ANTIGUA AND BARBUDA
TECHNOLOGY PLAN FOR ROAD TRANSPORT ELECTRIFICATION WITH RENEWABLES

Technology
and infrastructure

CLIMATE ACTION SUPPORT

ISBN: 978-92-9260-581-0

Citation: IRENA (2024), *Antigua and Barbuda: Technology plan for road transport electrification with renewables*, International Renewable Energy Agency, Abu Dhabi.

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About this document

This technical report summarises the main outcomes and findings of the assessment of a technology plan for transport electrification with renewables on the island of Antigua to inform the implementation of the country's updated Nationally Determined Contribution.

Acknowledgements

This report was prepared by Paula Nardone, Simon Benmarraze, Ines Jacob, Omar Marzouk (IRENA) and Alberto Pérez Ortiz (consultant).

The report benefited from the reviews and inputs of The Department of Environment - Ministry of Health, Wellness and the Environment of Antigua and Barbuda. IRENA appreciates the insights and comments provided by Melissa Le Blanc, Vekash Khan, Ato Lewis, Jasiel Murphy (Department of Environment - Ministry of Health, Wellness and the Environment of Antigua and Barbuda).

Valuable inputs and comments were provided by IRENA experts Gayathri Nair, Gabriel Castellanos, Nadia Mohammed and Ellsworth Dacon.

Editorial coordination and production were provided by Francis Field and Stephanie Clarke. The report was edited by Fayre Makeig and designed by Nacho Sanz.

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ABBREVIATIONS

ABTB	Antigua and Barbuda Transport Board
AC	alternating current
CAPEX	capital expenditure
BEV	battery electric vehicle
CM	connected mobility
CO_2	carbon dioxide
DC	direct current
DER	distributed energy resource
EI	energy internet
EMI	IRENA's Electric Mobility Infrastructure tool
EV	electric vehicle
EVGI	electric vehicle grid integration
GDP	gross domestic product
GHG	greenhouse gas
GWh	gigawatt hour
HEV	hybrid electric vehicle
HFO	heavy fuel oil
ICE	internal combustion engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
kW	kilowatt
kWh	kilowatt hours
MW	megawatt
MWh	megawatt hours
NDC	Nationally Determined Contribution
NEC	National Electric Code
NFPA	National Fire Protection Association
NOx	nitrogen oxides
OPEX	operational expenditure
PHEV	plug-in hybrid electric vehicle
PLC	power line communication
PM	particulate matter
PV	photovoltaic
SAE	Society for Automobile Engineers
SUV	sports utility vehicle
T&D	transmission and distribution
UL	Underwriters' Laboratories
UNFCCC	United Nations Framework Convention on Climate Change
USD	US dollar
V2B	vehicle to building
V2G	vehicle to grid
V2H	vehicle to home
VANET	vehicle ad hoc network
WPT	wireless power transfer

EXECUTIVE SUMMARY

Antigua and Barbuda is a sovereign island country located between the Caribbean Sea and the Atlantic Ocean in the West Indies of the Americas. It consists of two major islands, Antigua and Barbuda, which are around 40 kilometres apart, as well as numerous smaller islands. Antigua and Barbuda, like other island nations, is especially vulnerable to the impacts of climate change, including sea level rise and the increased frequency and magnitude of extreme weather events such as hurricanes. Direct repercussions, such as coastal erosion and water scarcity, are already evident.

In 2021, Antigua and Barbuda submitted its updated first Nationally Determined Contribution (NDC) which sets two key targets for the nation's energy sector: (1) 86% renewable electricity generation from local resources by 2030, and (2) 100% of new vehicle sales to be electric vehicles (EVs) by 2030. Both this and the country's intended NDC, submitted in 2015, seek to further the objectives of the Paris Agreement by committing to reduce emissions, address the impacts of climate change on the most vulnerable communities and economic sectors, and support the transition from fossil fuels to renewable energy. Antigua and Barbuda's NDC is conditional and based on the availability of financing and technological support.

Antigua and Barbuda requested support from the International Renewable Energy Agency (IRENA) in assessing a technology plan for shifting the transport sector to renewable-generated electricity, as a first step towards the NDC targets. This technical report summarises the assessment's main findings and evaluates the potential of several road fleet electrification scenarios to reduce greenhouse gas (GHG) emissions. The report aims to inform the implementation of the NDC, as well as its future update, and to recommend short- and medium-term targets for the transport sector. It complements on-going activities under the Global Environment Facility's (GEF's) Antigua and Barbuda Sustainable Low-Emission Island Mobility Project which aims to support the transition from internal combustion engine (ICE) vehicles to EVs in both public and private transport.

The methodology employed is based on IRENA's electric mobility and infrastructure (EMI) tool. The analysis is aligned with the NDC of Antigua and Barbuda as well as the study "Antigua and Barbuda: Renewable Energy Roadmap" (IRENA, 2021). Key findings include charging infrastructure requirements, recommended investment roll-outs, forecasted changes in the emissions of GHGs and other pollutants, fuel and electricity demand, required renewable energy capacity, and a preliminary estimate of investment and maintenance costs. The methods and data utilised for the assessment have successfully undergone:

- **Calibration.** Performed against the total consumption of fuel by the ICE fleet in Antigua.
- **Benchmarking.** The electricity consumption of EVs, total EV battery capacity and renewable energy capacity required to power a 100% EV fleet were benchmarked against the findings of the studies "Antigua and Barbuda: Renewable Energy Roadmap" (IRENA, 2021) and "Antigua and Barbuda's National Greenhouse Gas Reduction Report" (Climate Analytics, 2020).
- **Validation.** On 12 May 2022, a pre-validation workshop was held where the study's methodology, data and assumptions were presented, reviewed and validated with national stakeholders. IRENA and the Department of Environment of Antigua and Barbuda conducted a workshop in which major national stakeholders participated.

In the process of envisioning a shift from ICEs to a 100% electric road fleet, this report elaborates on the following relevant concepts:

- The benefits to the power sector from EVs' large-scale deployment.
- Overview of international standards for EVs and chargers.
- Monitoring, evaluation and verification of EV and charger performance.
- Importance of deploying EVs and renewable energy hand in hand.
- Next steps for EVs and their integration with the grid.

The key results of the technology plan for shifting the transport sector to renewable-generated electricity are summarised in Table 1.

Table 1 Key findings of technology plan

TOPIC	FORECASTS
100% electrification of transport sector	· It is possible to achieve a 100% EV fleet by 2046. · By 2050 Antigua's vehicle fleet is expected to total 73 693.
Electricity generation	· Meeting the energy demand of the EV fleet in 2050 would require 182.4 GWh of renewable electricity to be generated, from solar PV capacity of 89 MW and wind capacity of 19 MW.
Charging infrastructure	· The number of EV chargers required is close to 4 000 in 2031 and drops to just over 1 500 in 2050. · The required installed capacity of EV chargers peaks at 74 MW in 2041 and decreases to 64 MW in 2050.
Fuel and electricity	· In 2050, the annual cost of electricity to power the EV fleet is about USD 47 million. · If no EVs were implemented, the annual petrol cost for ICE vehicles in 2050 would be USD 637 million.
Cost of EVs and chargers	· In 2050 the total accumulated cost of EVs and EV chargers is estimated at USD 3 568 million and USD 54.2 million, respectively.
Emissions	· A 100% EV fleet has associated annual CO_2 emissions of 7 310 tonnes/year, compared to 223 000 tonnes/year without EVs. · A 100% EV fleet reduces the emissions of CO_2, PM_{10}, $PM_{2.5}$ and NOx by -97%, -90%, -95% and -99%, respectively, compared to the equivalent ICE fleet.
External costs	· The full electrification of road transport avoids an annual external cost of USD 22.6 million, of which CO_2 accounts for 81.5%.

