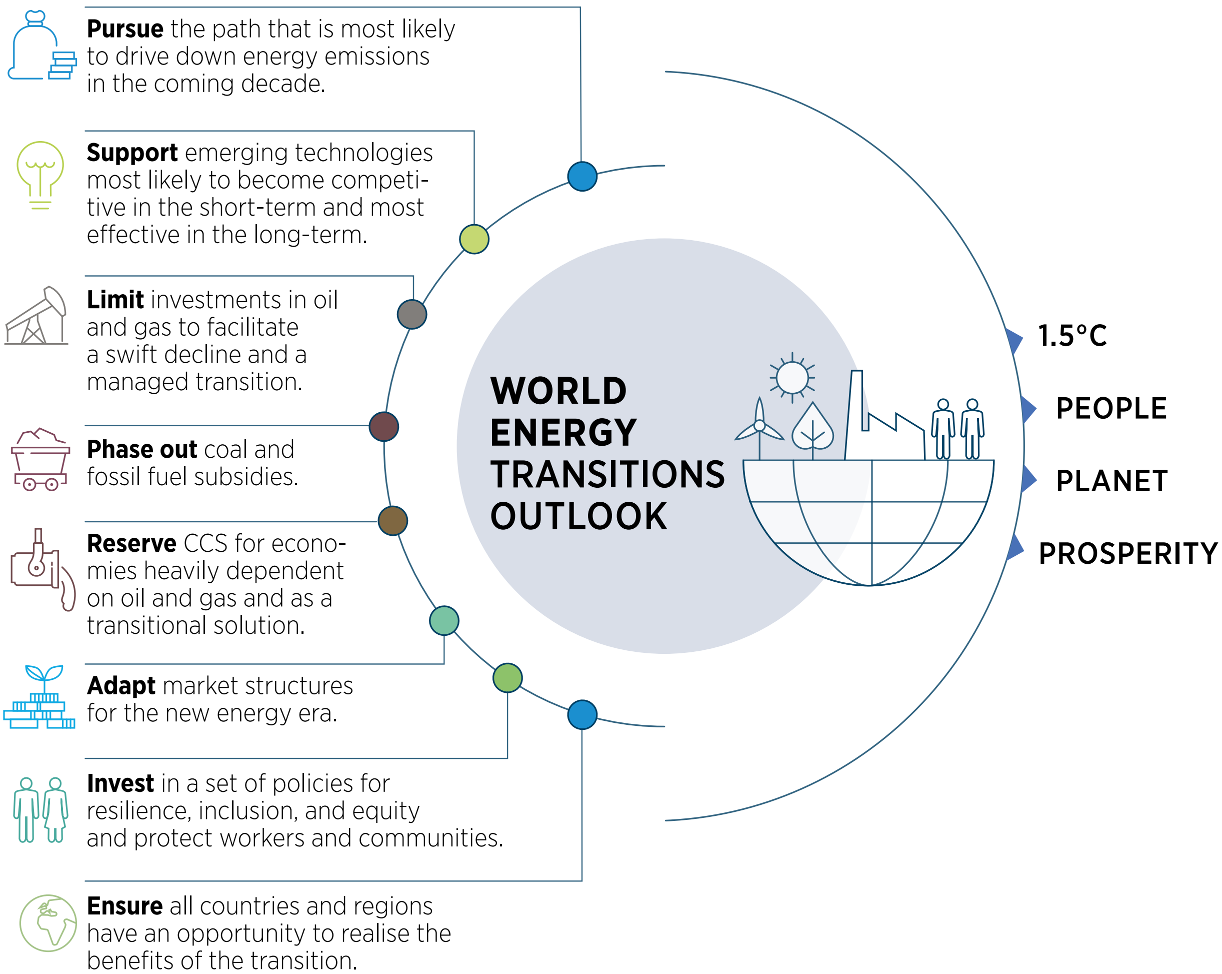
Notes: CCS = carbon capture and storage; CCU = carbon capture and utilisation; BECCS = bioenergy with carbon capture and storage; Gt CO_2 = gigatonnes of carbon dioxide.

Source: IRENA (2021a).

A global energy system transformation aligned with the 1.5°C climate goal has the potential to be a great equaliser in a world that needs to become more resilient, just and inclusive. A resilient energy system necessitates rapid development and deployment of resilient technologies, as well as investments in people and institutions. Significant progress has been made, but it has been uneven across geographies and communities. A few countries and regions have made great progress; in other areas, widespread energy poverty continues to stymie economic and social progress. In 2020, Europe, the United States, and the People's Republic of China (hereafter, "China") accounted for most of the new renewable capacity, while Africa accounted for only 1% of global new renewable capacity. This is the case even though Africa has the greatest need for expanded access to modern forms of energy and a renewable potential that far exceeds projected needs. Despite being a major avenue for expanding access, only USD 1 billion was invested in off-grid renewables between 2008 and 2019 in Africa.

Uneven deployment patterns are also reflected in the concentration of jobs and industries, leaving large parts of the world behind. Current plans fall far short of the 1.5°C target. Based on existing government energy plans and targets, including the first round of NDCs under the Paris Agreement, the policies in place will do nothing more than stabilise global emissions, with a slight drop as 2050 approaches. Despite clear evidence of human-caused climate change, widespread support for the Paris Agreement, and the prevalence of clean, affordable and sustainable energy options, annual energy-related carbon dioxide (CO_2) emissions increased by 1.3% on average between 2014 and 2019. Time is of the essence, and a rapid reduction in emissions must begin immediately in order to maintain a fighting chance of staying within 1.5°C. Coal and oil should have peaked by now, according to the Intergovernmental Panel on Climate Change (IPCC) report on limiting global warming to 1.5°C by 2050, with natural gas peaking in 2025. The resources and technologies required to accelerate the energy transition are now readily available. In line with the IPCC's schedule, IRENA plots a steep and continuous downward trajectory towards a 45% reduction in CO_2 emissions from 2010 levels by 2030, and net zero by 2050.

Figure 3: Guiding framework of World Energy Transitions Outlook theory of change



Source: IRENA (2021a).

The *World Energy Transitions Outlook* from the International Renewable Energy Agency (IRENA) is a 1.5°C-compatible pathway that also examines full socioeconomic and policy implications and provides insights on structural changes and finance. Rapid decarbonisation technologies are becoming more available, but thinking about the energy transition should not be limited to the energy sector. Realising the transition's far-reaching potential necessitates systemic innovation that considers both technologies and enabling frameworks. Renewable energy systems will bring about profound changes that will reverberate throughout economies and societies. Only by comprehending these deep currents will we be able to achieve the best results from the transition process. The inaugural edition of the *World Energy Transitions Outlook* draws on IRENA's extensive knowledge to make this possible, by providing policy makers with insights, tools and advice to help them chart the way forward.

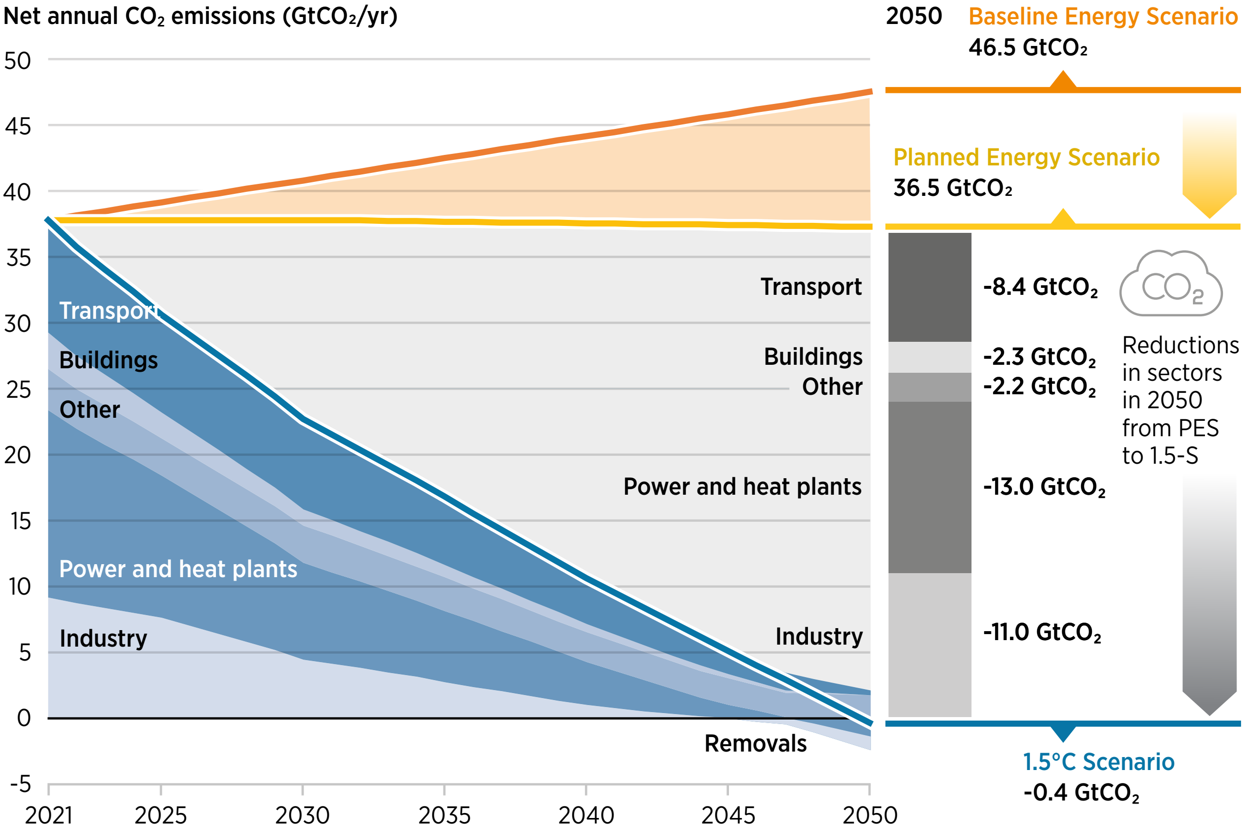
2.2 THE ROLE OF RENEWABLE ENERGY TECHNOLOGIES TOWARDS ACHIEVING NET ZERO BY 2050

The share of modern renewable energy in global final energy consumption has increased only slightly since 2010, staying around a threshold of about 10%. In simple terms, while renewables are increasing, so is energy demand. It shall be noted that modern renewable energy excludes traditional uses of bioenergy, which if included in this share would bring the share of all renewable energy in total final energy to 18% (IRENA, 2020a). Electricity costs from renewables have fallen sharply over the past decade (201019), driven by improving technologies, economies of scale, increasingly competitive supply chains and growing developer experience. 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 2020 seeing renewables account for 82% of all new capacity additions worldwide (IRENA, 2021b).

Energy is used in a wide range of sectors and areas of human activity, including for power generation, heating and cooling, and in industry, transport and buildings. Figure 4 summarises current global shares of greenhouse gas (GHG) emissions associated with energy use in these sectors. The analysis developed by IRENA outlines what is required for a global energy transition shift and 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. The IRENA analysis starts with the goal of reducing global CO_2 emissions in a steep and continuous downward trajectory from now on and reaching net zero by 2050. The energy sector is responsible for around 80% of anthropogenic CO_2 emissions and has a central role in delivering the decarbonisation required. To reach net zero by 2050, CO_2 emissions must decline 3.5% year-on-year, on average. The 1.5°C Scenario shows that this is achievable but extremely challenging, requiring urgent action on multiple fronts. In the Planned Energy Scenario (scenario on energy system developments based on governments' current energy plans and other planned targets and policies [as of 2019], including Nationally Determined Contributions [NDCs] under the Paris Agreement) annual emissions reach 36.5 Gt CO_2 in 2050. For the 1.5°C Scenario, emissions need to drop to net zero. All sectors need to reach almost 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. Over 90% of the solutions in 2050 involve renewable energy through direct supply, electrification, energy efficiency, green hydrogen and BECCS (IRENA, 2021a).

There are plenty of opportunities for renewable energy technologies throughout the entire energy sector. Focus is currently on decarbonising the power sector. Renewables for power generation have gained prominence due to cost reductions in technology, which both encourages and is driven by increased uptake. For example, the global average levelised cost of electricity from utility-scale solar photovoltaics (PV) fell by 82% between 2010 and 2019 (IRENA, 2020c) and by 7% between 2019 and 2020 (IRENA, 2021c). By 2050, electricity generation triples compared with the 2018 level, and renewables supply 90% of total electricity, up from 25% in 2018 (IRENA, 2021a). Therefore, the decarbonisation of electricity generation will continue to be a key focus.

Figure 4: For the 1.5°C climate target, global CO_2 emissions need to drop to net zero by 2050



Notes: PES = Planned Energy Scenario; 1.5-S = 1.5°C Scenario.

Source: IRENA (2021a).

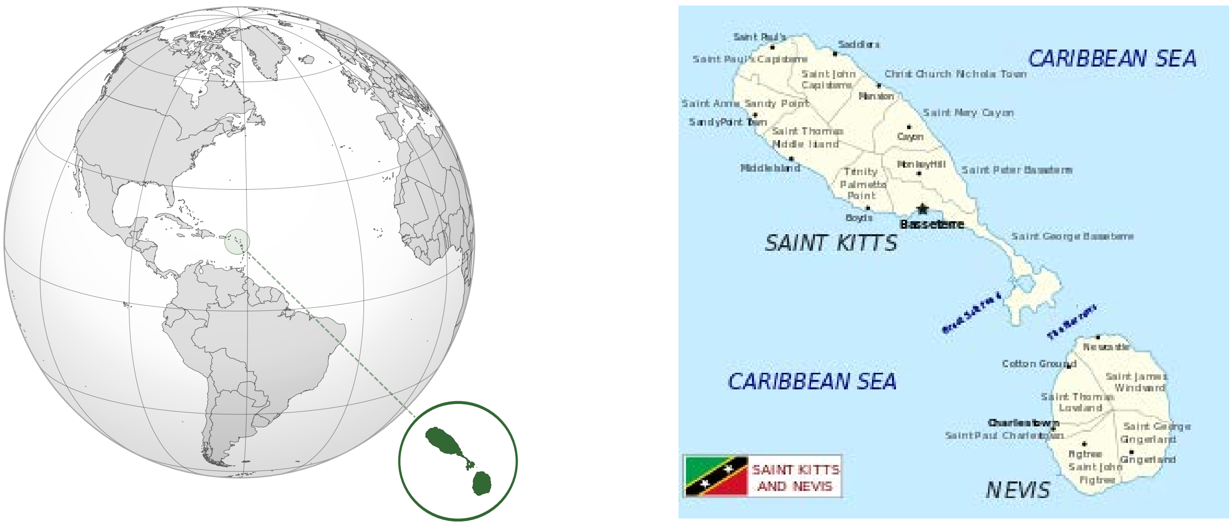
With the ever-increasing deployment of renewable energy in the power sector, the shift from energy use to electricity in other sectors, including transport, buildings (heating and cooling) and industry, could make a significant contribution to decarbonisation. In transport, the sustained growth of electric vehicle adoption, supported by the international roll-out of infrastructure support, offers an opportunity to decarbonise the sector. However, the increase in demand for electricity may be a challenge for the power sector, becoming a key issue to be analysed by local experts.

For a more in-depth analysis of the IRENA's *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: 1.5°C Pathway* (IRENA, 2021a).

2.3 NATIONAL CONTEXT

The Federation of Saint Christopher and Nevis is a Caribbean island country that is part of the Leeward Islands and is located about 400 kilometres south-east of Puerto Rico. Both islands are mountainous, formed by volcanic activity, and the landscape is dominated by high central peaks covered in tropical rainforest. With a total land area of 261 square kilometres, the islands are the smallest sovereign country in the Americas. Mount Liamuiga, at 1156 metres, is the highest point on Saint Kitts. Basseterre is the country's capital. Saint Kitts and Nevis is a full member of IRENA, the Caribbean Community (CARICOM), the Organisation of Eastern Caribbean States and the Organization of American States.

Figure 5: Geographical location of Saint Kitts and Nevis



Source: wikipedia.org.

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

Figure 6: View of Basseterre, Saint Kitts

Source: nationsonline.org / wikivoyage.org.

The population of Saint Kitts and Nevis is estimated to be around 53 000 people (World Bank, 2021). Coastal areas are home to more than 60% of the island's population. As a result, Saint Kitts and Nevis is particularly vulnerable to rising sea levels, coastal erosion and flooding, all of which are exacerbated by human-caused deforestation and climate change-related risks.