Note: CO_2 = carbon dioxide; EV = electric vehicle; GWh = gigawatt hour; ICE = internal combustion engine; MW = megawatt; NOx = nitrogen oxides; PM = particulate matter; PV = photovoltaic.

1 INTRODUCTION

In 2021, Antigua and Barbuda updated its Nationally Determined Contribution (NDC) which set two key targets for the energy sector: (1) 86% renewable electricity generation from local resources by 2030, and (2) 100% of new vehicle sales to be electric vehicles (EVs) by 2030. NDCs are national climate action plans that serve as the backbone of the Paris agreement, which was adopted by 197 member states of the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, thereby committing them to pursue the efforts necessary to keep global warming at 1.5°C. NDCs include mitigation measures, and in most cases, adaptation measures 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 reviewed, updated and enhanced every five years. Antigua and Barbuda was one of many countries to update its NDC in preparation for the 26th Conference of the Parties (COP26) in Glasgow in November 2021.

This technical report summarises the main findings of a technology plan for shifting the transport sector to renewable-generated electricity, as a first step towards the NDC targets. The report is structured as follows:

- **Chapter 2** outlines a technical analysis, based on 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 its updated NDC. The chapter also outlines the current status and future prospects of EVs, as a technology supporting the transition to net-zero emissions.
- **Chapter 3** outlines the study's main objectives, scope of work and contribution to climate action in Antigua and Barbuda.
- **Chapter 4** describes the methodology, data and assumptions underlying the technology plan for transport electrification.
- **Chapter 5** details the calibration and benchmarking of the technology plan, including at validation workshops.
- **Chapter 6** presents the results of the technology plan.
- **Chapter 7** summarises key findings, focusing on the importance of deploying renewable energy hand in hand with EVs.
- **Chapter 8** offers a list of recommendations based on the study findings.

2 BACKGROUND

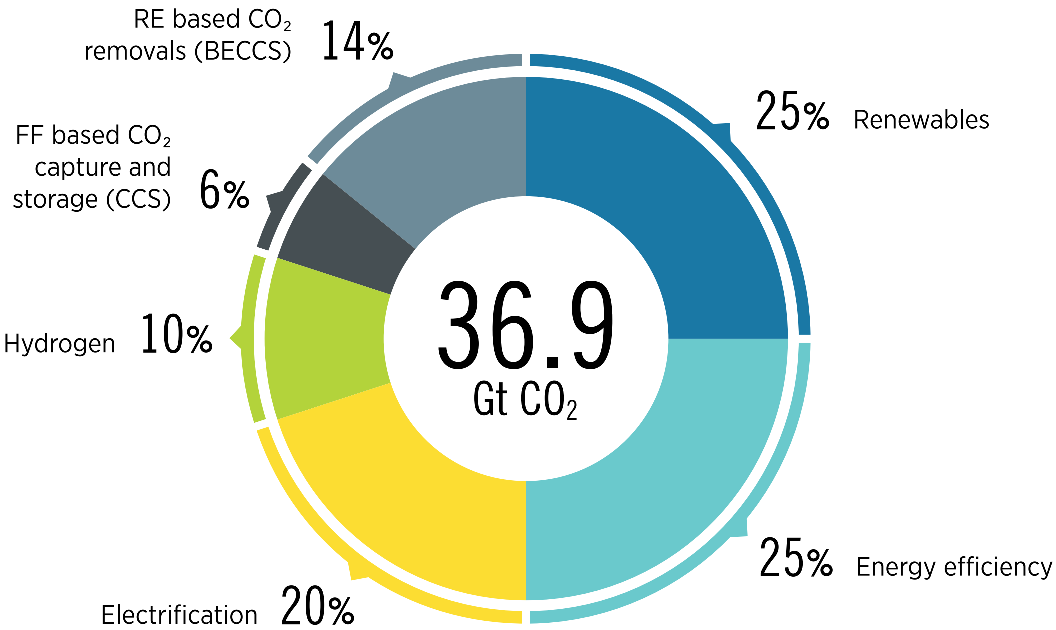
This section outlines priority areas for action to achieve net-zero emissions by mid-century worldwide.

2.1 TOWARDS THE 2050 GOAL

The growing number of countries committing to net zero carbon policies suggests a substantial shift in the global climate dialogue. There are parallel developments at all levels of government and in the private sector, including efforts focused on the oil and gas sectors, where emissions are hard to abate (IRENA, 2020b). In fact, a number of countries have made substantial promises to allocate public funds to supporting options 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. Yet every country possesses renewable energy resources that can be deployed to promote energy security and independence at a lower cost (IRENA, 2019b).

IRENA's 1.5°C pathway views electrification and energy efficiency as the primary drivers of the energy transition, with renewables, hydrogen and sustainable biomass serving as enablers. This approach, which necessitates a significant shift in how societies generate and consume energy, would result in a reduction of nearly 37 gigatonnes (Gt) of annual carbon dioxide (CO_2) emissions by 2050 (IRENA, 2022). As depicted in Figure 1, these reductions can be achieved through (1) significant increases in generation and direct uses of renewables-based electricity; (2) substantial improvements in energy efficiency; (3) the electrification of end-use sectors (*e.g.* electric vehicles [EVs] and heat pumps); (4) clean hydrogen and its derivatives; (5) bioenergy coupled with carbon capture and storage; and (6) last-mile use of carbon capture and storage.

Figure 1 Reducing emissions by 2050 through six technological avenues

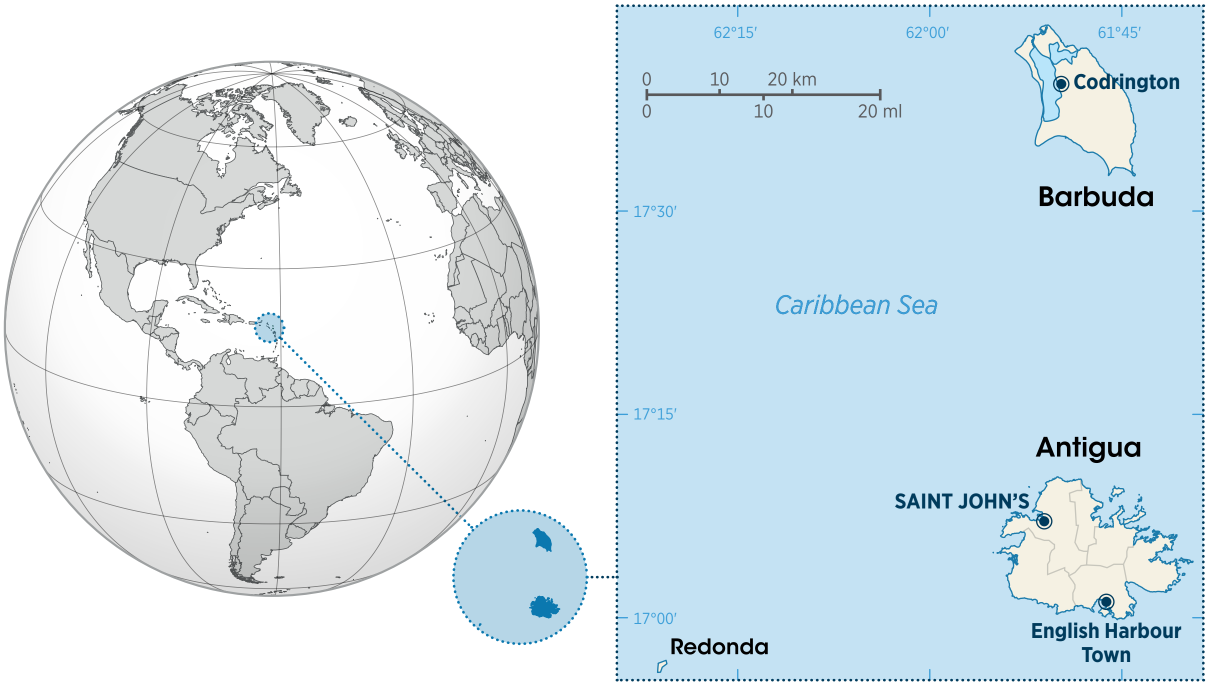


Source: IRENA, 2022.
Note: BECCS = bioenergy combined with carbon capture and storage; FF = fossil fuels; RE = renewable energy.

2.2 NATIONAL CONTEXT

Antigua and Barbuda is a sovereign island country located between the Caribbean Sea and the Atlantic Ocean in the West Indies of the Americas (Figure 2). It comprises two major islands, Antigua and Barbuda, separated by approximately 40 kilometres (km), as well as numerous smaller islands. Saint John's is the capital, a major port and the largest city on Antigua; Codrington is the largest town on Barbuda. Tourism contributes 80% of Antigua and Barbuda's gross domestic product. Antigua and Barbuda, like other island nations, is especially vulnerable to the impacts of climate change, including sea level rise and the increased frequency and magnitude of extreme weather events such as hurricanes. Direct repercussions, such as coastal erosion and water scarcity, are already evident.

Figure 2 Geographical location of Antigua and Barbuda



Based on: https://en.wikipedia.org/wiki/Antigua_and_Barbuda; and (CIA, n.d.).

Disclaimer: This map is provided for illustration purposes only. The designations employed and the presentation of material herein 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.

Antigua and Barbuda's population has been growing steadily for decades and is estimated at 98 000 (World Bank, 2020). The most populous cities in Antigua and Barbuda are mostly on Antigua, being Saint John's (Figure 6), All Saints, Piggotts and Liberta.

2.3 ANTIGUA AND BARBUDA'S UPDATED FIRST NDC

In 2021 Antigua and Barbuda submitted its updated first Nationally Determined Contribution (NDC) to the UNFCCC secretariat. This updated NDC is an update to the 2015 Intended Nationally Determined Contribution (INDC) and does not replace the previously disclosed INDC targets. Rather, the updated NDC preserves unmet objectives and revises certain targets to become more ambitious. Specifically, the Cabinet of Antigua and Barbuda considered and approved the following targets for the updated NDC:

- 86% renewable energy generation from local resources in the electricity sector by 2030.
- 100% all new vehicle sales to be electric vehicles by 2030.
- Explore the potential for emissions reductions in the waste sector by 2025.
- Explore the potential for emissions reductions in the agriculture, forestry and other land use (AFOLU) sector by 2030.

The sectors covered in the document are energy, waste and AFOLU. Specific indicative actions relevant to the transport sector are listed in Table 2.

Table 2 NDC measures to mitigate emissions from the transport sector, 2021

SECTOR	POLICIES AND MEASURES	ESTIMATED COMPLETION DATE	CONDITIONALITY
Transport sector	Change fiscal policies on fossil fuel by 2025 to enable the transition to 100% renewable energy generation in the transport sector	2025	Conditional
	Establish efficiency standards for all vehicles to be imported	2025	Conditional
	Ban the importation of new internal combustion engine vehicles (with an indicative start year of 2025)	2030	Conditional
	100% of government vehicles to be electric vehicles	2035	Conditional

3 CONTEXT

3.1 A SMALL ISLAND DEVELOPING STATE

As a small island developing state, Antigua and Barbuda's emissions account for a minor share of the global total.[1] However, the nation's greenhouse gas (GHG) emissions per capita are high relative to nations such as Spain or France. The energy sector accounts for 76% of the country's total emissions due to the combustion of fossil fuels. Electricity generation and transport are the primary sources of emissions because they rely almost exclusively on imported fossil fuels. Road transport alone accounts for more than 20% of the nation's total GHG emissions. The country's reliance on imported fossil fuels for power generation and road transport has a significant effect on its gross domestic product (GDP). Up to 13.7% of the country's GDP is spent annually on such imports.

Antigua and Barbuda presented their target of achieving 100% of all new vehicle sales to be electric vehicles by 2030 within the framework of their updated first NDC, which represents the country's current ambition and target for lowering emissions nationally. In this regard, the country requested assistance from IRENA to plan implementation of their NDC mitigation targets, with a particular focus on the transport sector.

3.2 MAIN STUDY OBJECTIVES

Antigua and Barbuda requested IRENA's support in planning the implementation of its Nationally Determined Contribution targets, with a focus on the transport sector. The resulting analysis looks at the techno-economic feasibility of electrifying road transport fleets, and buses in particular. The main objectives are:

- Assess the techno-economic feasibility of electrification of the road transport fleets and establish the requirements for charging infrastructure across varying degrees of electric mobility penetration.
- Forecast the electricity demand of the transport sector, and also estimate renewable energy capacity additions and the integration of EVs in the grid.
- Establish the required roll-out of investments in EVs and required infrastructure.
- Analyse the efficacy of vehicle electrification in mitigating emissions, especially considering the country's power system.
- Understand the impacts of different vehicle growth rates and target years for the electrification of road transport fleets.

[1] *Antigua and Barbuda accounts for 0.001% of global GHG emissions (Climate Resource, 2022).*

3.3 SCOPE OF WORK

The study identified appropriate charging infrastructure and equipment requirements based on international standards, regulations and communication protocols, as well as vehicle certification regulations used in various markets to ensure vehicle safety. Additionally, initial cost estimates and investment requirements have been assessed.

The findings can serve as a roadmap for the early stages of transport decarbonisation, in parallel with the increased deployment of renewable energy. Meeting key milestones would require the increased involvement of the private sector.

3.4 CONTRIBUTION TO CLIMATE ACTION IN THE COUNTRY

Meeting international climate commitments requires a global shift to low- and zero-emission mobility. Around a quarter of energy-related carbon dioxide emissions are released by the transport sector, and these emissions are projected to increase by 2050. By 2050, three out of every five vehicles are expected to be located in low- and middle-income countries which are anticipated to account for nearly all of the growth in GHG emissions from transport. Achieving global climate goals necessitates a significant shift away from the use of private vehicles towards zero-emission mobility in all countries.

There is a direct link between the present study and ongoing activities in Antigua and Barbuda as part of the Sustainable Low-Emission Island Mobility Project, which aims to support the transition from internal combustion engine vehicles to EVs in both public and private transport. This project is supported by the Global Environment Facility and co-funded by the Government of Antigua and Barbuda. It is implemented by the United Nations Environment Programme and carried out by the Department of Environment.

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4 METHODOLOGY

This section details the methodological approach, data sets and assumptions applied in the study.