2.4 SAINT KITTS AND NEVIS' FIRST NDC

Saint Kitts and Nevis submitted in 2016 its Intended National Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. It proposed GHG emissions reduction targets of 22% by 2025 and 35% by 2030, relative to that projected in the business-as-usual scenario. These targets correspond to emissions reaching 528 Gg CO_2 by 2025 and 540 Gg CO_2 by 2030. All economic sectors were considered and targeted in Saint Kitts and Nevis' INDC, with an emphasis on the power and transportation sectors, which account for most of the country's GHG emissions. In terms of specific mitigation options for the energy sector, the country stated the measures illustrated in Table 1.

In this context, Saint Kitts and Nevis has started implementing utility solar PV plants and has already completed the electricity uses and consumption sector measures, according to the INDC presentation.

Table 1: Mitigation measures included in the country's INDC (2016)

SECTOR	POLICIES AND MEASURES	TARGET	IMPLEMENTATION TERM
Electricity generation	Geothermal sources	At least 35 megawatts (MW)	Mid and long term
	Solar sources	At least 1 859 kilowatts (kW)	Short, mid and long term
	Wind sources	At least 7.6 MW	Mid and long term
	Waste sources	0.5 MW	Long term
Electricity uses and consumption	Smart meters and net metering	Losses reduces at least 50% of the current level	Short, mid and long term
	Replacement of inefficient equipment and automation of high-consumption equipment	At least reduce 5% of the national energy consumption	Short, mid and long term
Transport	Incentive for more efficient vehicles Tax on vehicles with high fuel consumption Retrofitting inefficient vehicles More efficient public transportation New alternative infrastructure Road repair/creation of new roads Parking and transit regulation	At least reduce 5% of national fuel consumption	Short, mid and long term

3. METHODOLOGY AND KEY ASSUMPTIONS

The marginal abatement cost curve (MACC) methodology is employed to perform the cost-effectiveness assessment. MACC is a useful tool to support climate policy decision-making as it informs on the greenhouse gas (GHG) abatement potential and associated costs of the policies and technology options assessed. A three-step process is required to evaluate the cost-effectiveness of mitigation measures, as illustrated in Figure 7.

This chapter describes in detail the methodological approaches, datasets and assumptions applied in each methodology process step. Chapter 3.1 describes the development of the business-as-usual scenario, the “baseline scenario”; Chapter 3.2 describes the process of identifying mitigation options; and Chapter 3.3 describes how the GHG reduction potential and marginal abatement costs of mitigation options were assessed.

Figure 7: Methodology for developing a MACC assessment

3.1 BASELINE SCENARIO

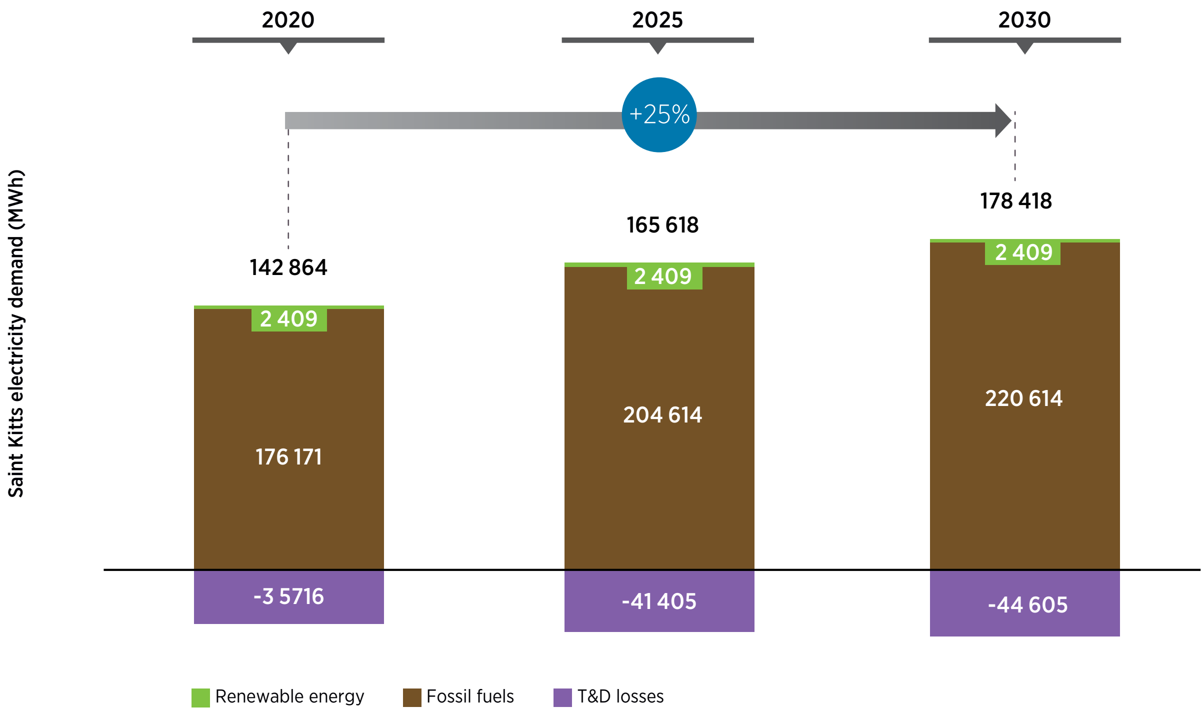
This section describes the methodology, data and assumptions used to develop the baseline scenario, which served as the starting point for the analysis. A baseline scenario must be set to serve as a benchmark against which the GHG reduction potential and cost-effectiveness of various mitigation options can be compared.

Electricity demand

To estimate total annual electricity demand, the electricity demand was calculated separately for Saint Kitts and Nevis, extrapolated to 2030 and subsequently aggregated to compute the total electricity demand for the nation. The electricity demand growth rates considered were a 3% growth rate until 2025 and 1.5% for the period 2025-30 (Deloitte, 2017). Since the electricity demand data were not directly available from the national statistics, they were calculated and deducted from the electricity supply data.

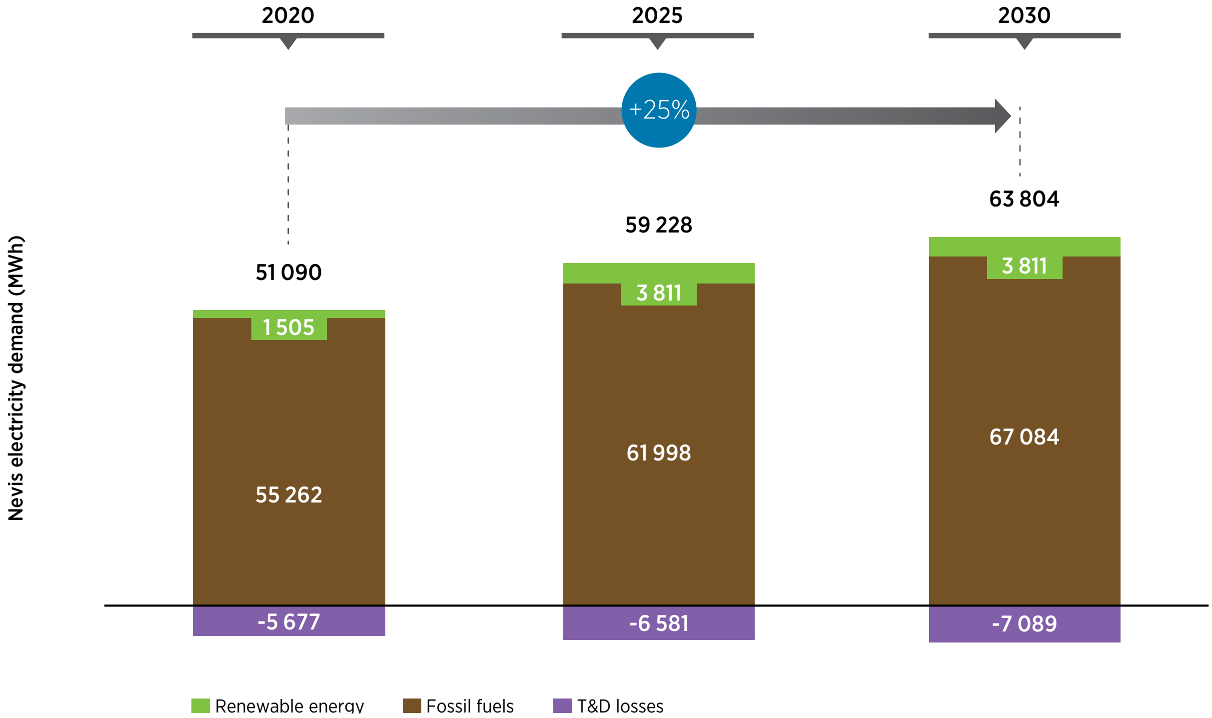
For Saint Kitts, fuel-based electricity generation was provided by St Kitts Electricity Co Ltd (SKELEC) for 2020. It is also acknowledged that the island features a 1.3 megawatt (MW) solar photovoltaic (PV) plant installed capacity, being the production of the solar capacity estimated with a representative country capacity factor for the solar resource. A load factor of 1 927 hours, equal to a 22% capacity factor, was used, which led to an estimated 2 409 megawatt hours (MWh) of annual production (Deloitte, 2017). Additionally, a loss factor of 20% was then applied to the total generation to estimate the total island demand in 2020. The demand was then extrapolated from 2017 to 2030 using the demand growth factors. As the demand is known for each year, the method was then reverted to calculate the fuel-based generation for all years. Figure 8 illustrates the results for Saint Kitts.

Figure 8: Saint Kitts electricity demand 2020-30 (MWh)



Note: T&D = transmission and distribution.

Figure 9: Nevis electricity demand 2020-30 (MWh)

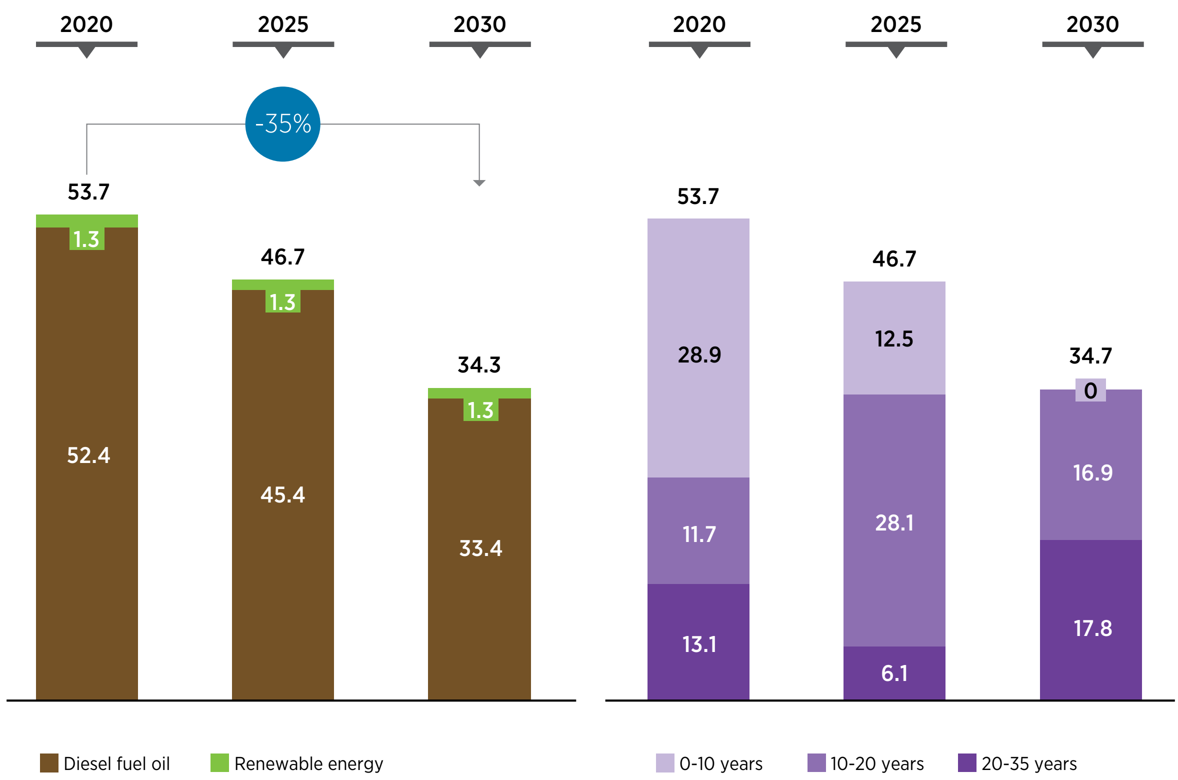


For Nevis, based on datasets provided by Nevis Electricity Company Limited (NEVLEC), the total electricity production, the fuel-based generation and the production of the wind farm (estimated at 1.5 MW in capacity) were used to initiate the model for the years 2017 to 2020. It is noted that the wind farm production (eight turbines in total, for a capacity of 2.2 MW) varies significantly (3 146 MWh in 2018, halved in 2020), which tends to indicate failures in several of the 230 kilowatt (kW) wind turbines between 2018 and 2020. On the recommendation of NEVLEC, the wind farm capacity was revised to 1.5 MW. The extrapolation of the wind production over the 2021-30 period was performed on this basis, with a load factor of 2 540h, equal to a 29% capacity factor (Deloitte, 2017). Finally, a loss factor of 10%[1] was applied to the total generation to estimate the total demand. In line with this, the demand was extrapolated forward to 2030 using the demand growth factors. Similarly, as in the case of Saint Kitts, as the demand was known for each year, the method was then reverted to calculate the fuel-based generation for all years. Figure 9 illustrates the resulting electricity demand for Nevis.

Electricity supply

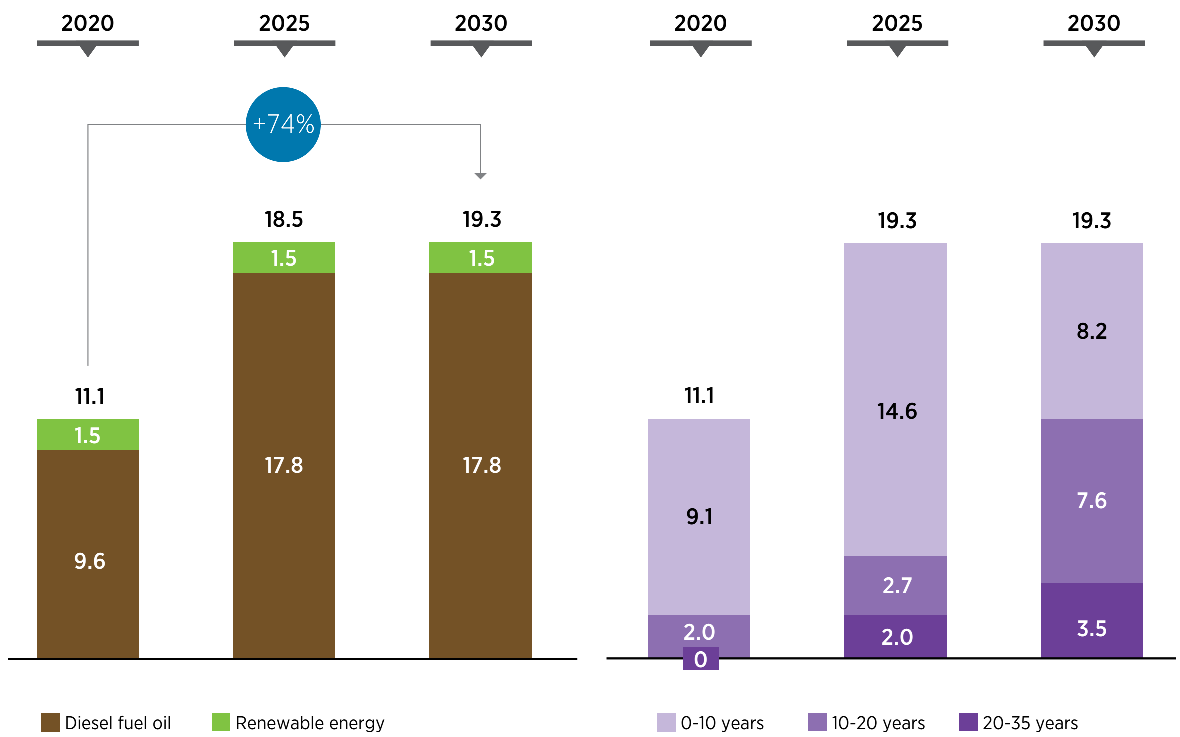
For the modelling of the electricity supply, the available generation fleet was compiled from datasets provided by SKELEC and NEVLEC for the year 2020. The datasets were checked and compared with (Deloitte, 2017) for validation and consistency. Since the commissioning date of each plant is known, in order to consider potential decommissioning in the model, a lifetime assumption was applied to determine the availability of the capacity at each year. In this context, fuel-based generation was given a lifetime operation of 35 years, while 10 years was assumed for mobile sets and 20 years for renewable energy assets. The final baseline capacities and age profile of the existing fleet for Saint Kitts are presented in Figure 10. The final baseline capacities and age profile of the existing fleet for Nevis are presented in Figure 11.