4.1 TRANSPORT SECTOR ELECTRIFICATION

The electrification of road transport links two key components: power and transport. Large-scale adoption of EVs can benefit power generation mixes dominated by variable renewable energy sources (*e.g.* wind, solar photovoltaic [PV]), as EVs can provide decentralised electricity storage and ancillary grid services. Since EVs are typically parked 95% of their lifespans (IRENA, 2019d), their batteries can be used to provide grid services. This flexibility inherent to EVs can help minimise the requirements for flexible and fast-responding fossil fuel plants in a renewable-dominated energy mix (IRENA, 2019c).

EVs' adoption will increase electricity demand by a small amount, though at peak consumption times, where smart charging strategies are lacking. Also, charging stations and a reverse flow of power in the distribution grids will cause changes in the voltage profile that need to be regulated. The increased load will require upgrades of the grid at distribution, transmission and generation levels. A fact-based analysis can assist understanding of the requirements of additional generation, EV infrastructure and. The present study compares different renewable energy penetration scenarios and their resulting emissions.

The electricity demand profile associated with EVs is determined by the EV users' behaviour, which is unlikely to match the generation profile of intermittent renewable energy sources such as solar or wind. Coupling EV charging with generation could be improved through, for example, market price signals, where electricity cost is reduced at those hours of the day when there is a surplus of solar energy generation. Innovative technologies such as smart chargers could help match EV charging and generation profiles.

As EVs' share in the vehicle market increases, the reuse of second-life batteries becomes more important. Such batteries are no longer suitable for EV applications because their capacity has reduced to 70-80% (IRENA, 2019d), but can still be used in behind-the-meter, stationary applications.

4.2 ANALYTICAL APPROACH

The present assessment is based on an analytical framework designed to help plan the transition of Antigua and Barbuda's vehicle fleet from one based on internal combustion engines (ICEs) to one that is 100% EVs. It is carried out in line with the country's updated Nationally Determined Contribution (NDC) and based on the criteria set out in the IRENA report "Antigua and Barbuda: Renewable Energy Roadmap" (IRENA, 2021).

A spreadsheet-based tool known as the Electric Mobility Infrastructure (EMI) tool was utilised to conduct the assessment. The tool relies on national inputs such as vehicle growth ratio, mobility data, infrastructure data and cost data to analyse electrification options for different vehicle categories based on current and projected road vehicle fleets.

The EMI tool estimates the charging infrastructure requirements, investment requirements, likely GHG and other pollutant emission reductions, fuel and electricity demand changes, and potential renewable energy capacities required to meet the associated changes in electricity demand.

The tool also allows the modelling of various scenarios, for example, that no new ICE vehicles can be purchased after a specified year, after which all vehicles that are retired are replaced by EVs.

Vehicle segmentation

EVs can be split into hybrid electric vehicles (HEVs) and all-electric vehicles (AEVs), of which the second category can be further subdivided into battery EVs (BEVs) and fuel cell EVs (FCEVs) (Das *et al.*, 2019).

The EMI tool was calibrated to focus on one transition in particular: from ICEs to BEVs. Hereafter, BEVs are referred to as EVs. In addition, it is assumed that all ICE vehicles run on gasoline.[2]

The EMI tool divides the vehicle fleet into six types of vehicles: scooters, cars, taxis, sports utility vehicles (SUVs), mini-buses and large buses, each of which can be found on the market as either (1) an ICE variant, a vehicle that is powered by a regular ICE and uses fuel which combusts inside a combustion chamber with the assistance of an oxidiser (typically air), or (2) an EV variant, a vehicle that is propelled by one or more electric motors, using only energy stored in batteries.

Tool structure

The EMI tool allows users to compare options or alternatives based on various assumptions such as grid electricity mix, vehicle technology, vehicle and fuel prices, external costs, investments in public transport services, vehicle and fuel market shares, and other factors. For this assessment, the EMI tool has a one-year timestep and covers the time period from 2020 to 2050. Vehicle user behaviour is parameterised in terms of daily usage. The EMI tool was developed around three primary operational sections: Data input, Calculation and Results.

The flow of data across the three sections is broken down visually in Figure 3; the input tabs are used in calculation tabs to produce the needed outcomes in the results.

Figure 3 General data flow of the tool

Data inputs	Calculations	Results
National data	Mobility calculations	Mobility output
Mobility data	Emissions calculations	Emission reduction output
Cost data	External costs calculations	External costs output
Infrastructure data	Charging calculations	Electricity consumption and charging output
	Cost calculations	Costs output

[2] *According to data provided by the government, there are currently 52 537 road transport vehicles in the country, of which more than 97% are powered by gasoline and less than 2% by diesel.*

The data input section contains the tabs where the user inputs the bulk of the data needed for the tool to run. Because this tool supports time series, the majority of the user's inputs are required from 2020 to 2050. The inputs are based on primary national data, secondary research, logical assumptions or a combination of different data sets. Calculation tabs are interconnected and utilise values from data input tabs to determine data relationships and generate results.

Limitations

The tool does not currently capture hourly dynamics such as EV charging or hourly generation profiles.

4.3 DATA REQUIREMENTS

The data requirements for the EMI tool can be split into four main categories: national, mobility, infrastructure and cost which are presented in the next chapters.

The first step is the collection of national data from relevant country stakeholders, such as the ministries of energy and environment, and transport associations, among others. These inputs are preferably country-level primary data. However, if some of the primary data are not available, default inputs derived from secondary sources are used. Some logical assumptions for data inputs are used where no primary or secondary data are available. Table 6 lists the various parameters used to characterise each required data category.

4.4 EXISTING INFORMATION

There are some differences in the transport-related assumptions considered by IRENA (2021) and the present study:

- **Number of vehicles.** IRENA (2021) assumes that the number of vehicles in the fleet does not change across the time horizon analysed, while the technology plan estimates a growth in the number of vehicles in lockstep with average population growth between 2015 and 2020.
- **EV battery size.** While IRENA (2021) establishes that the battery size (in kilowatt hours) of EVs remains constant across the period of analysis, the technology plan assumes it will increase by 75% between 2020 and 2030 for all types of EVs, and will be constant from 2030 to 2050.
- **EV charger.** IRENA (2021) sets EV charger capacity constant in the period analysed as well as a single charger for each vehicle with a rated power in line with the average energy consumption of the vehicle type. The technology plan does not define a single charger per EV, and assumes an increase in the rated power and the utilisation of chargers between 2020 and 2050. The plan also defines the efficiency of EV chargers as well as temperature effects over the charging cycle of EVs; defines locations for EV chargers using a set distribution pattern; and considers user behaviour to determine where users charge their EVs.

The above variations yield differences in findings.

4.5 NATIONAL-LEVEL DATA SETS

The technology plan focuses on the island of Antigua and uses two general data sets: population and vehicle inventory. Table 3 presents the total population and annual population growth rate in the country between 2015 and 2020. Based on the collected data, the average population growth between 2105 and 2020 is computed to be 1.13%. This growth rate is used to extrapolate the population between 2020 and 2050.

Table 3 Population and annual population growth rate in Antigua and Barbuda, 2015-2020

PARAMETER	UNIT	2015	2016	2017	2018	2019	2020
Total population	Number of people	92 562	93 571	95 425	96 282	97 115	97 928
Annual population growth rate	%	n.a.	1.09	1.98	0.90	0.87	0.84

Source: World Bank, 2022.