Figure 10: Existing fleet fuel type (left) and age profile (right) in Saint Kitts (MW)



1 Assumption defined by local utility NEVLEC.

Figure 11: Existing fleet fuel type (left) and age profile (right) in Nevis (MW)



Dispatch strategy and load

Across the model, a dispatch model is included to factor 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 priority order proposed, and validated with stakeholders, ranks geothermal first, followed by wind energy and solar energy. The remaining demand is then supplied by diesel fuel oil (DFO). The load factors proposed for each technology are depicted in Table 2.

The choice to rank geothermal as a priority from a merit-order perspective is to acknowledge the upfront costs of geothermal prospection and investment, which would require maximising the plant's load factors to optimise the life-cycle cost of energy. The subsequent ranking of wind and solar energy above DFO is consistent with (Deloitte, 2017).

Table 2: Capacity factors for renewable energy technologies

GENERATION UNIT	CAPACITY FACTOR	ANNUAL YIELD	ASSUMPTION/SOURCE
Geothermal	90%	7 884 h/year	Own assumption
Wind	28%	2 540 h/year	Deloitte, 2017
Solar	22%	1 927 h/year	Deloitte, 2017

This approach estimates that the share of renewable electricity in the mix would account for 1.1% for Saint Kitts and 5.4% for Nevis in 2030. Additionally, it is noted that the DFO capacities are running currently at moderate capacities, being around 40% in Saint Kitts and 57% in Nevis. The load increases towards 2030 and reaches shares around 75% in Saint Kitts and 40% in Nevis. These baseline calculations tend to show that Saint Kitts and Nevis is not at risk to face a shortage of capacity in the short to medium term. Rather, the drivers for adding renewable energy generation rely mainly on lower marginal generation cost with stable prices over time, coupled with GHG emissions reductions.

Grid emission factors

For the grid emission factors, the model considers the real calculated factors performed by the United Nations Framework Convention on Climate Change (UNFCCC) technical team. Grid emission factors of 0.66 tonne (t)CO_2 per MWh were considered for Saint Kitts and 0.72 t CO_2/MWh for Nevis. This consideration has led to a significant reduction in CO_2 emissions estimates of the baseline, compared with the use of a DFO standard grid emission factor, which is 0.8 t CO_2/MWh (IPCC, 2006).

3.2 DEVELOPMENT OF INDIVIDUAL MITIGATION OPTIONS

A mitigation option is a specific action undertaken with the goal of reducing GHG emissions from the energy sector. The identification and revision of suitable mitigation options was done through a consultative process with key national stakeholders, such as the Energy Unit within the Department of Environment, together with representatives from both utilities. Mitigation options were identified from the first Nationally Determined Contribution (NDC) as well as other plans, ongoing projects and current investment plans of the government.

A total of six mitigation options in the power sector were identified, as shown in Table 3. For each mitigation option, a model was developed to evaluate its GHG reduction potential and cost-effectiveness. The methodology and assumptions behind the development of the mitigation options are described in detail in this chapter.

Table 3: Mitigation options for the power sector

REF.	MITIGATION OPTION*	DESCRIPTION	ISLAND	TARGET YEAR
A	Onshore wind power	6.6 MW of wind power capacity additions	Saint Kitts	2024
B	Utility-scale solar PV**	35.7 MW of utility-scale solar PV capacity additions	Saint Kitts	2023
C	Geothermal power plants	Total of 25 MW of geothermal power capacity additions (10 MW in Nevis and 15 MW in Saint Kitts)	Nevis Saint Kitts	2025 2030

Table 3: Mitigation options for the power sector *(continued)*

REF.	MITIGATION OPTION*	DESCRIPTION	ISLAND	TARGET YEAR
D	Solar PV-powered desalination plans	Additions of two solar PV plants of 0.75 MW each to supply two desalination plants	Saint Kitts Nevis	2030
E	Grid efficiency	Reduction of T&D losses	Saint Kitts Nevis	2030
F	Solar water heating systems	Reduction of 5% in power demand	Saint Kitts Nevis	2030

* In comparison with the options included in the country's first NDC, all mitigation options have been revised and updated.

** Distributed rooftop solar PV is planned to be implemented on both islands at the government's direction. Due to a lack of data at the time of this analysis, the relatively minor overall expected mitigation impact, it was decided not to include it as an independent additional mitigation measure in the modelling exercise.

Supply-side mitigation options: Renewable energy technologies

Several supply-side mitigation simulations were performed. The options are depicted in Table 4. These options are composed of different renewable energy power projects. The capacity factors (hours/year) of each technology was multiplied by the project capacity (MW) to determine the annual electricity generation (MWh). The electricity generated by renewable energy power plants would replace the electricity generated by DFO in the baseline scenario. By multiplying the emissions factors by the respective electricity production, the GHG emissions for each mitigation option is determined.

The strategy from each island is markedly different. Saint Kitts would diversify its electricity supply with different renewable energy sources, considering geothermal energy at the end of the decade, while Nevis would instead focus on adding geothermal energy to the mix as early as 2025.

Table 4: Supply-side mitigation options

REF.	MITIGATION OPTION	SAINT KITTS	NEVIS
A	Onshore wind power	6.6 MW by 2024	N/A
B	Utility-scale solar PV	35.7 MW by 2023	N/A
C	Geothermal power plants	15 MW by 2030	10 MW by 2025
D	Solar PV-powered desalination plans	0.75 MW by 2030	0.75 MW by 2030

Demand-side mitigation options: System efficiency

Apart from the supply-demand mitigation options, several measures are contemplated that would have an impact on the demand side of the energy systems and consequently on the overall GHG emissions. Particularly, there are two mitigation options which depict efforts on energy efficiency; one focuses on the efficiency of the T&D networks (option E) and the other an overall reduction in electricity demand (option F).

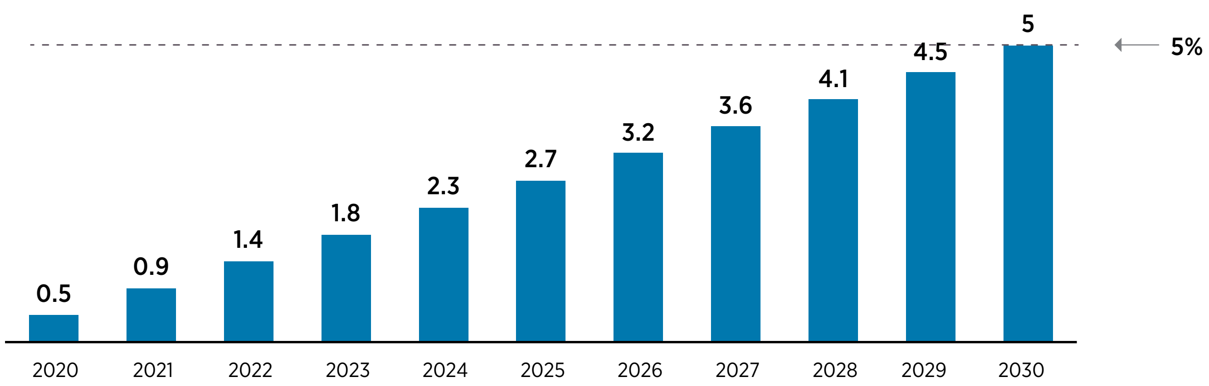
Table 5: Demand-side mitigation scenarios

REF.	MITIGATION OPTION	SAINT KITTS	NEVIS
E	Grid efficiency	T&D losses reduced from 20% in 2020 to 10% in 2030	T&D losses reduced from 10% in 2020 to 6% in 2030
F	Energy efficiency – solar water heating systems*	Reduction of 5% in the electricity demand in each island/ power system by 2030	

* Mitigation option identified and validated with national stakeholders based on current national plans.

Regarding the scenario F on demand efficiency, Figure 12 illustrates how the energy efficiency on the demand was modelled with an incremental demand reduction share from 0.5% until reaching 5% by 2030.

Figure 12: Share of energy efficiency on the demand 2020-30 (%)



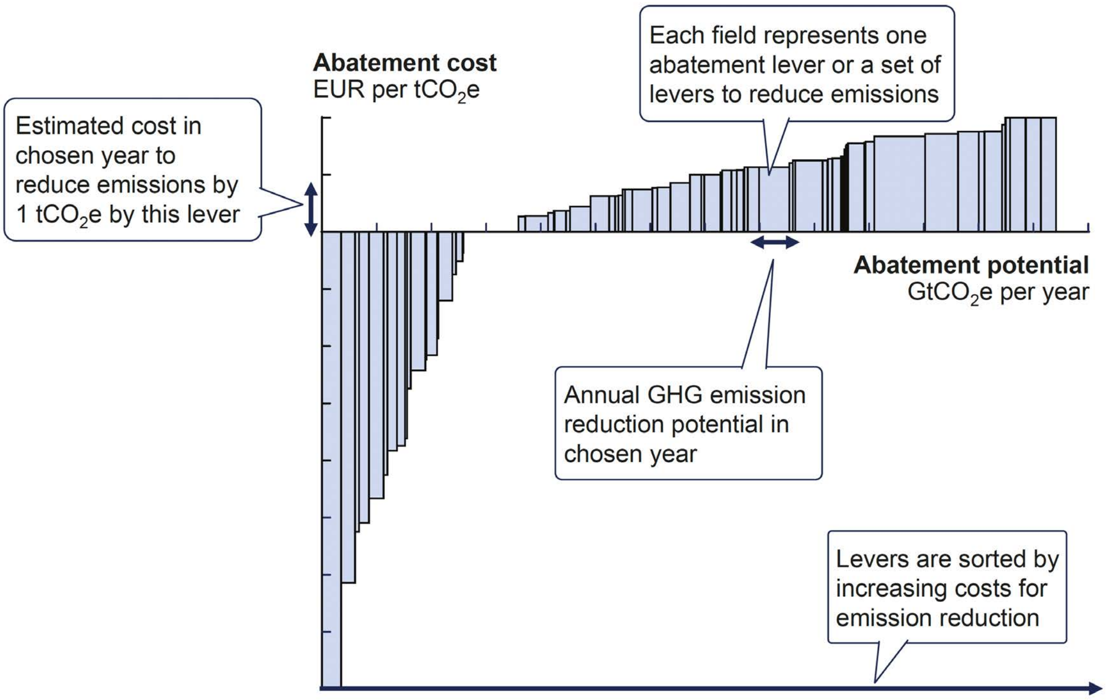
3.3 COST-EFFECTIVENESS ANALYSIS

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

Marginal abatement cost curves

The cost-effectiveness analysis is performed based on the MACC methodology. As shown in Figure 13, the MACC is a two-axis graph in which the horizontal axis indicates the GHG abatement potential, typically in gigatonnes of carbon dioxide per year, and the width of each bar indicates the abatement potential to reduce annual GHG emissions for a particular mitigation option. The vertical axis displays the abatement cost, in for example US dollar per tonne of carbon dioxide, which is the cost to reduce or offset one unit of GHG emissions and it is indicated by the height of the bar.

Figure 13: Example of MACCs



Source: Nauclér and Enkvist, 2009.

GHG emissions reduction potential

The overall system emissions are calculated for every year of analysis. The implementation of each individual mitigation option identified is considered for accounting for the emissions abated in a specific year. In regard to the methodology, GHG emissions are calculated for each mitigation option by multiplying the emissions factors for each fuel type by the respective electricity production and then compared with the baseline scenario emissions. The emissions factors applied are presented in Table 6. Emissions associated with manufacturing, installation, operation and decommissioning of renewable energy power projects have not been considered, and it is therefore assumed that they present zero emissions. The emissions have been calculated for every year of analysis based on the estimated abatement potential.

Table 7 summarises the reference solutions used to evaluate the mitigation options in terms of cost-effectiveness and GHG reduction potential. Since DFO represents most of the installed capacity in the grid of both Saint Kitts and Nevis, at around 95% in 2017, DFO is used as the reference solution for all the supply- and demand-side mitigation options. Therefore, for the assessment of all options associated with electricity generation (i.e. wind, solar PV and geothermal), as well as for the analysis of the system efficiencies (i.e. T&D upgrade and the electricity demand), DFO is used as reference solution.

Table 6: Emission factors for each fuel type considered

FUEL	EMISSION FACTOR ($T\ CO_2$/MWH)	SOURCE
Renewable energy generation technologies	0	Own assumption
DFO – Saint Kitts	0.66	UNFCCC
DFO – Nevis	0.72	UNFCCC

Table 7: Reference solutions considered for the evaluation of the analysed mitigation options

REF	MITIGATION OPTION	REFERENCE SOLUTION
A	Onshore wind power	DFO
B	Utility-scale solar PV	DFO
C	Geothermal power plants	DFO
D	Solar PV-powered desalination plans	DFO
E	Grid efficiency	DFO
F	Energy efficiency (solar water heating systems)	DFO

ABATEMENT COSTS

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

Equation 1: Abatement cost of each individual mitigation option

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

The full cost of mitigation options and the baseline scenario includes the annual repayment of the capital expenditure (CAPEX), operational expenditure (OPEX), and costs associated with the usage of fuel or savings (e.g. energy savings in the case of energy efficiency solutions). Finance availability is not considered a constraint, and full costs do not include transaction expenditure, subsidies or taxes (McKinsey & Company, 2009). No decommissioning costs are considered.

The abatement costs are computed yearly in the time period between 2020 and 2030. The following sections outline the cost assumptions, as well as technical assumptions affecting costs, that were used to evaluate each mitigation option. For the evaluation of each mitigation option, a linear learning curve of 3% was considered to adjust both CAPEX and OPEX of mitigation measures and reference solutions in the 2021-30 period.

Key assumptions for diesel fuel oil generation

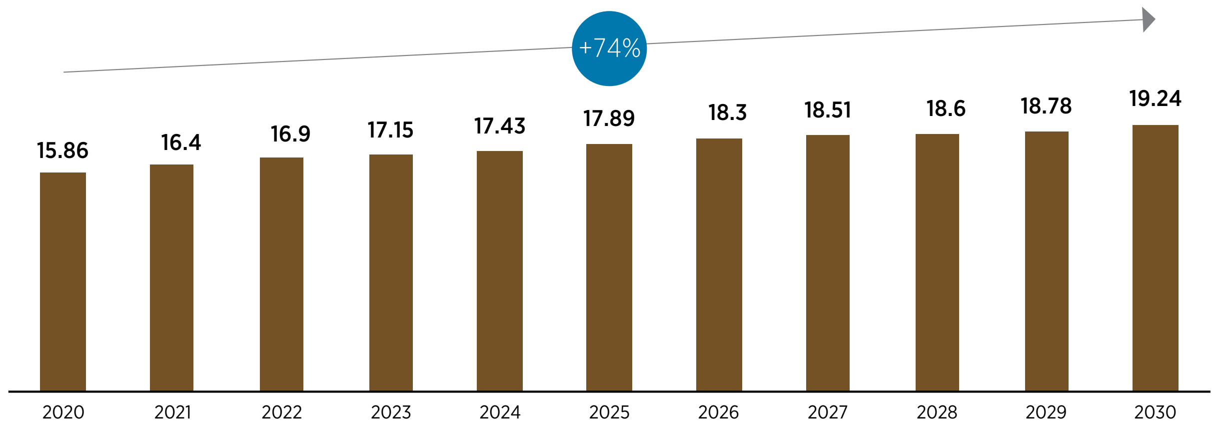
Table 8 presents the cost and technical assumptions taken for reference solution DFO, including system availability, costs and generation efficiency. Figure 14 depicts the trend base for fuel price projections. The precise datasets can be found in the appendix. Identical CAPEX and OPEX have been assumed for all generation units running with the same fuel.

Table 8: Cost and technical assumptions considered for the reference solution DFO

ITEM	VALUE	UNITS	SOURCE
CAPEX	1 200	USD/kW	Deloitte, 2017
Variable operation and maintenance cost	30	USD/MWh	Deloitte, 2017
Heat rate	9 000	Btu/kWh	Deloitte, 2017
Fuel projections	Trend base (Figure 14)	USD/MBtu	Deloitte, 2017
Availability	90	%	Deloitte, 2017
DFO – Saint Kitts	0.66	t CO_2/MWh	UNFCCC
DFO – Nevis	0.72	t CO_2/MWh	UNFCCC

Notes: Btu = British thermal unit; MBtu = million British thermal unit.

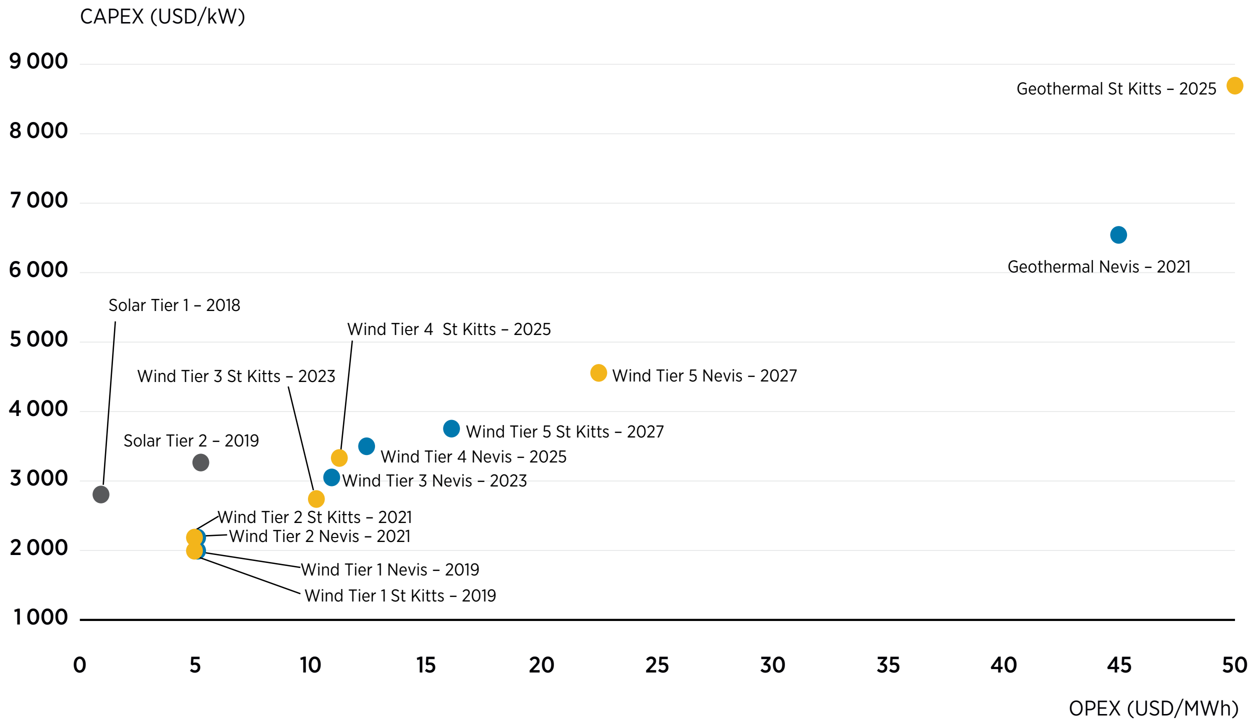
Figure 14: Projected fuel costs (in USD/MBtu)



Renewable energy technologies

Figure 15 illustrates the investment and operation costs (CAPEX and OPEX), lifetime, and year available considered for the renewable energy generation technology solutions, namely mitigation options A to D. Costs of wind power are classified into five tiers. Tiers 1 and 2 do not include storage costs and consider low levels of wind capacity in the grid, while tiers 3 to 5 consider high levels of wind capacity in the grid and the requirements for increasing storage capacity. Likewise, solar PV costs are split into tier 1 without storage and tier 2 with storage. The tiers are also linked to the year when they become available. A complete list of cost assumptions, along with their sources, can be found in Appendix C.

Figure 15: Cost assumptions considered for the evaluation of renewable energy generation technologies



Source: Deloitte (2017).

Grid efficiency

For the mitigation option addressing the T&D grid upgrade, the analysis has considered the cost and technical data from a World Bank project in the Dominican Republic (World Bank, 2015) the first component being rehabilitation of selected distribution circuits and upgrading of metering systems and implementation of environmental management system for the EDEs. This component will support investments to rehabilitate circuits selected by each EDE. The second component is the Citizen Engagement and community participation. This component will implement a Social Management Strategy (SMS, adapted to the conditions of Saint Kitts and Nevis. The CAPEX for this project was USD 358.35 million and led to a reduction in T&D losses of 6.03%. A 40-year lifetime and a 1% OPEX (Hernández et al., 2020) are considered.

Table 9 presents the cost and technical assumptions taken for the modelling of the grid efficiency mitigation option.

Table 9: Assumptions considered for the evaluation of grid efficiency

ITEM	VALUE	UNITS	SOURCE
Lifetime	40	Years	Own assumption
CAPEX	358 350 000	USD	World Bank, 2015
OPEX	1%	% of CAPEX	Hernández et al., 2020
Reduction in T&D losses	6	%	World Bank, 2015
CAPEX to T&D upgrade levels SKELEC	346 873 319	USD	Own calculation
CAPEX to T&D upgrade levels NEVLEC	44 105 628	USD	Own calculation

Solar water heating systems

For the mitigation option related to energy efficiency and its corresponding 5% reduction of the overall system's electricity demand, the calculation of costs considers that the decrease in demand is achieved through the installation of solar water heaters. Table 10 lists the technical and economic assumptions considered for the evaluation of solar water heaters. Due to lack of granular data at the time of this analysis, Figure 16 illustrates the assumptions chosen to disaggregate the sectoral final energy consumption shares. Additionally, it was considered that share energy consumption for water heating is 34% in households and 22% in the services sector. In the Appendix, Table 10 datasets and sources are shown in detail.

Figure 16: Assumptions on final energy consumption by sector (%)

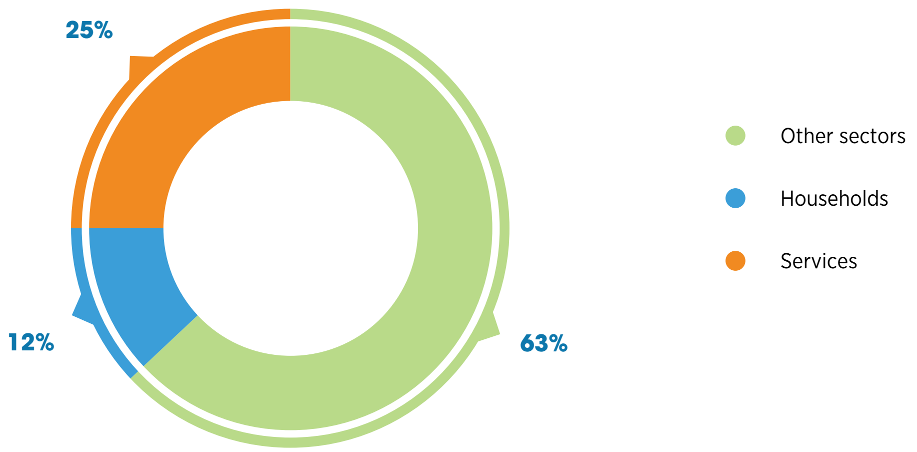


Table 10: Technical and economic assumptions considered for the evaluation of solar water heaters

ITEM	VALUE	UNITS	SOURCE
Power capacity	2	kW	Gischler et al., 2016
Collector area	2 857	square metres	Gischler et al., 2016
Lifetime	20	Years	Gischler et al., 2016
CAPEX	1 600	USD/water heater	Gischler et al., 2016
OPEX	2.5	% of CAPEX	Gischler et al., 2016
Efficiency system	30	%	Maldonado et al., 2014
Solar fraction	60	%	Rodríguez-Hidalgo et al., 2012

3.4 DEVELOPMENT OF AGGREGATED MITIGATION OPTIONS

In addition to the individual mitigation options based on the previously described supply- and demand-side options, several aggregated options combining multiple mitigation options were developed to analyse and highlight potential synergies between mitigation options that are typically not captured by a MACC. The aggregated mitigation options developed are depicted in Table 11.

The "Conservative renewable mix" option (G) aggregates the most mature mitigation options to be implemented within a shorter time frame to supply the baseline demand, with 35.7 MW PV by 2023 in Saint Kitts and 10 MW geothermal energy by 2025 in Nevis.

Table 11: Aggregated mitigation options developed

REF.	MITIGATION OPTIONS	DESCRIPTION	COMBINATION OF MITIGATION OPTIONS
G	Conservative renewable mix	Conservative alternative with most mature mitigation options to be implemented within a shorter time frame	35.7 MW PV by 2023 in Saint Kitts, and 10 MW geothermal energy by 2025 in Nevis
H	Conservative renewable mix + interconnection	Idem option G considering interconnected islands (one power system)	35.7 MW PV by 2023 in Saint Kitts, and 10 MW geothermal energy by 2025 in Nevis. Islands are interconnected.
I	Ambitious renewable mix	Ambitious alternative combining all mitigation options	All mitigation options A to F are considered

Additionally, another joint alternative was modelled based on option (G) which simulates the grid systems from both islands to be interconnected, the "Conservative renewable mix + interconnection" option (H). The method utilised for modelling addresses a simplified approach assuming perfect dispatch with no additional losses, and it aims to exploit the synergies between the various renewable energy sources and brings Saint Kitts and Nevis as an integrated power system.

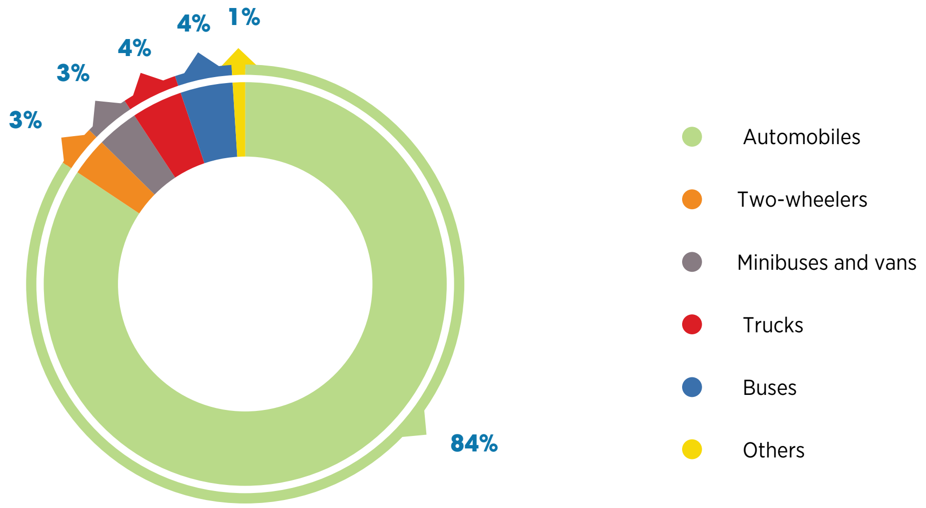
Finally, an aggregated option (I) was generated, which includes all mitigation options included as part of this analysis, options A to F. This alternative does not consider the interconnection of the islands.

3.5 OPTIONS FOR THE TRANSPORT SECTOR

The transport sector in Saint Kitts and Nevis consumes the most energy and is dominated by fossil fuels. According to data from the Saint Kitts and Nevis Energy Balances 2010-2012, the country registered 22 208 vehicles in 2010, 22 208 in 2011, and 22 226 in 2012. According to 2012 data, approximately 60% of all vehicles ran on gasoline. Diesel oil comes in second place with a share of 23%, followed by kerosene/jet fuel with a share of 17%.

According to Figure 17, 18 745 (84%) of all vehicles registered in 2012 were classified as motorcars, which include private cars, taxi cars, taxi sport utility vehicles (SUVs), rental cars and pickups. The remainder of the fleet is made up of two-wheel vehicles (677), minibuses and vans (742), trucks (908), buses (932) and others (222). The figure reflects both the fossil dependence and preference for gasoline as the main fuel for powering vehicles. Given the relatively small land area of Small Island Developing States, as in the case of Saint Kitts and Nevis, with just 261 square kilometres, electric vehicles (EVs) represent an attractive option for meeting a large share of the transport demand with renewable energy. It should be noted that for EVs to contribute to an increased share of renewable energy in the national energy balance, they must be charged with renewable energy.

Figure 17: Total vehicles registered in 2012 by type (%)



The mitigation analysis investigated the possibility of replacing part of the gasoline consumption in the transport sector with EVs by 2030. Due to the high preference for gasoline as the principal fuel for most vehicles in Saint Kitts and Nevis, the analysis and calculations were performed based only on vehicles running on gasoline.

As already illustrated, Saint Kitts and Nevis' transport sector is dominated by fossil fuels, mainly gasoline and diesel-powered vehicles. Hence, the analysis for the potential of renewable energy in the transport sector focused on the potential reduction in fuel imports for transport and the level of renewable electricity generation required to power EVs. The analysis investigated the possibility of progressively replacing the current fleet of vehicles with EVs by 2030.

The transport sector was analysed by developing two options which assessed the impact of emobility considering two different power mixes. Table 12 presents the modelled transport sector options.

Table 12: Options developed for the transport sector mitigation analysis

REF.	MITIGATION OPTION	DESCRIPTION
J	E-mobility (conservative)	10% fuel savings calculated on the conservative renewable mix alternative by 2030
K	E-mobility (ambitious)	10% fuel savings calculated on the ambitious renewable mix alternative by 2030

As for the modelling methodology, the objective was to reduce the gasoline fuel consumption by a target value of 10% by switching a share of the vehicle fleet with light EVs. The balance of emissions was estimated between the GHG emissions abated from fuel consumption savings and the potential increased emissions by the increase in electricity demand.

The approach consisted of estimating the equivalent transport service (in kilometres) to the energy savings (in terajoules [TJ]). Then, a ratio of kilowatt hours per kilometre (kWh/km) is applied to deduct the corresponding electricity demand from EVs. The total demand is finally shared between Saint Kitts and Nevis, according to population census ratios.

The energy balance for Saint Kitts and Nevis provides the gasoline consumption for the period 2010 to 2012 (OLADE, 2015). The consumption is extrapolated to 2030 using a 3% growth rate, equivalent to the Intended Nationally Determined Contribution assumptions. Fuel cost for gasoline cars is considered to follow the same increasing trend presented in Figure 14 between 2020 and 2030.

For the mitigation potential calculations of the transport sector, gasoline cars were used as the reference solution. Regarding the EV charging characteristics, it was assumed that the vehicles had a nominal battery capacity of 40 kWh/vehicle (typically for personal cars). These assumptions were based on the newest EV models currently available in the market for each type. The EV efficiency was also assumed based on the data sheets of the currently available EVs. The conversion key assumptions along with the assumed EV characteristics and costs are shown in Table 13.

Table 13: Technical assumptions for transport sector analysis

ITEM	ASSUMPTION	UNIT	DATA SOURCE
Energy-related emissions factor	69.3	t CO_2/TJ	(IPCC, 2006)
Equivalent gasoline car mileage	0.66	GJ/km	(IEA, 2020)
Corresponding EV consumption	0.16	kWh/km	(Weiss, 2020)
Saint Kitts population	75	% of total	(CARICOM, 2000)
Nevis population	25	% of total	(CARICOM, 2000)
CAPEX EV 40 kWh (includes charger)	33 273	USD/car	Nissan, 2021
CAPEX equivalent gasoline car	16 637	USD/car	Gay, Rogers and Shirley, 2018
Lifetime EV and gasoline car	10	Years	IEA, 2020b
Average daily mileage	40	km/day	Gay, Rogers and Shirley, 2018
Petroleum gas/Gasoline cost	0.94	USD/L	Gay, Rogers and Shirley, 2018
EV consumption	16	kWh/100 km	Weiss, Cloos and Helmers, 2020
Equivalent gasoline car consumption	7.2	L/100 km	IEA, 2020a

Notes: GJ = gigajoule; km = kilometre ; L = litre.