Apart from the methodology assumptions presented in Section 4.3, there are a few additional specific assumptions considered for Antigua:

- Starting date for transport sector decarbonisation is 2022.[3]
- Growth rate of vehicles in the country between 2022 and 2050 is in lockstep with the average population growth between 2015 and 2020 of 1.13%.
- ICE vehicles are gradually replaced by EVs in the 2022-2050 time horizon.
- From 2030, no more new ICE vehicles can be purchased, and vehicles that have reached their end of life are replaced by EVs.
- The whole vehicle fleet is set to be decarbonised by 2050 (or earlier).
- Once 100% electrification rate is achieved, additional vehicles associated to population growth are all EVs.

4.6 POWER SECTOR DATA SETS

Technologies

Total electricity generation in 2019 on the island of Antigua accounted for 375 332 megawatt hours (MWh). Electricity generation on Antigua is dominated by heavy fuel oil (HFO) technology, accounting for more than 95% of the total generation in 2019 (APUA, 2022a). The dominance of HFO in the electricity grid mix led to a grid emission factor of 0.62 kilogrammes of carbon dioxide per kilowatt hour ($kgCO_2/kWh$) in 2021 (UNFCCC, 2021).

The generation mix in 2030 is set to reach the NDC target for the power sector whereby 86% of the electricity generation is provided by renewable energy sources. By 2031, the renewable energy fraction increases to 93%, in line with the results from the Scenario Optimal System + EVs from IRENA (2021). The remaining electricity generation is assumed to be produced with the existing HFO capacity.

[3] *Considering the effects of the COVID-19 pandemic and by government request, Appendix A presents the summarised results of a case in which decarbonisation of the transport sector begins in 2025.*

To calculate the additional renewable energy capacity[4] to power a 100% EV fleet, the two renewable energy sources considered are solar PV and wind. The capacity factors considered for solar PV and wind in Antigua and Barbuda are 16% and 33%, respectively (IRENA, 2021). The additional renewable energy capacity is computed so that solar PV and wind produce 69% and 31%, respectively, of the total electricity required by EVs.

Transmission and distribution (T&D) losses are considered to account for 18% of the total generated electricity in 2015 (CARICOM Energy, 2018). Additionally, a 1% annual improvement in the T&D losses is accounted from 2015 to 2050, reaching 12.7% by 2050.

Costs

Concerning the costs of the additional renewable energy capacity required to supply the EV fleet, Table 4 lists the 2020 capital expenditure (CAPEX) and operational expenditure (OPEX) of the renewable energy technologies considered. An annual reduction of -2% in the CAPEX is assumed between 2020 and 2050 for all renewable energy technologies.

Table 4 CAPEX and OPEX considered for solar PV and wind energy technologies

RENEWABLE ENERGY TECHNOLOGY	CAPEX (USD MILLION/MW)	OPEX (USD MILLION/MW/YEAR)
Solar PV	0.6	0.01
Wind energy	1.5	0.015

Source: IRENA, 2021.
Note: CAPEX = capital expenditure; MW = megawatt; OPEX = operational expenditure; PV = photovoltaic.

In terms of electricity retail prices, in 2020 these are assumed to be USD 0.4/kWh (IRENA, 2021; APUA, 2022b), where an annual reduction of -1% is assumed for the electricity retail price between 2020 and 2050 as penetration of renewables in the grid mix increases.

Emissions

The generation of the electricity consumed by EVs during operation is what produces the emissions related to EVs' use. The key emission pollutants associated to transport and included in this analysis are carbon dioxide (CO_2), particulate matters (PM_{10} and $PM_{2.5}$) and nitrogen oxides (NOx).

Table 5 lists the emissions factors for the generation technologies considered in the grid mix: renewable energy (solar PV and wind) and HFO. Only the emissions associated to the actual generation of electricity are considered, and not those linked to the manufacturing, construction and decommissioning of the generation units.

[4] *Calculated based on the additional energy generation required to cover the demand from EVs, and not optimised based on actual hourly generation and EV demand profiles.*

Table 5 Emission factors of the generation technologies considered

POLLUTANT	UNIT	GENERATION TECHNOLOGY		SOURCE
		RENEWABLES	HEAVY FUEL OIL	
CO_2	kg/MWh	0	702	(Gómez and Watterson, 2006)
PM_{10}	kg/MWh	0	0.04	(Kothari *et al.*, 2021)
$PM_{2.5}$	kg/MWh	0	0.03	(Kothari *et al.*, 2021; Trozzi, 2016)
NOx	kg/MWh	0	0.47	(Kothari *et al.*, 2021)

Note: CO_2 = carbon dioxide; kg = kilogramme; MWh = megawatt hour; NOx = nitrogen oxides; PM = particulate matter.

4.7 TRANSPORT SECTOR DATA SETS

Technologies

Two main technologies are considered: EVs used on roads, and EV chargers.

Road vehicles

Table 6 lists the 2019 vehicle inventory of Antigua, which is used in the tool as the starting vehicle fleet in 2020. It is assumed that the modal split remains unchanged in the 2020-2050 time horizon. In the starting year of the assessment, all vehicles in the fleet are assumed to be ICE. Both ICE vehicles and EVs are set to have an operational lifespan of 20 years on Antigua (ABTB, 2022a). Table 11. also lists per vehicle type on Antigua. This number of users per vehicle is assumed to remain constant across the time horizon analysed.

Table 6 Vehicle inventory in 2019 and number of users per vehicle type on Antigua

VEHICLE TYPE	NUMBER OF VEHICLES	NUMBER OF USERS
Scooters	989	1
Cars	31 820	2
Taxis	1 233	4
Sports utility vehicles	18 253	2
Mini-buses	193	12
Large buses	49	24
Total	**52 537**	**n/a**

Source: ABTB, 2022a; Department of Environment of Antigua and Barbuda.

The precise data sets related to the consumption rates of fuel and electricity for ICE vehicles and EVs can be found in the appendix in Table C.1 and C.2, respectively. These consumption rates are assumed to remain unchanged in the period of analysis.

Table 7 lists the daily mileage considered for each vehicle type. The daily mileage is set to be constant in the time horizon analysed. The average daily mileage for mini-buses and large buses is computed based on the bus route and frequency data provided by the Antigua and Barbuda Transport Board (ABTB, 2022b) as well as data from IRENA (2021). The daily mileage for scooters and motorcycles is set in agreement with IRENA's Energy Roadmap (IRENA, 2021). For the remaining vehicles, the data set from IRENA's Energy Roadmap (IRENA, 2021) is used as a starting point, but the final daily mileage is used as a calibration parameter to ensure that the total consumption of petrol by the vehicle fleet is consistent with the gasoline consumption data supplied by the Department of Environment of Antigua and Barbuda.

Table 7 Estimated daily mileage for the vehicle fleet on Antigua

VEHICLE TYPE	DAILY MILEAGE (KM/DAY)	SOURCE
Scooters	10	(IRENA, 2021)
Cars	30	(IRENA, 2021; Climate Analytics, 2020)
Taxis	76.5	(IRENA, 2021; Climate Analytics, 2020)
Sports utility vehicles	29.5	(IRENA, 2021; Climate Analytics, 2020)
Mini-buses	85	(ABTB, 2022b)
Large buses	200	(IRENA, 2021; ABTB, 2022b)

Note: km = kilometre.

EV battery and chargers

Table 8 lists the battery rated capacity set in the year 2020 for each type of EV. The capacity is considered to increase by 75% between 2020 and 2030 for all types of EVs, and to stay constant from 2030 to 2050 (IEA, 2020). The mileage range for each EV type is computed based on the respective battery rated capacity and consumption rates listed in Table C.2, Appendix C.