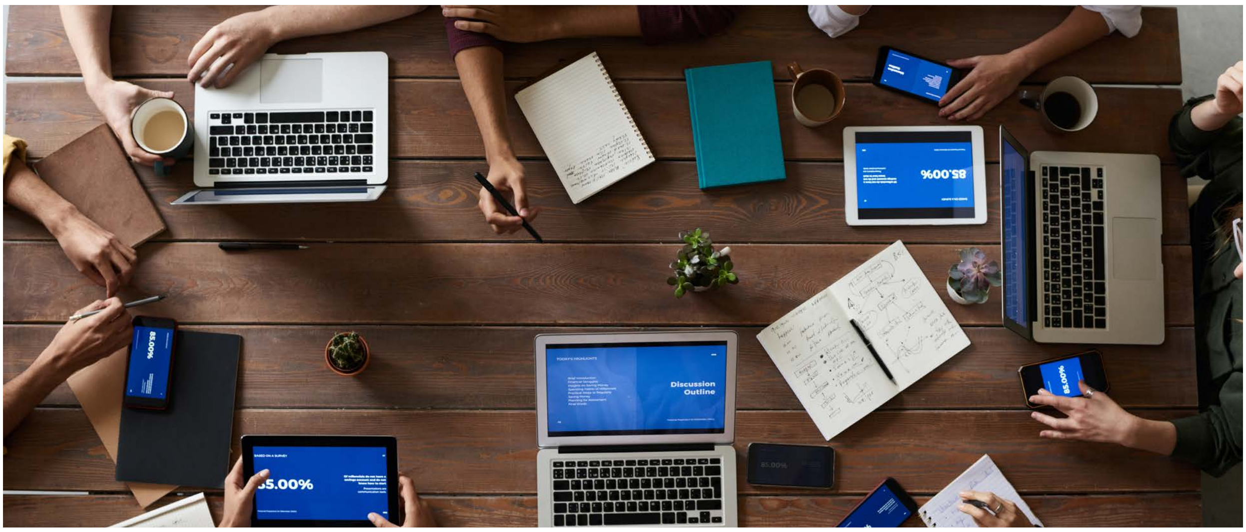
4. VALIDATION

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

Three technical sessions were held in collaboration with the Department of Environment of Saint Kitts and Nevis to present, discuss and validate the methodology used in the technical analysis, as well as the datasets used, key assumptions and revised mitigation options. The technical sessions were held with key national stakeholders to gather feedback and 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 representatives from the Department of Environment – Ministry of Environment and Cooperatives, Ministry of Public Infrastructure – Energy Unit, Nevis Electricity Company Limited (NEVLEC), St. Kitts Electricity Co Ltd (SKELEC), Traffic Department, Inland Revenue Department and other relevant policy makers.

The first technical session was an inception workshop held in February 2021, during which the International Renewable Energy Agency (IRENA) presented the scope of work and objectives of the mitigation analysis, as well as preliminary timelines for activity development. The formal kick-off meeting was held in April 2021 as the second technical session. The kick-off technical session's goal was to explain the proposed scope of work in detail, discuss the underlying methodology for analysing and modelling enhanced mitigation options, and clarify the availability of energy datasets. The third meeting, held in June 2021, was a prevalidation, at which key national stakeholders were presented with the specific datasets and assumptions used, as well as the preliminary results and findings of the modelling exercise. Based on the previous session, IRENA shared a Technical Memorandum with key national stakeholders that illustrated the information, data and assumptions for the development of the enhanced mitigation model to support the analysis for the revision of Saint Kitts and Nevis' Nationally Determined Contribution, as well as a feedback form to collect feedback for potential model revisions or adjustments. A set of feedback and comments was prepared by key national stakeholders, including the Department of Environment, the Energy Unit, and both utilities, to refine some of the model assumptions. As a result, given the methodology behind the analysis, IRENA updated some assumptions and incorporated the inputs to the greatest extent possible. The revisions and updates are already reflected in the report's results.

In collaboration with the Department of Environment of Saint Kitts and Nevis, a final close-out technical session will be held to present the findings and overall results of the technical study, as well as provide insights and recommendations for climate action implementation.



5. RESULTS

The main findings from the modelling for each option are presented in this chapter. The results and outcomes are discussed in detail, with key figures and charts showing how Saint Kitts and Nevis can meet ambitious renewable energy generation targets in the power sector and implement emobility by 2030.

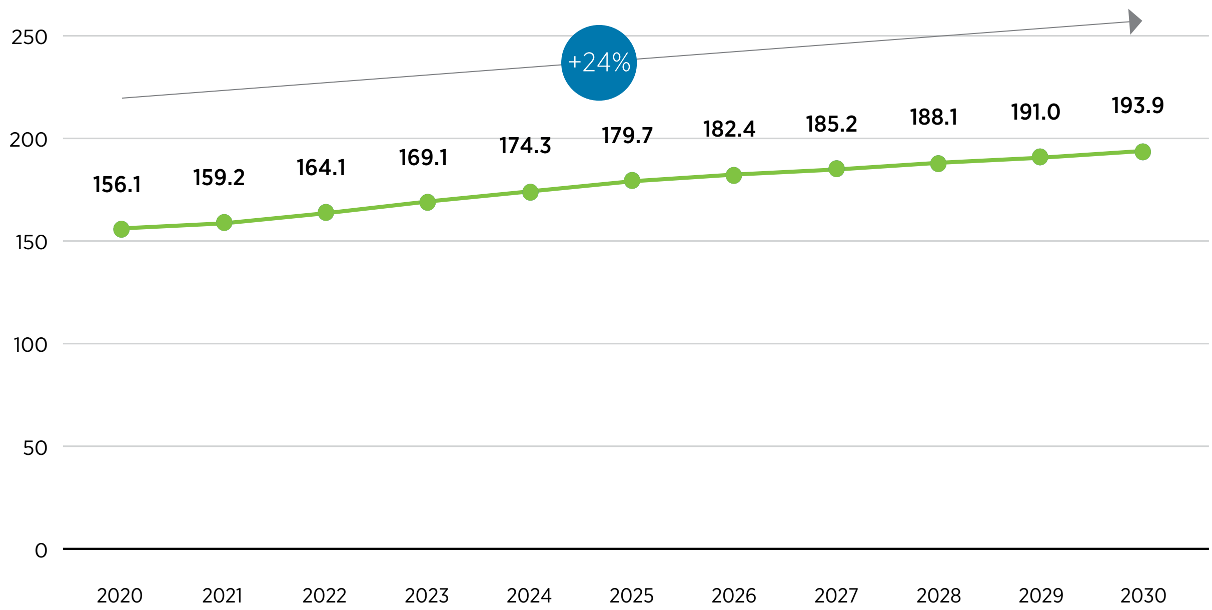
The first two sections, respectively, describe the baseline emissions scenario and the greenhouse gas (GHG) reduction potential of the various mitigation options considered for the power sector. Following that, in the third section, the cost-effectiveness of the mitigation options considered is presented. Finally, sections 5.4 and 5.5 examine the results of combined mitigation options as well as the findings of the transport sector analysis.

5.1 BASELINE EMISSIONS

The results of the baseline emissions, the business-as-usual scenario, performed for the current power system of Saint Kitts and Nevis show that the power system is highly dominated by fossil fuels with around 97% of the current electricity demand of Saint Kitts and Nevis being covered by fossil fuels and only a small electricity share coming from renewables. Hence, there is a lot of potential to increase the share of renewables and subsequently reduce fossil fuel generation. The baseline scenario shows high emission values of GHG emissions per year. Figure 18 illustrates the estimated amount of GHG emissions from 2020 to 2030.

As shown in the chart, for the baseline scenario, the total carbon dioxide (CO_2) emissions for the power sector from both systems (grid-connected) accounts for 156 gigagrammes of CO_2 (Gg CO_2) in 2020 and is projected to reach 180 Gg CO_2 in 2025 and 194 Gg CO_2 in 2030.

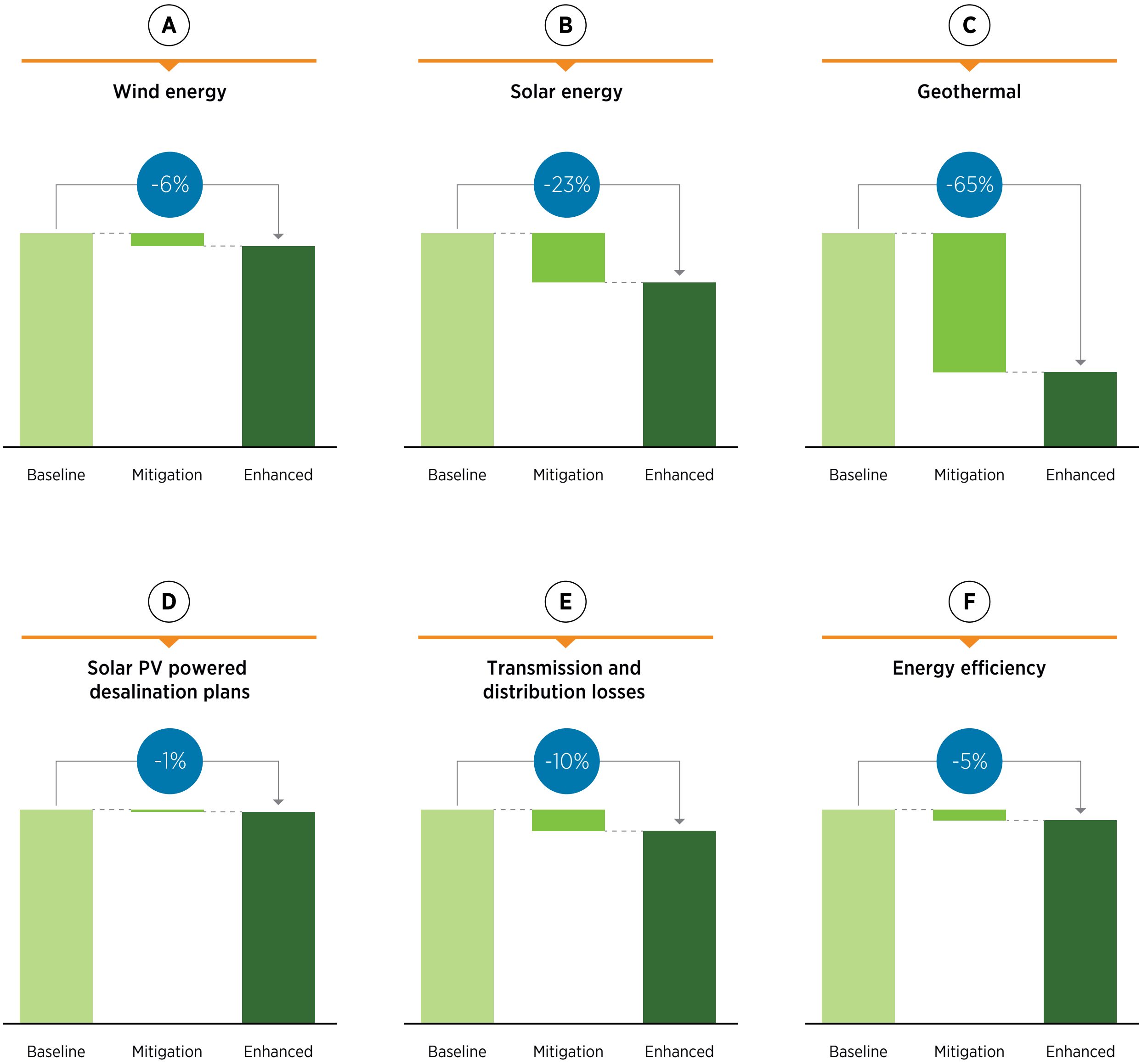
Figure 18: GHG emissions in the power sector based on a baseline scenario for the years 2020-30 (Gg CO_2)



5.2 MITIGATION POTENTIAL IN THE POWER SECTOR

The GHG reduction potentials of the analysed individual mitigation options are presented in Figure 19. In 2030, the baseline emissions are estimated to be 194 Gg CO_2. The figure illustrates that the most effective mitigation measures consist of actions directly impacting the carbon intensity on the supply side, as well as from the transmission and distribution (T&D) grid upgrade. In this context, the geothermal power plants mitigation option is the one with the largest GHG mitigation potential, with savings of up to 65% compared with the baseline scenario in 2030. Other mitigation options are the utility-scale solar photovoltaic (PV) (23% reduction by 2030 compared with baseline), grid efficiency (10% reduction), onshore wind power (6%) and solar water heating systems (5%). Due to their lower power capacity, the mitigation option involving the solar PV facilities that will power the two desalination plants has no significant impact on GHG emissions.

Figure 19: GHG reduction potential of individual mitigation option in 2030 compared with the baseline scenario (in %)



The options related to geothermal power plants and utility-scale solar PV lead to the largest share of renewable electricity in the mix and the largest emissions reductions. It is important to highlight that a surplus electricity production is noted for the geothermal power option specifically in the context of Nevis' energy system with 125.6% renewable power by 2025 and 116.6% by 2030. As this alternative considers the power systems as separate with no interconnection between the islands, the excess renewable energy does not benefit the overall GHG balance of the system. The case of interconnection is illustrated and analysed in the section related to aggregated options.

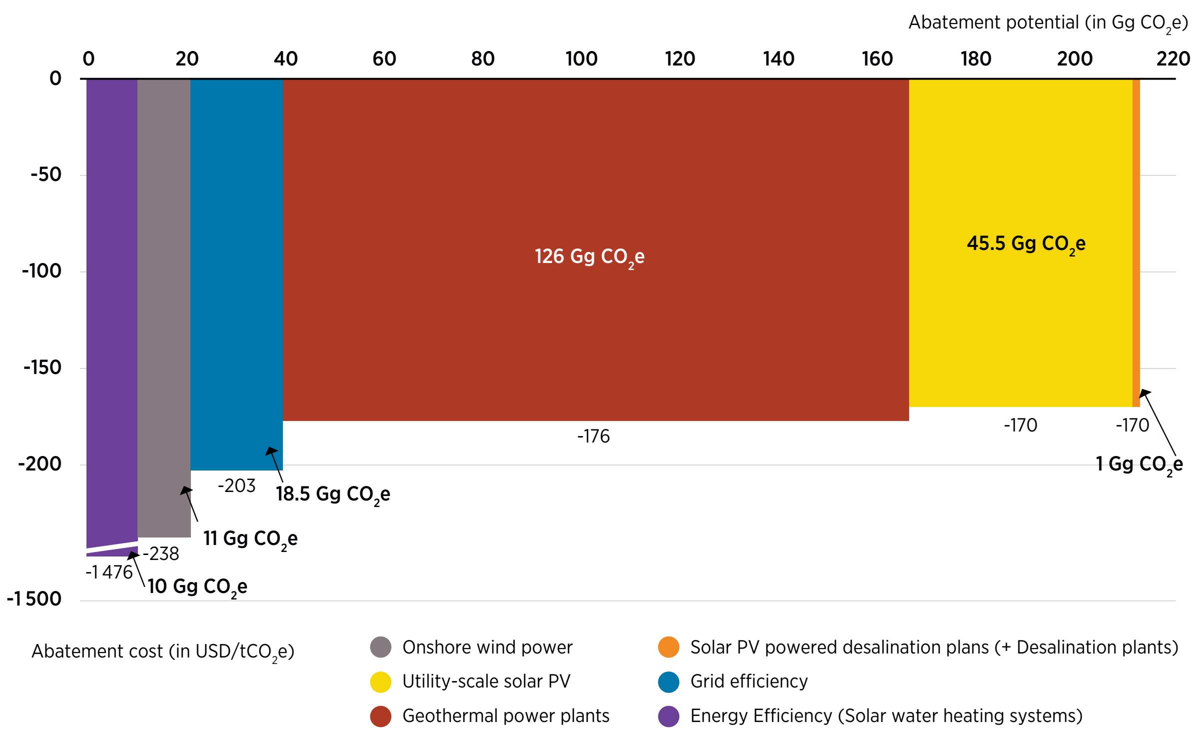
5.3 MARGINAL ABATEMENT COST CURVES FOR THE POWER SECTOR

This section presents the outcomes of the cost-effectiveness analysis of individual mitigation options for the power sector, which is presented as marginal abatement costs curves, as described in Chapter 3.3.

Figure 20 presents the results of the assessed mitigation options for the year 2030. The estimated GHG reduction potential varies greatly between the mitigation options as presented in the previous section. The results represent a snapshot in time of evaluating the mitigation options based on current information available.

The individual mitigation options are ranked according to the increasing marginal abatement cost per tonne of CO_2 reduction (USD/t CO_2). However, it is important to note that the marginal abatement cost curve represents a visual representation of the various choices being evaluated. As a result, it conducts an individual evaluation and disregards potential interactions between the options considered, as well as their probable effects on the calculated abated GHG and cost. The MACCs assess the individual mitigation options when compared with the baseline, not including the aggregation of different options.

Figure 20: Marginal abatement cost curves for power sector (2030)



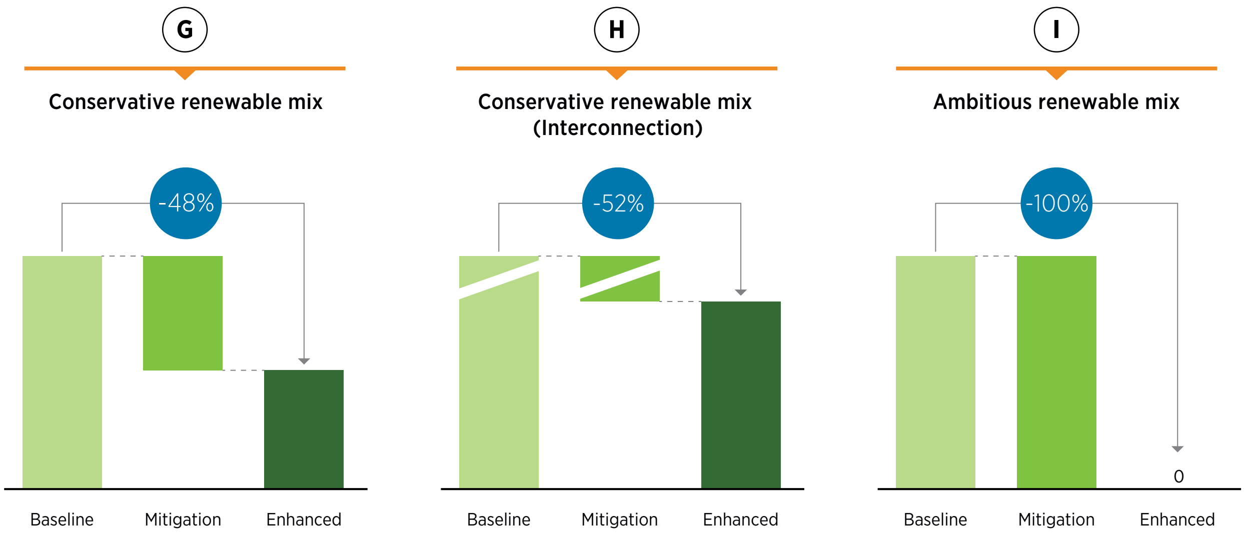
All the mitigation options demonstrate a negative GHG abatement cost, implying that the initial investment is converted into economical savings compared with the current practice of the country. The most cost-effective measure is energy efficiency, which considers the inclusion of 5% solar water heating systems for the residential and services sectors, followed by onshore wind, the upgrade of the T&D grid, geothermal power plants, utility-scale solar PV and, finally, the small-size on-grid solar PV power plants to supply the desalination plants. The mitigation option considering the solar PV facilities which will power the two desalination plants does not have significant impacts on GHG emissions due to their relatively small power capacity.

5.4 MITIGATION POTENTIAL FROM AGGREGATED SCENARIOS

As explained in the previous section, besides from the individual mitigation options based on those in the supply- and demand-side sectors, several aggregated options which combine various mitigation options were developed to analyse and highlight potential synergies between the mitigation options, which are usually not captured through a MACC.

The GHG reduction potentials of the aggregated mitigation options are presented in Figure 21. In 2030, the baseline emissions are estimated at 194 Gg CO_2. The figure illustrates the emissions abatement for the three different aggregated options.

Figure 21: GHG reduction potentials of the aggregated mitigation options in 2030



The "Conservative renewable mix" alternative (G) aggregates the most mature mitigation options to be implemented within a shorter time frame to supply the baseline demand, these being the 35.7 megawatts (MW) of PV by 2023 in Saint Kitts and the 10 MW of geothermal energy by 2025 in Nevis. As illustrated in Figure 22 and Figure 23, this alternative features excess renewable electricity production from renewable energy in Nevis. The renewable power generation reaches 32% in Saint Kitts and 117% in Nevis, showing an oversupply of electricity in the smaller island. As the islands are not interconnected, the generation excess does not impact the energy system or the potential GHG emissions reductions in Saint Kitts.

In this context, based on alternative (G), the "Conservative renewable mix + interconnection" alternative (H) simulates the grid systems from both islands to be interconnected, with the demand and supply from both energy systems aggregated. It is noted that Saint Kitts' power system would benefit from the excess renewable energy generated in Nevis, resulting in an aggregated interconnected power system with 53% renewable energy share and, respectively, lower emissions compared with an alternative in which no interconnection is assumed. This specific alternative highlights the complementarity of the strategies of each island in terms of renewable sources, while foreseeing a decarbonised energy supply mix. Since interconnection is not a mitigation measure in and of itself and the analysis is focused on determining the effectiveness of cost-mitigation measures, the associated costs were not considered.

Finally, the aggregated "Ambitious renewable mix" alternative (I), which includes all mitigation options included as part of this analysis, namely options A to F, illustrates a situation whereby Saint Kitts and Nevis' power sector, due to the high share of renewable energy installed capacities and reduced demand due to grid and demand efficiency, is carbon-neutral by 2030. The alternative highlights that there is a benefit for both islands from generation surpluses, a 6% surplus for Saint Kitts and 18% for Nevis, which will become the base of the analysis of potential electricity cross-sectoral uses, such as for the introduction of electric vehicles (EVs) which can absorb the excess renewable electricity. In this context, the specific case of the coupling strategy with the transport sector will be analysed in Chapter 5.5. This strategy will show to have an increased beneficial GHG impact to the overall energy sector besides that from the already decarbonised power mix. The shares of renewables in the power mix reached by each aggregated option is illustrated in Figure 22 for Saint Kitts and Figure 23 for Nevis.

Figure 22: Renewable energy share for the aggregated options in Saint Kitts (in %)

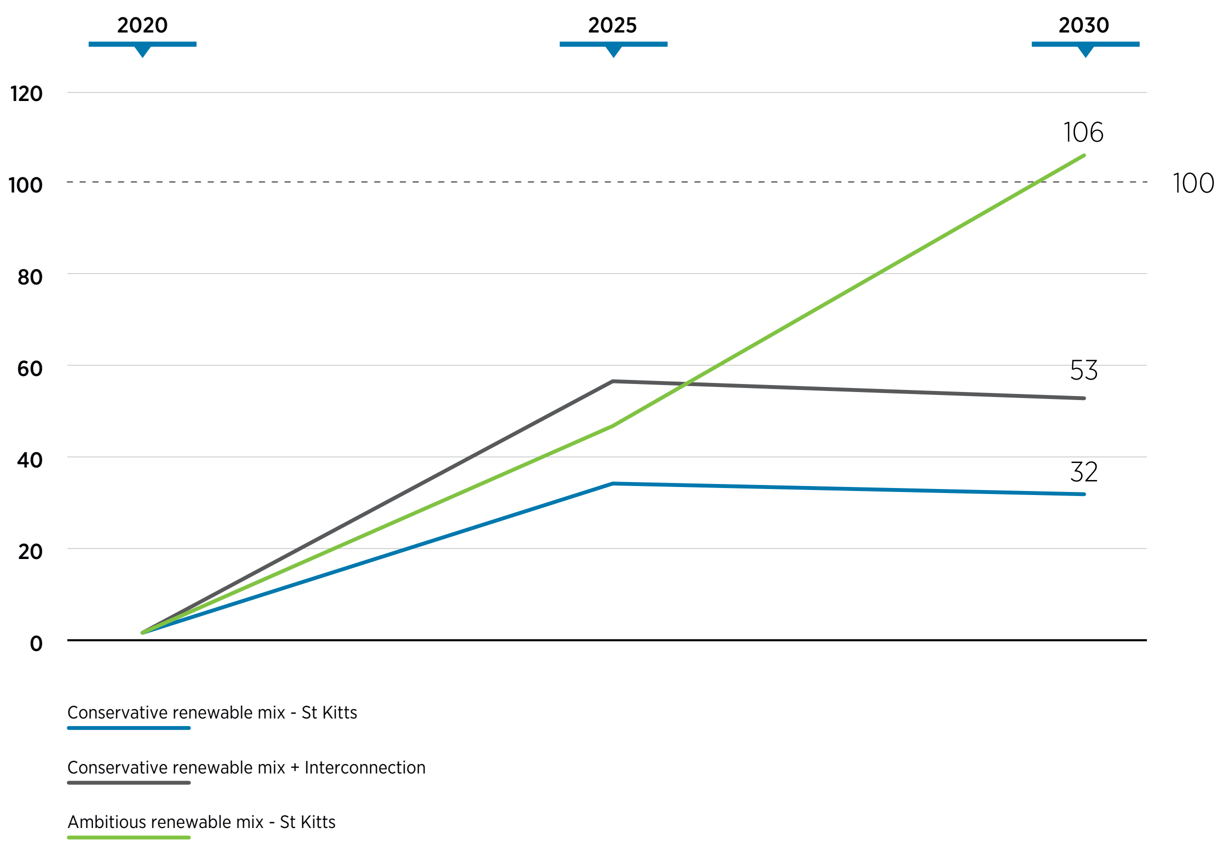
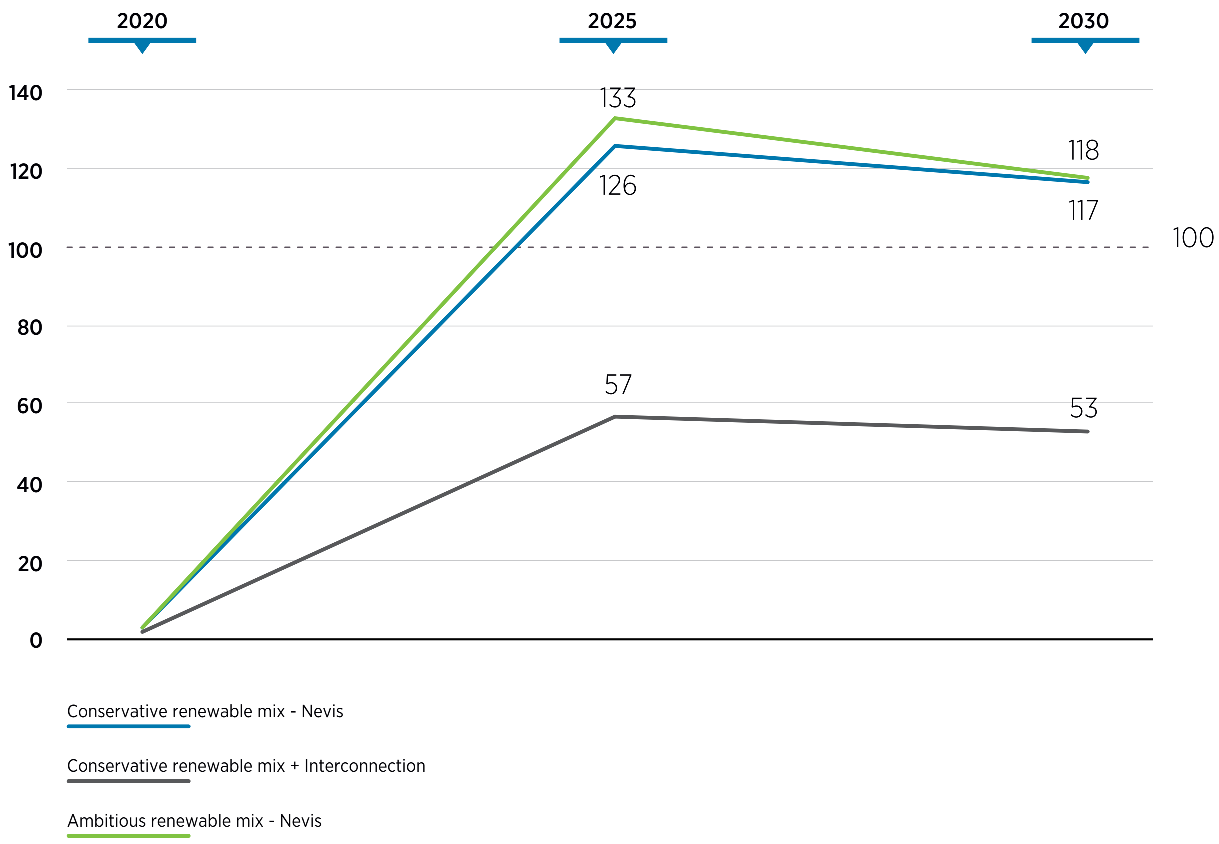


Figure 23: Renewable energy share for the aggregated options in Nevis (in %)



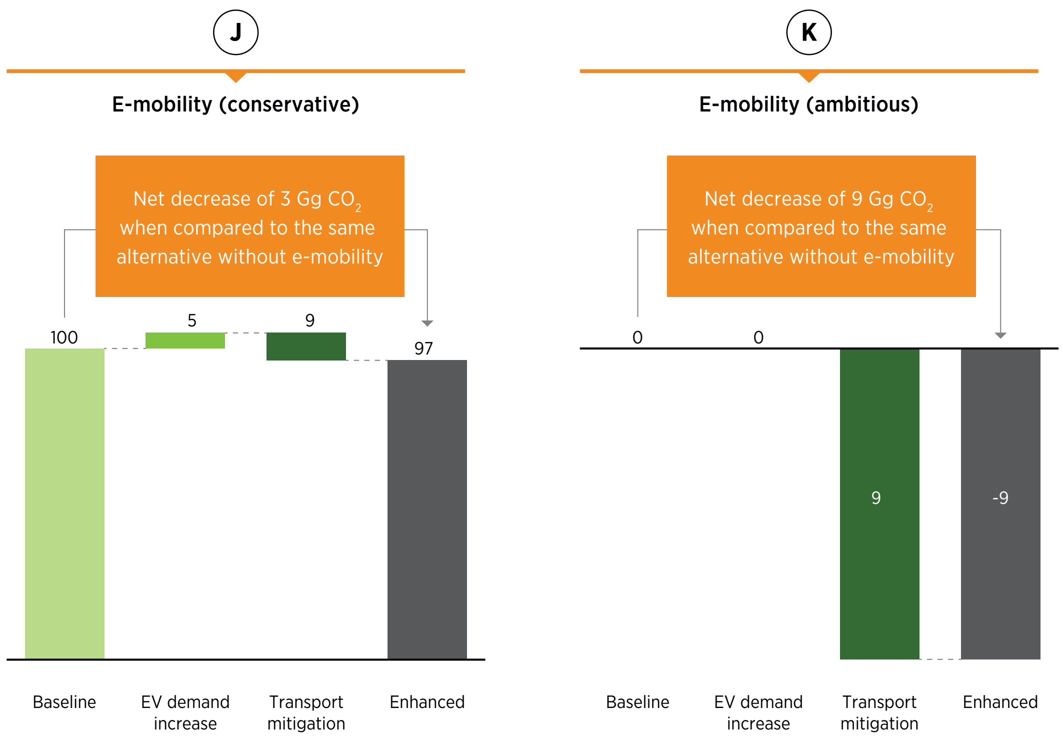
5.5 MITIGATION POTENTIAL IN THE TRANSPORT SECTOR

Saint Kitts and Nevis' transport sector is dominated by fossil fuels, mainly gasoline and diesel-powered vehicles. Hence, the analysis for the potential of renewable energy in the transport sector focused on the potential reduction in fuel imports for transport and the level of renewable electricity generation required to power EVs. The analysis investigated the possibility of progressively replacing the current fleet of vehicles with EVs by 2030.

As introduced in Chapter 5.4, some aggregated options introduce generation surpluses which can lead to potential cross-sectoral uses beyond the power sector, such as the case for EVs which can absorb the excess renewable electricity produced by the system. The aim of the transport sector analysis was to assess what level of ambition would lead to increased GHG reductions for the overall energy sector combined with the analysed power mitigation options.