Table 8 Battery rated capacity considered for each type of EV, 2020

VEHICLE TYPE	BATTERY SIZE (KWh)	SOURCE
Scooters	5	(IRENA, 2019c)
Cars	40	(IRENA, 2019c)
Taxis	40	(IRENA, 2019c)
Sports utility vehicles	70	(EVD, 2022)
Mini-buses	100	(IRENA, 2019c)
Large buses	240	(IRENA, 2019c)

Note: kWh = kilowatt hour.

EV chargers are classified into five different types. Table 9 includes the rated power and efficiency for each type considered for the year 2020. A 60% increase in the rated power of the chargers is considered between 2020 and 2030, while a 150% increase is assumed in the period 2030-2050 (IRENA, 2019c). It is assumed that the efficiency of the chargers remains constant in the time period of analysis.

A lifespan of ten years is set for all EV charger types and this is constant across the time horizon of the analysis (Daniel Chang *et al.*, 2012; Smith and Castellano, 2015).

Table 9 Type of charger and charger rated power defined for year 2020

EV CHARGER TYPE	RATED POWER (kW)	SOURCE	ENERGY EFFICIENCY (%)	SOURCE
Light-duty vehicle – Level 1	3.7	(IRENA, 2019c)	86	(Díaz *et al.*, 2015)
Light-duty vehicle – Level 2	7.4	(IRENA, 2019c)	86	(Díaz *et al.*, 2015)
Light-duty vehicle – Level 3	22	(IRENA, 2019c)	95	(ABB, 2019)
Heavy-duty vehicle – Slow	50	(Satterfield *et al.*, 2020)	95	(ABB, 2019)
Heavy-duty vehicle – Fast	150	(IRENA, 2019c)	95	(ABB, 2019)

Note: kW = kilowatt.

Four locations for the EV chargers are defined in the analysis: home, work, public and depot. Figure 4 shows the 2020 distribution of EV charger types across the four locations. The weight of Level 1 chargers in homes is supposed to gradually decrease from 38% to 14% in 2030 in favour of Level 2 chargers (Engel *et al.*, 2018). The distribution of chargers for work, public and depot is assumed to remain constant across the 2020-2050 time horizon.

Figure 4 Distribution of electric vehicle charger type across four locations, 2020

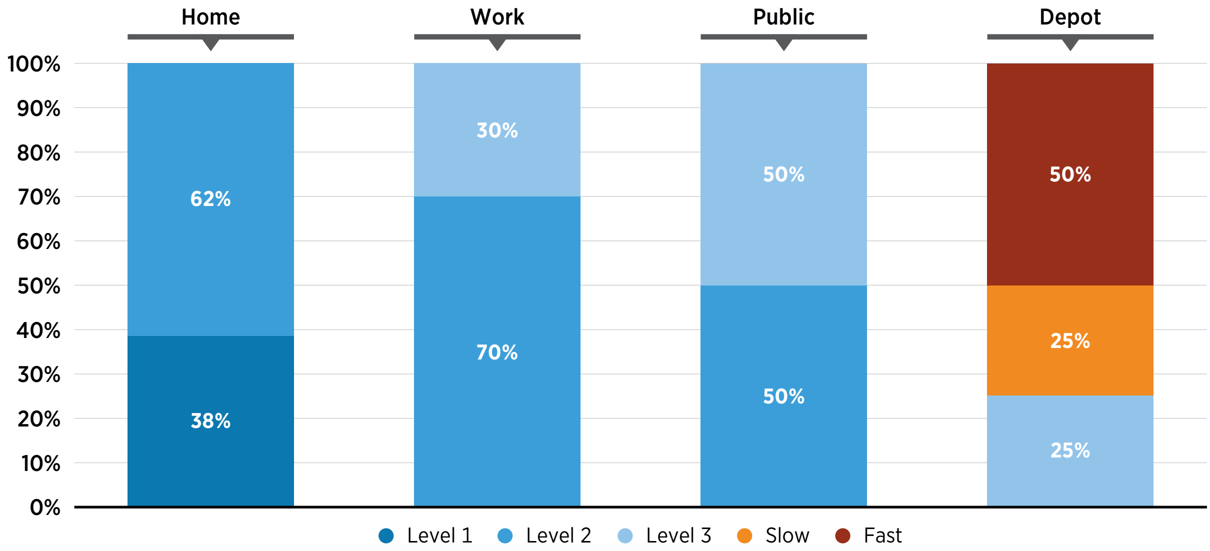
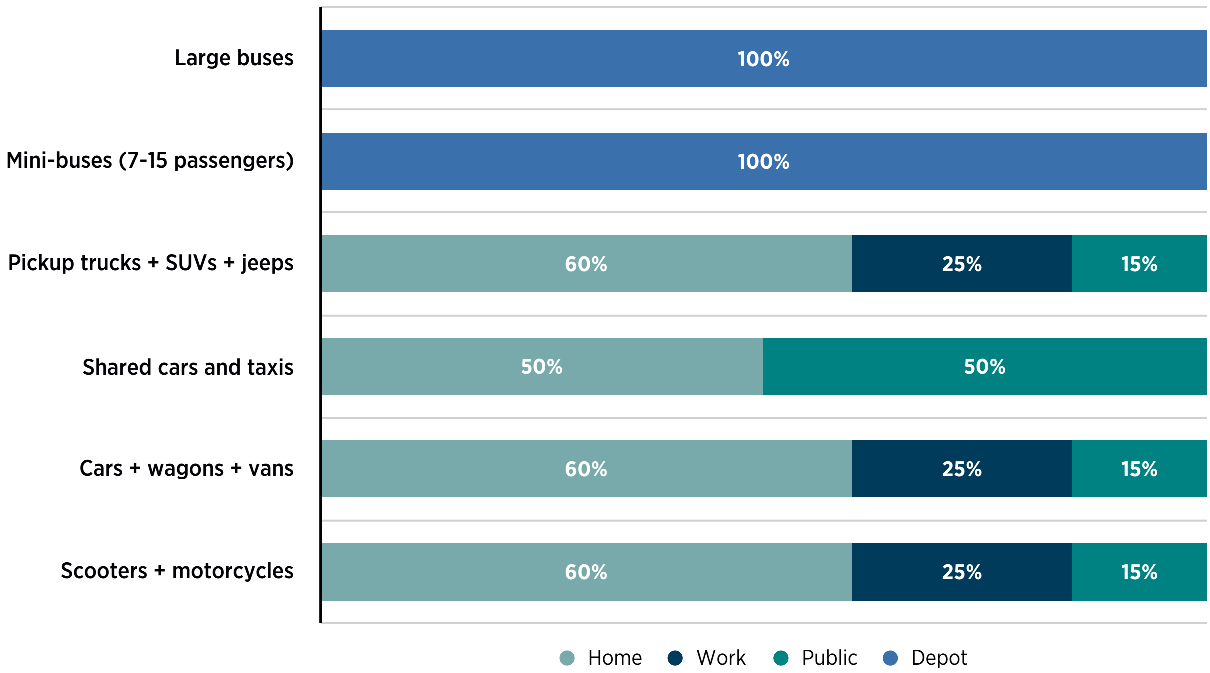


Figure 5 plots the distribution of charger users' behaviour for 2020. An increase in the usage of public EV chargers is expected in private vehicles by 2030 (motorbikes and cars) (Engel *et al.*, 2018; Lee *et al.*, 2020), while no change in user patterns is defined for public and shared vehicles.