In this context, after the mitigation options were analysed, two different transport sector options were modelled, one based on the "Conservative renewable mix" (option G) and the other on the "Ambitious renewable mix" (option I). The methodology for modelling the deferrable load, namely how the electrical demand would increase to support the uptake of the EVs, was described in Chapter 3.5. In this context, the results of the model have shown that by replacing a share of 10% of the gasoline consumption in the transport sector with EVs by 2030, the total corresponding electricity demand for both Saint Kitts and Nevis increases to around 8 500 megawatt hours per year.

Figure 24: GHG reduction potentials of the transport options in 2030 (in Gg CO_2)



For the assessment of the "E-mobility (conservative)" transport option, the "Conservative renewable mix" (option G) was used as the baseline scenario with total GHG emissions of 100 Gg CO_2. The increased load by the EVs was attributed 75% to Saint Kitts and 25% to Nevis. The "E-mobility (conservative)" alternative resulted in an overall decrease of 3.4% (3 Gg CO_2) GHG emissions. In this case, since the power mix is not fully renewable, the GHG emissions from this alternative increase for the power sector to 105 Gg CO_2 but decrease even more for the respective savings in the transport sector (9 Gg CO_2), resulting in the net GHG savings of 3 Gg CO_2. In this case it is noted that all emissions are the result of the Saint Kitts power mix, which is about 70% fossil fuels in this alternative.

For the assessment of the "E-mobility (ambitious)" transport option, the "Ambitious renewable mix" (option I) was used as the baseline scenario. This baseline scenario, as depicted in Figure 22 and Figure 23, relies completely on renewable energy sources and, therefore, is carbon-free. Consequently, the whole decrease in GHG emissions from the transport sector (9 Gg CO_2) does not need to be offset by any increase in emissions in the power sector, resulting in the net GHG savings of 9 Gg CO_2.

All mitigation measures for transitioning to EVs that have been evaluated result in a reduction in GHG emissions.

When analysing the cost of the transport options, the results show positive abatement costs for both, meaning that with the current assumptions there would be an associated increase in cost compared with the reference solution considered. For the assessment of the "E-mobility (conservative)" transport option, the abatement cost is estimated at USD 207.8 per tonne of CO_2.

6. DISCUSSION AND RECOMMENDATIONS

The purpose of this study was to determine the cost-effectiveness of identified mitigation options in Saint Kitts and Nevis, with an emphasis on the power sector and an assessment of sector coupling resulting from the country's adoption of emobility. The cost-effectiveness analysis was conducted using the marginal abatement cost curve (MACC) methodology, and this report details the technical and economic assumptions used. This methodology can be an effective tool for assisting in climate policy decision-making because it provides information on the potential for greenhouse gas (GHG) abatement and associated costs of the identified mitigation options.

The findings of the analysis provide critical information for identifying, quantifying and selecting appropriate mitigation options to help the country meet its climate goals. This analysis can aid in the development and implementation of the updated Nationally Determined Contribution (NDC), as well as inform policy makers about potential pathways for increasing renewable energy deployment during a national energy transition. The MACC methodology is appropriate for assessing the cost-effectiveness and implementation of individual mitigation options. Additionally, aggregated alternatives were presented to evaluate power sector combination strategies and to evaluate the integration of transportation sector analysis via sector coupling in order to evaluate the combination of various mitigation options.

The cost-effectiveness analysis conducted to inform Saint Kitts and Nevis' update of the NDC concludes that implementing the "Conservative renewable mix" alternative (G) reduces overall GHG emissions from 194 gigagrammes (Gg) to 100 Gg in 2030 compared with the business-as-usual scenario, whereas implementing the "Ambitious renewable mix" alternative (I) results in an overall renewable-powered and carbon-free power system. Additionally, the transport sector analysis revealed the potential to reduce transportation emissions beyond the power sector by implementing vehicle fleet electrification strategies. As a result, the updated GHG mitigation assessment includes a set of mitigation options that not only meets but also exceeds the level of ambition committed in Saint Kitts and Nevis' first NDC, owing to updated mitigation options in the power sector, and the adoption of sector coupling strategies in conjunction with the introduction of emobility.

It is critical to understand that without the necessary policies and regulations, the identified mitigation options and associated GHG reductions are unlikely to occur. The following sections provide some context for future policy developments that will enable Saint Kitts and Nevis to implement mitigation measures and decarbonise the country's energy system.

6.1 INCREASE RENEWABLE ENERGY DEPLOYMENT IN THE ENERGY SECTOR

Saint Kitts and Nevis has renewable energy potential that can be harnessed to increase energy security and independence at a lower cost than fossil fuel imports. The transition away from fossil fuel generation, which comprises nearly all diesel fuel oil units, and towards a green energy mix based on renewables has the potential to provide significant long-term benefits, but it will require significant investment. Governments, ministries, utilities, and public and private stakeholders must all be engaged and benefit from full participation in resolving these complex and dynamic issues in order to ensure a smooth transition to a cleaner and greener energy system. Saint Kitts and Nevis benefits from extensive renewable energy resources, which enables this transition to occur. To do so, the government must enact action plans for accelerating the adoption of low-cost renewable energy and grid infrastructure at a rate that can support both power sector decarbonisation and end-use electrification.

The technological pathways towards a decarbonised energy system have crystallised, with rapid deployment and scale-up solutions dominating. While technologies, markets and business models evolve constantly, there is no reason to wait for new solutions. With existing options, significant advancement is possible. According to the International Renewable Energy Agency (IRENA) *World Energy Transitions Outlook*, electricity needs to be the primary energy carrier by 2050, rising from a 21% share of total final energy consumption in 2018 to over 50% in 2050. In this context, IRENA's analysis indicates that sectoral boundaries are shifting as end-use applications such as transportation and heating electrify. This increase is primarily due to the substitution of renewable energy for fossil fuels in end-use applications. As a result of this shift, the annual growth rate of renewable technologies will more than double. End-use electrification will also reshape several sectors, most notably transportation, with electric vehicles (EVs) accounting for 80% of all road traffic by 2050.

Source: www.pexels.com/.

Due to the number of cost-effective renewable energy solutions revealed in this analysis, Saint Kitts and Nevis can rapidly deploy them at scale and convert plans into a set of investment, regulatory and societal opportunities. According to current estimates, the electricity sector in Saint Kitts and Nevis could be carbon-neutral by 2030. It is crucial to note that all mitigation solutions resulted in negative abatement costs, showing that they are both economically and environmentally viable under the conditions evaluated.

Deployment policies foster market development, enabling scale-up, lowering technology costs and increasing investment levels consistent with energy transition needs. Given the large amounts of public finance injected into economies as part of recovery efforts, such policies will shape the energy transition's direction and lay the groundwork for the significant increase in private-sector investment required until 2050. (IRENA, 2021a).

6.2 BUILD CLIMATE RESILIENCE THROUGH ISLAND INTERCONNECTION

The country is made up of two main islands, Saint Kitts and Nevis, which are separated by a 3 kilometre strait, The Narrows. The strait is relatively shallow, measuring 7-10 metres in depth. These characteristics make it technically feasible to connect Saint Kitts and Nevis via submarine cable.

A preliminary assessment identified the suitability of a 10 megawatt (MW) capacity interconnection cable (Deloitte, 2017). Though the power exchange capacity will be restricted to 10 MW, the assessed cable connection will be made up of two 10 MW lines using separate pathways, thus increasing the reliability of the connection through the addition of a second redundant line. The study assumed an overnight cost of USD 25 million for a 20 MW line.

The interconnection between the two islands could increase supply reliability for both islands and the respective grid systems of St Kitts Electricity Co Ltd (SKELEC) and Nevis Electricity Company Limited (NEVLEC) due to the share of reserve capacity. Based on the renewable technology implementation plans, renewable energy surplus from solar in Saint Kitts or geothermal in Nevis could serve the load of both islands via the interconnection system.

Herein, the island interconnection has been evaluated exclusively from a GHG point of view. In an alternative where the most mature renewable energy capacities of solar and geothermal are implemented, namely the "Conservative renewable mix + interconnection" alternative (H), it is forecast that the power sector will become decarbonised by 2030. Compared with the same alternative with no interconnection between the islands, the forecast renewable energy generation would exceed demand in Nevis with a share of 116% while Saint Kitts would reach a renewable share of 92%. Therefore, the addition of an interconnection reduces the emissions by an average of 7 Gg CO_2 in 2030.

Figure 25: A map of Saint Kitts and Nevis and The Narrows strait

Disclaimer: Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA. Maps in this report, including the present appendix, do not imply any official endorsement or acceptance by IRENA in regard to country names, borders, territorial claims or sovereignty.

Source: wikipedia.org.

6.3 SCALE UP DISTRIBUTED ROOFTOP SOLAR PV SOLUTIONS[2]

In the last decade, rooftop solar photovoltaic (PV) has become very popular as distributed energy technology. The decrease in prices, ease of installation and simplicity have helped the installation of these systems in residential, commercial and industrial buildings. Distributed renewable energy systems are located close to the load, which minimises transmission and distribution (T&D) losses, and can help the grid by stabilising voltage locally.

Solar PV systems can be coupled with a battery system to provide energy storage. For example, when coupled with residential PV, the battery storage system can absorb excess electricity during the day and use it at night. This is also known as behind-the-meter (BTM) storage because it is located downstream of the connection point between the utility and the customer (IRENA, 2020c). BTM storage can aid consumers in decreasing their electricity bill, through demand-side management. This is done by absorbing electricity when there is excess renewable energy generation or when electricity prices are cheaper and selling the absorbed electricity to the grid when electricity prices are expensive. However, this works only if the consumer can sell back to the grid, which is not always the case. Aggregated BTM storage can provide support for system operation, while also deferring network and peak capacity investment (IRENA, 2019b).

The deployment of rooftop PV systems can be promoted via different support schemes, and some of these include feed-in tariffs, tax rebates or net metering. Another suggestion for making rooftop PV beneficial is to design time-of-use tariffs. Such tariffs are designed to incentivise customers to use more electricity at off-peak times. Time-of-use tariffs charge higher rates during peak demand and lower rates during certain hours of the day or night when the electricity demand is at its lowest. This enables the customers to adjust their electricity consumption voluntarily in order to balance demand (IRENA, 2019c).

Source: www.pexels.com/.

2 Distributed rooftop solar photovoltaic (PV) is planned to be implemented on both islands at the government's direction. Due to a lack of data at the time of this analysis and the relatively minor overall expected mitigation impact, it was decided not to include it as an independent additional mitigation measure in the modelling exercise.

6.4 ACCELERATE THE TRANSITION IN THE TRANSPORT SECTOR

The electrification of transport is in many ways an ideal use of renewable power, given the variable output of sources such as solar and wind. Road vehicles are parked about 90% of the time, allowing their charging schedules to be optimised using smart power management tools to accommodate (or even take advantage of) those variations in power generation (IRENA, 2019d). Recent research finds that adjusting charging rates up or down to match the changes in wind and solar generation, in combination with price-sensitive smart charging systems, can more than double the share of renewable energy used by EVs (Kasten et al., 2016; Schuller, Flath and Gottwalt, 2015).

EVs offer several advantages, including improved air quality and reduced operating and maintenance costs. Adoption rates will depend heavily on both public policies and continuing declines in the cost of batteries. Bloomberg New Energy Finance estimates that battery costs will drop quickly enough to make EVs cost-competitive without subsidies by 2024 (Bloomberg NEF, 2018). Especially in urban environments, the air pollution benefits of EVs can make a decisive difference. As a result, an increasing number of cities have put in place regulations that favour electric driving.

Source: www.pexels.com/.

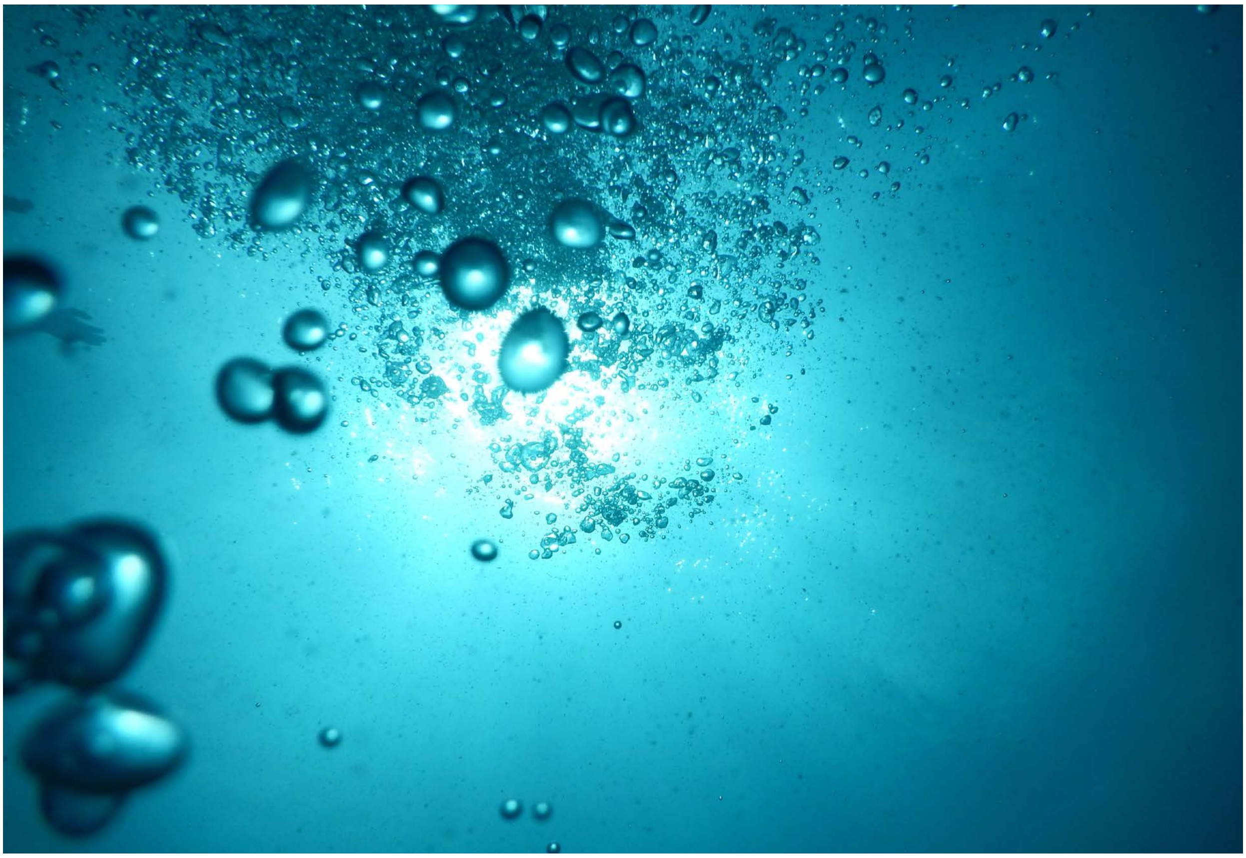
EVs also offer the potential of so-called vehicle-to-grid (V2G) services. When parked and connected to the grid, their batteries can help regulate voltage and frequency, or supply electricity to meet spikes in demand. The vehicle capacities are significant: car battery capacity already far exceeds the capacity of all other electricity storage. However, this V2G potential has not yet been widely taken advantage of, outside of certain pilot projects. Realising these potential synergies requires intelligent grids and smart power management strategies. This is especially important to avoid the massive investment in upgrading distribution networks that would be required if EV charging were uncontrolled. Making the transition requires careful planning. Expansion of electrification without the corresponding expansion of renewable energy will result in higher emissions from the power sector, even though emissions from the transport sector significantly decline (IRENA, 2019d).

6.5 PREPARE FOR A GLOBAL MARKET FOR GREEN HYDROGEN[3]

Hydrogen can be produced with multiple processes and energy sources. Natural gas and coal presently account for approximately 95% of global hydrogen production (IRENA, 2020b). As energy transitions progress, green hydrogen produced from low-cost renewable electricity will play a growing role.

One of the alternatives modelled as part of this analysis, the aggregated "Ambitious renewable mix", which includes all mitigation options identified, sees Saint Kitts and Nevis' power sector as carbon-neutral by 2030. It is to highlight that this alternative benefits in both islands from generation surpluses, a 6% surplus for Saint Kitts and a 18% for Nevis, which can become the base of additional analysis of potential electricity cross-sectoral uses, such as green hydrogen production.