Figure 5 Charger user behaviour, 2020



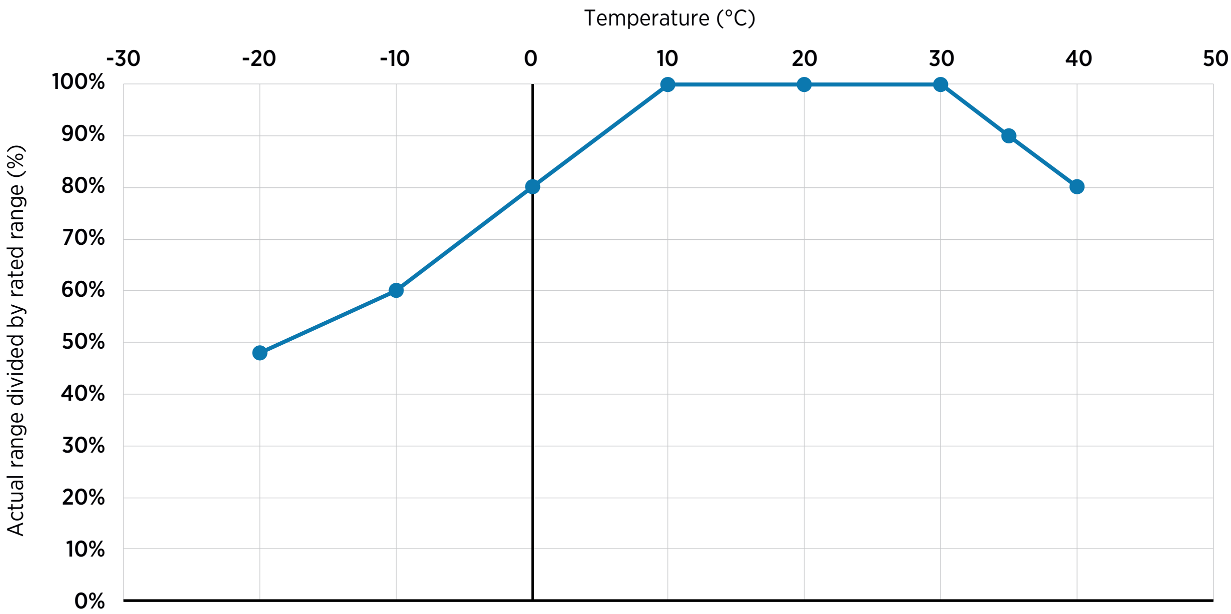
Note: SUVs = sports utility vehicles.

The EV charger utilisation rates at the four charger locations were analysed, namely the proportion of time the chargers are in use. Utilisation rates are assumed to increase with time. In 2020, the utilisation rate is set to be 5%, doubling to 10% in 2030 and reaching 30% in 2050 (Fitzgeral and Nelder, 2019; Wolbertus *et al.*, 2018; PwC, 2021).

The tool includes the effect that the local climate can have on the battery range and, thus, on electricity consumption rates listed in

Table C.2 (Appendix C) shows the actual range of a battery divided by the rated range across a range of ambient temperatures. The actual battery range degrades at temperatures below 10°C and above 33°C. For temperatures between 10°C and 33°C, no degradation is considered, while in reality the actual battery range may be slightly higher than the rated one. Since the tool uses a year time-step, an average annual temperature of 26.8°C (Meteotest, 2022) is considered for Antigua to compute the performance of the EV batteries.

Figure 6 Actual battery range divided by rated range of EVs as function of ambient temperature



Based on: Argue (2020).

Costs

Decarbonising mobility would involve major changes in the energy sector. The needed upfront capital expenditures would be high, but total costs in the subsector would be expected to decrease. This assessment includes cost parameters, including the purchase price of ICE vehicles and EVs, the maintenance cost of ICE vehicles and EVs, the CAPEX and OPEX of charging infrastructure and renewable energy capacity, and the retail price of fuel and electricity. Table 9 lists the retail costs in constant dollars considered for ICEs and EVs in 2020, 2030 and 2050. Between 2020 and 2030, the price of all EVs is anticipated to decrease, totalling -25% for motorbikes, -17% for large buses and -5.5% for the rest of vehicles. Between 2030 and 2050, the purchase of all vehicle types is projected to decrease by a total of 3%. An accumulated increase of 1% is considered on ICE vehicle costs between 2020 and 2030, while for the 2030-2050 time period an accumulated decrease of -0.6% in the cost is assumed.

Table 10 Retail cost of EVs, 2020, 2030 and 2050

VEHICLE TYPE	RETAIL COST (CONSTANT USD)			SOURCE	RETAIL COST (CONSTANT USD)			SOURCE
	2020	2030	2050		2020	2030	2050	
Scooters	2 000	1 500	1 452	(UNEP, 2018; ECF, 2018)	1 100	1 110	1 103	(UNEP, 2018)
Cars	33 268	31 414	30 405	(ECF, 2018)	25 451	25 677	25 529	(ECF, 2018)
Taxis	33 268	31 414	30 405	(ECF, 2018)	25 451	25 677	25 529	(ECF, 2018)
Sports utility vehicles	44 000	41 547	40 213	(EVD, 2022; ECF, 2018)	37 290	37 622	37 404	(Trans Automobile, 2022)
Mini-buses	49 500	46 741	45 240	(EVD, 2022; ECF, 2018)	41 951	42 325	42 080	
Large buses	162 604	135 000	130 665	(UNEP, 2018; ECF, 2018)	90 000	90 801	90 276	(UNEP, 2018)

The costs of vehicle types – cars, SUVs and mini-buses – for both EVs and ICE vehicles presented were benchmarked against the cost of new vehicles from dealerships on Antigua (DoE, 2022a).

Table 11 lists the maintenance costs considered for EVs and ICE vehicles in 2020. Maintenance costs are considered to remain constant in the 2020-2050 period, except for EV mini-buses that would see an accumulated -14% reduction between 2020 and 2030.

Table 11 Maintenance costs for EV and ICE vehicles, 2020

VEHICLE TYPE	UNIT	EV	ICE	SOURCE
Scooters	USD/km	0.004	0.01	(UNEP, 2018)
Cars	USD/km	0.02	0.04	(UNEP, 2018)
Taxis	USD/km	0.02	0.04	(UNEP, 2018)
Sports utility vehicles	USD/km	0.04	0.08	(Lutsey *et al.*, 2018)
Mini-buses	USD/km	0.11	0.12	(UNEP, 2018)
Large buses	USD/km	0.42	0.74	(Eudy and Jeffers, 2018)

Note: EV = electric vehicle; ICE = internal combustion engine; km = kilometre.

Table 12 presents the CAPEX considered for the EV chargers for the year 2020. CAPEX of EV chargers does not consider taxes and it includes installation costs (labour, materials and permits) and associated utility upgrades. An annual reduction of -3% in the CAPEX is assumed between 2020 and 2050 (ECF, 2018; Eudy *et al.*, 2018). For the OPEX of the EV chargers, an annual value of 3% of the CAPEX is defined for the entire 2020-2050 period (Satterfield *et al.*, 2020).

Table 12 CAPEX considered for EV chargers, 2020

EV CHARGER TYPE	CAPEX (USD/kW)	SOURCE
Light-duty vehicle – Level 1	425	(Nicholas, 2019)
Light-duty vehicle – Level 2	401	(Nicholas, 2019)
Light-duty vehicle – Level 3	558	(Satterfield *et al.*, 2020)
Heavy-duty vehicle – Slow	929	(Nicholas, 2019)
Heavy-duty vehicle – Fast	626	(Nicholas, 2019)

Note: CAPEX = capital expenditure; kW = kilowatt.