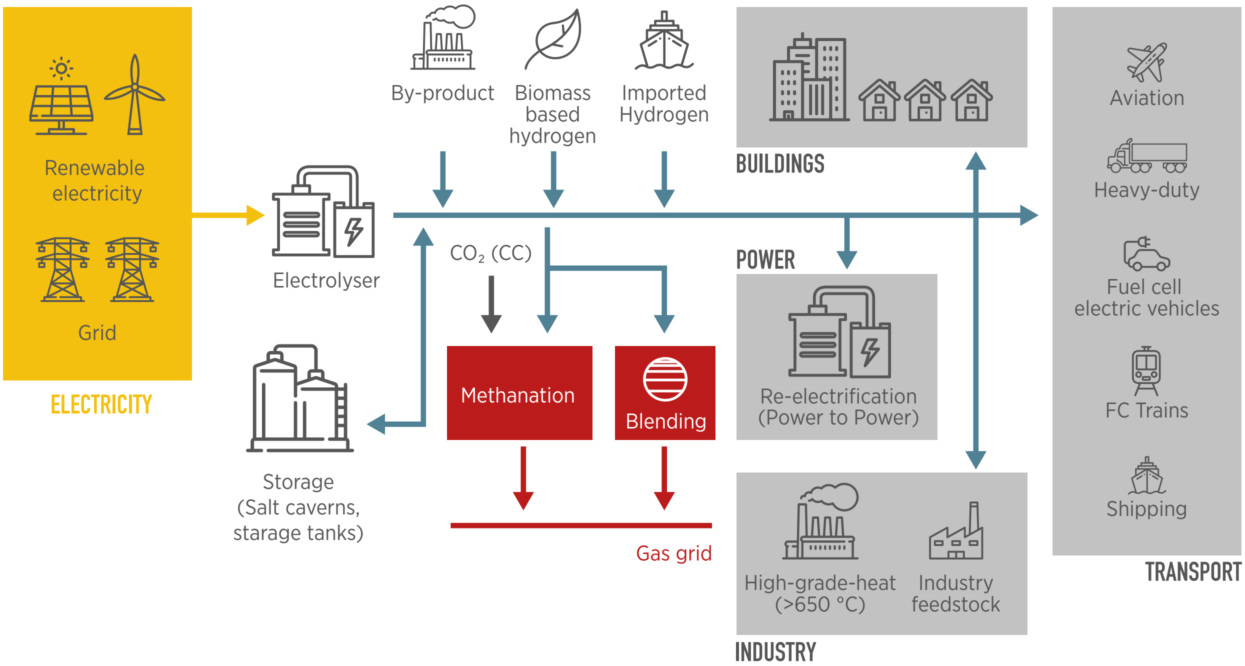
Green hydrogen offers a diversity of potential uses. While direct electrification via renewable energy and energy efficiency is the most efficient path to reducing emissions in easier-to-abate sectors such as buildings, low-temperature industry (e.g. agriculture, pulp and paper) as well as some transport (mainly light and short-haul freight vehicles, but also long-haul transport in cases where charging infrastructure can be deployed), green hydrogen can play a crucial role in supporting the decarbonisation of harder-to-abate sectors where direct renewable electrification is not technically feasible or would take too long (IRENA Coalition for Action, 2021b). According to IRENA's *World Energy Transitions Outlook*, green hydrogen can contribute to significant carbon dioxide (CO_2) emissions abatement as part of a 1.5°C pathway – particularly in the industrial sector as well as long-haul transport, shipping and aviation (IRENA, 2021a).



Source: www.pexels.com/.

3 Hydrogen is planned to be analysed in future studies at the direction of the government. Due to a lack of data at the time of this analysis and the fact that hydrogen production as a mitigation option had not been nationally validated, it was decided not to include it as an additional mitigation measure in the modelling exercise.

Figure 26: Integration of variable renewable energy sources into end uses by means of hydrogen



Source: IRENA (2018).

Figure 26 illustrates how power-to-hydrogen can provide flexibility to accommodate increasing shares of variable renewable energies into the power system (IRENA, 2018).

Each country's hydrogen strategy is driven by its domestic energy demand and renewable energy potential. Through the export of green hydrogen, countries rich in renewable resources but low in national electricity demand are well-positioned to support the deployment of additional renewable energy for green hydrogen production. Other countries can reduce pressures on limited domestic resources and make further progress on climate objectives through green hydrogen imports.

Initial efforts to develop global trading of green hydrogen are beginning to emerge. Countries with high production potential and countries with high demand for green hydrogen are entering into bilateral agreements to explore new trade routes (IRENA, 2021c). Moving forward, the path towards a global green hydrogen market will not only require overcoming technical and economic barriers, but also the removal of market and regulatory obstacles. For green hydrogen to become a tradeable commodity, producers must be able to get their product to international markets, off-takers of green hydrogen must also have assurance the hydrogen product they are receiving is produced from 100% renewable energy, and governments must create or adapt existing regulatory frameworks to enable producers to generate, transport and store green hydrogen when and where efficient (IRENA Coalition for Action, 2021b).

Sizing the hydrogen conversion capacity for a country must be done hand in hand with renewable energy capacity planning and a good understanding of the future trends of electricity consumption as well as technology and fuel costs. The need for a dedicated new supply infrastructure may limit hydrogen use to certain countries that decide to follow this strategy. Therefore, hydrogen represents a complementary solution that is especially relevant for countries with ambitious climate objectives (IRENA, 2019a).

6.6 RECOMMENDED MITIGATION OPTIONS

Based on the current planned renewable energy project portfolio, the power sector of Saint Kitts and Nevis could be decarbonised by 2030, according to this technical study. The country's renewable energy resources are vast. In terms of GHG emissions abatement, the study supported the quantification of individual mitigation options' potential and cost-effectiveness, as well as the potentials of scenario aggregation and the electrification of the transport sector. The analysis indicates that the most effective mitigation options consist of actions directly impacting the carbon intensity on the supply side, as well as from the T&D grid upgrade. In this context, the geothermal power plants mitigation option is the one with the largest GHG mitigation potential with average savings of up to 65% compared with the baseline scenario by 2030. Other mitigation options are utility-scale solar PV (23% reduction by 2030 compared with baseline), grid efficiency (10%), onshore wind power (6%) and energy efficiency (5%). All mitigation measures have negative abatement costs, indicating that they are both economically and environmentally attractive in the circumstances examined. The results for the transport sector highlight a further 9 Gg CO_2 potential abatement relying on the renewable generation surpluses from the mitigation options in the power sector. The latter has a resulting positive abatement cost indicating the additional cost of implementing this measure compared with the reference solution. Based on the results from the analysis, Table 14 lists the recommended mitigation options to be included in the NDC update, ordered from higher to lower GHG abatement potential.

Table 14: Summary of mitigation measures evaluated for GHG emissions reduction potential in Saint Kitts and Nevis

MITIGATION OPTION	DESCRIPTION	TARGET YEAR
Geothermal power plants	Installation of **25 megawatts (MW) of geothermal power capacity** additions with 10 MW in Nevis by 2025 and 15 MW in Saint Kitts by 2030.	2025 2030
Utility-scale solar PV	Installation of **35.7 MW of utility-scale solar photovoltaic (PV) capacity** additions in Saint Kitts by 2023.	2023
Grid efficiency	Transmission and distribution loss reductions of **10%** in Saint Kitts and **6%** in Nevis by 2030.	2030
Onshore wind power	Development of **6.6 MW of wind power capacity** additions in Saint Kitts by 2024.	2024
Solar water heating systems	Reduction of **5% in the electricity demand** with the introduction of solar water heating systems in Saint Kitts and Nevis by 2030.	2030
Solar PV-powered desalination plans	Additions of **two solar PV plants of 0.75 MW** each to supply two desalination plants, one in Saint Kitts and one in Nevis, by 2030.	2030
Emobility	Achieve **10% fuel savings**, compared with the baseline scenario, with the deployment of emobility in Saint Kitts and Nevis by 2030.	2030

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8. APPENDICES

8.1 APPENDIX A – BASELINE ELECTRICITY GENERATION CAPACITIES

Table 15: Baseline electricity generation capacities for Saint Kitts

NAME	COMMISSIONING	LIFETIME	DECOMMISSIONING	UNIT	2020	2025	2030
G1	1999	35	2034	MW	6.1	6.1	6.1
G2	2009	35	2044	MW	3.9	3.9	3.9
G3	2008	35	2043	MW	3.9	3.9	3.9
G4	2007	35	2042	MW	3.9	3.9	3.9
KV12 #1	1971	35	2006	MW	0.0	0.0	0.0
KV12 #2	1971	35	2006	MW	0.0	0.0	0.0
K8	1987	35	2022	MW	3.5	0.0	0.0
G9	1987	35	2022	MW	3.5	0.0	0.0
G10	2010	35	2045	MW	3.9	3.9	3.9
G11	2010	35	2045	MW	3.9	3.9	3.9
G12	2011	35	2046	MW	3.9	3.9	3.9
G14	2011	35	2046	MW	3.9	3.9	3.9
Mobile set 1	2017	10	2027	MW	2.0	2.0	0.0
Mobile set 2	2018	10	2028	MW	2.0	2.0	0.0
Mobile set 3	2017	10	2027	MW	2.0	2.0	0.0
Mobile set 4	2018	10	2028	MW	2.0	2.0	0.0
Mobile set 5	2019	10	2029	MW	2.0	2.0	0.0
Mobile set 6	2019	10	2029	MW	2.0	2.0	0.0
SCASPA	2013	20	2033	MW	0.8	0.8	0.8
SKELEC Solar	2016	20	2036	MW	0.5	0.5	0.5

Note: SCASPA = St. Christopher Air & Sea Ports Authority.

Table 16: Baseline electricity generation capacities for Nevis

NAME	COMMISSIONING	LIFETIME	DECOMMISSIONING	UNIT	2020	2025	2030
Unit G3	1983	34	2017	MW	0.0	0.0	0.0
Unit G4	1989	28	2017	MW	0.0	0.0	0.0
Unit G5	1996	35	2031	MW	2.2	2.2	2.2
Unit G6[4]	1995	35	2030	MW	0.3	0.3	0.3
Unit G7[1]	1997	35	2032	MW	2.4	2.4	2.4
Unit G8	2002	35	2037	MW	2.7	2.7	2.7
Unit G9	2013	35	2048	MW	1.2	1.2	1.2
Unit G10	2016	35	2051	MW	2.5	2.5	2.5
Unit G11	2016	35	2051	MW	3.9	3.9	3.9
Nevis Wind	2010	20	2030	MW	1.5	1.5	1.5
Upgrade unit	2022	20	2042	MW	0	4.4	4.4
New unit	2021	35	2056	MW	0	3.8	3.8

4 As of 2025 and 2030, they are expected to be inactive.

8.2 APPENDIX B – RENEWABLE ENERGY SHARES OF TOTAL GENERATION FOR EACH INDIVIDUAL MITIGATION SCENARIO

Table 17: Renewable energy share of total generation for each mitigation option in Saint Kitts (%)

REF.	SCENARIO	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	Onshore wind power	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	1.2%	9.5%	9.3%	9.1%	9.0%	8.9%	8.7%	8.6%
B	Utility-scale solar PV	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	36.5%	35.4%	34.4%	33.9%	33.4%	32.9%	32.4%	31.9%
C	Geothermal power plants	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	1.2%	1.2%	1.2%	1.1%	1.1%	1.1%	1.1%	54.1%
D	Solar PV-powered desalination plants (+ desalination plants)	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	1.2%	1.2%	1.2%	1.1%	1.1%	1.1%	1.1%	1.7%
E	Grid efficiency	1.5%	1.4%	1.4%	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%	1.2%	1.2%	1.2%	1.2%	1.2%
F	Energy efficiency	1.5%	1.4%	1.4%	1.4%	1.3%	1.3%	1.3%	1.2%	1.2%	1.2%	1.2%	1.2%	1.1%	1.1%

Table 18: Renewable energy share of total generation for each mitigation option in Nevis (%)

REF	SCENARIO	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A	Onshore wind power	3.7%	5.2%	3.3%	2.7%	6.5%	6.3%	6.1%	6.0%	5.8%	5.7%	5.6%	5.5%	5.5%	5.4%
B	Utility-scale solar PV	3.7%	5.2%	3.3%	2.7%	6.5%	6.3%	6.1%	6.0%	5.8%	5.7%	5.6%	5.5%	5.5%	5.4%
C	Geothermal power plants	3.7%	5.2%	3.3%	2.7%	6.5%	6.3%	6.1%	6.0%	126%	124%	122%	120%	118%	117%
D	Solar PV-powered desalination plans (+ desalination plants)	3.7%	5.2%	3.3%	2.7%	6.5%	6.3%	6.1%	6.0%	5.8%	5.7%	5.6%	5.5%	5.5%	7.3%
E	Grid efficiency	3.7%	5.2%	3.4%	2.7%	6.6%	6.4%	6.3%	6.1%	5.9%	5.9%	5.8%	5.7%	5.7%	5.6%
F	Energy efficiency	3.7%	5.2%	3.3%	2.7%	6.6%	6.4%	6.3%	6.1%	6.0%	5.9%	5.8%	5.8%	5.7%	5.7%

8.3 APPENDIX C – GREENHOUSE GAS EMISSIONS FROM MODELLED OPTIONS

Table 19: GHG emissions from mitigation options in the power sector

REF	SCENARIO	UNIT	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	Baseline	Gg CO_2	147	151	155	156	159	164	169	174	180	182	185	188	191	194
A	Onshore wind power	Gg CO_2	147	151	155	156	159	164	169	163	169	171	174	177	180	183
B	Utility-scale solar PV	Gg CO_2	147	151	155	156	159	164	124	129	134	137	140	143	146	148
C	Geothermal power plants	Gg CO_2	147	151	155	156	159	164	169	174	135	137	139	141	143	68
D	Solar PV-powered desalination plans (+ desalination plants)	Gg CO_2	147	151	155	156	159	164	169	174	180	182	185	188	191	203
E	Grid efficiency	Gg CO_2	147	150	153	152	154	158	161	165	169	170	171	173	174	175
F	Energy efficiency	Gg CO_2	147	151	155	155	158	162	166	170	175	177	178	180	182	184

8.4 APPENDIX D – OTHER GENERAL KEY ASSUMPTIONS DATASETS

Table 20: Trend base of fuel cost projections

YEAR	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Base cost (USD/MBtu)	15.86	16.40	16.90	17.15	17.43	17.89	18.30	18.51	18.60	18.78	19.24

Table 21: Cost assumptions considered for the evaluation of renewable energy generation technologies

RENEWABLE TECHNOLOGY	CAPEX (USD/KW)	OPEX (USD/MWH)	LIFETIME	YEAR AVAILABLE	SOURCE
Wind Tier 1 Nevis	1 950	5	20	2019	Deloitte, 2017
Wind Tier 2 Nevis	2 100	5	20	2021	Deloitte, 2017
Wind Tier 3 Nevis	3 003	11.58	20	2023	Deloitte, 2017
Wind Tier 4 Nevis	3 348	12.43	20	2025	Deloitte, 2017
Wind Tier 5 Nevis	4 522	23.24	20	2027	Deloitte, 2017
Wind Tier 1 Saint Kitts	1 950	5	20	2019	Deloitte, 2017
Wind Tier 2 Saint Kitts	2 100	5	20	2021	Deloitte, 2017
Wind Tier 3 Saint Kitts	2 865	10.29	20	2023	Deloitte, 2017
Wind Tier 4 Saint Kitts	3 209	11.13	20	2025	Deloitte, 2017
Wind Tier 5 Saint Kitts	3 773	16.31	20	2027	Deloitte, 2017
Solar Tier 1	2 750	1	20	2018	Deloitte, 2017
Solar Tier 2	3 164	5.57	20	2019	Deloitte, 2017
Geothermal Nevis	6 500	45	20	2021	Deloitte, 2017
Geothermal Saint Kitts	8 750	50	20	2025	Deloitte, 2017

Table 22: Percentage of final energy consumption by households and services and share of energy used for water heating

ITEM	VALUE	SOURCE
Percentage of final energy consumption by households	12%	Howard, 2019
Percentage of final energy consumption by services	25%	Howard, 2019
Share energy consumption for water heating in households	34%	Howard, 2019
Share energy consumption for water heating in services	22%	Pérez et al., 2019

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