The retail prices of petrol considered for 2020 are USD 2.7/litre (DoE, 2022b), with an annual increase of 3% assumed for the 2020-2050 period, in line with the projections for other similar small island developing states in the Caribbean region (Deloitte, 2017).

Emissions

Emissions of ICE vehicles are linked to the use of petrol. The emissions embedded in EV operations are not local, but these are associated to the generation of their stored electricity. The key emission pollutants associated to transport and included in this analysis are CO_2, PM_{10}, $PM_{2.5}$ and NOx.

4.8 AIR POLLUTANT DATA SETS

External costs associated to emissions of certain pollutants are defined as an estimate of the economic costs, or damages, such as air pollution, associated with emitting one more tonne of pollutants into the atmosphere, and consequently the benefits of reducing these emissions (Song, 2016).

Table 13 presents the external costs in 2020, 2030 and 2050 considered for the key transport sector emission pollutants CO_2, PM_{10}, $PM_{2.5}$ and NOx. An accumulated 70% increase in the cost of CO_2 is expected between 2020 and 2050. For the other pollutants it is assumed that their cost does not vary in the period of analysis.

Table 13 External cost factors of emission pollutants (CO_2, PM_{10}, $PM_{2.5}$ and NOx), 2020, 2030 and 2050

POLLUTANT	EXTERNAL COST ESTIMATE (USD/TONNE)			SOURCE
	2020	2030	2050	
CO_2	51	62	85	(IWG, 2021)
PM_{10}	62 702	62 702	62 702	(Song, 2016; Gilmore *et al.*, 2019)
$PM_{2.5}$	126 799	126 799	126 799	(Song, 2016; Gilmore *et al.*, 2019)
NOx	7 565	7 565	7 565	(Song, 2016; Gilmore *et al.*, 2019)

Note: CO_2 = carbon dioxide; g = gramme; kg = kilogramme; km = kilometre; NOx = nitrogen oxides; PM = particulate matter.

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5 COUNTRY VALIDATION

This section details the calibration, benchmarking and validation exercises conducted to improve the reliability and robustness of the technology plan.

5.1 CALIBRATION OF TOOL FOR NATIONAL CONTEXT, AND COMPARISON WITH PREVIOUS STUDIES

The internal combustion engine (ICE) fleet's fuel consumption was input using 2016 data provided by the Department of Environment. Although fuel consumption data include gasoline, diesel and ultra-low-sulphur diesel, it is assumed that all fuel is gasoline for the calibration exercise. In 2016, total fuel sales amounted to 65.6 million litres.

As described in Section 4.7, the parameter used for the calibration exercise is the average daily mileage of the following vehicle types: cars, taxis and sports utility vehicles. The absence of documented mileage data for these vehicles makes them a good choice for use in the calibration process. The mileage of scooters and motorbikes, mini-buses and large buses are not included in the calibration procedure, as these data are either derived from published sources or are based on actual data and are used directly in the study.

The vehicle inventory used corresponds to the year 2019, and as such, the 2016 gasoline consumption figure is extrapolated to 2019 based on the population growth trend between 2016 and 2019, resulting in a total gasoline consumption of 68.05 million litres in 2019.

This consumption of gasoline is also factored into the estimate of the decarbonisation of the transport sector beginning in 2020. The mileage resulting from the calibration method for the vehicle types studied is presented in Table 14.

Table 14 Resulting daily mileage for the vehicle types included in the calibration process

VEHICLE TYPE	MILEAGE (km/day)
Cars	30
Taxis	76.5
Sports utility vehicles	29.5

Note: km = kilometre.

5.2 BENCHMARKING

A number of outputs from the technology plan were benchmarked against two published studies: "Antigua and Barbuda: Renewable Energy Roadmap" (IRENA, 2021), and "Antigua and Barbuda's National Greenhouse Gas Reduction Report" (Climate Analytics, 2020).

Antigua and Barbuda: Renewable Energy Roadmap

The following outputs were used in the benchmarking:

- Electricity consumption by electric vehicles (EVs) when 100% of the vehicle fleet is electric.

  EVs' annual electricity consumption, as estimated by IRENA (2021), totals 113 gigawatt hours (GWh). The equivalent figure in the technology plan, after the difference in the number of EVs (73 696) between both studies has been accounted for, is 110 GWh. If transmission and distribution losses are included, the actual annual electricity required to power the EVs resulting from the assessment is 127 GWh.

- Total EV battery capacity when 100% of the vehicle fleet is electrified.

  IRENA (2021) estimates the EV battery capacity of Antigua's grid at 2 569 MWh. The EV battery capacity that the analysis yields, taking into account the difference in number of EVs but also the assumed increase in EV battery size, is 2 583 MWh.

- Renewable energy capacity required to power the grid for a 100% EV fleet.

  The renewable energy capacity estimated by IRENA (2021) is 199 MW of solar photovoltaic (PV) and 89 MW of wind. Based on the electricity demand and generation ratio of solar PV to wind in IRENA (2021), the results from the Electric Mobility Infrastructure (EMI) tool would yield an estimated capacity of 202 MW and 89 MW of solar PV and wind, respectively.

The roadmap (IRENA, 2021) assumes that the number of vehicles in the fleet is 51 490 and does not change across the time horizon analysed, while this assessment estimates the number of vehicles in 2050 to reach 73 696. Another difference is the expected trend in battery size, where IRENA (2021) assumes that the battery size of EVs remains constant across the entire period of analysis.

Antigua and Barbuda's National Greenhouse Gas Reduction Report

The following outputs are used in the benchmarking analysis:

- Total EV battery capacity when all the vehicle fleet is electrified.

  The report (Climate Analytics, 2020) estimates the EV battery capacity of Antigua's grid at 4 250 MWh. The EMI tool estimates the EV battery capacity to be 4 252 MWh once the difference in number of EVs and battery sizes are accounted for. The report (Climate Analytics, 2020) considers the total number of EVs in 2050 to be 67 800, while the battery size is assumed to remain constant across the period of analysis.

5.3 VALIDATION WORKSHOPS

Three technical sessions were held in collaboration with the Department of Environment of Antigua and Barbuda to present, discuss and validate the methodology used in the technical analysis, as well as the data sets used, key assumptions and electrification alternatives. 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 transport sector stakeholders from public organisations such as representatives from the Department of Environment – Ministry of Health, Wellness and the Environment; the Ministry of Energy; the Antigua and Barbuda Transport Board; the West Indies Oil Company; the United Nations Environment Programme as well as other relevant policy makers.

The first session was a technical kick-off workshop held in December 2021, during which IRENA presented the scope of work in detail, discussed the underlying methodology for analysing the vehicle fleet transition and clarified the availability of energy data sets. The second meeting, held in May 2022, was a pre-validation, at which key national stakeholders were presented with the specific data sets and assumptions used, as well as the preliminary results and findings of the analytical exercise. Based on the previous session, IRENA shared a technical memorandum with key national stakeholders that illustrated the information, data and assumptions of the technology plan, and requested feedback to inform potential tool revisions or adjustments. A set of comments was prepared by key national stakeholders, including the Department of Environment, to refine some of the tool assumptions, including the revision of the current vehicle fleet, the target year for full road fleet electrification, as well as assumptions on transmission and distribution losses. IRENA updated some assumptions and incorporated the inputs to the greatest extent possible. These revisions and updates are reflected in the report’s results.

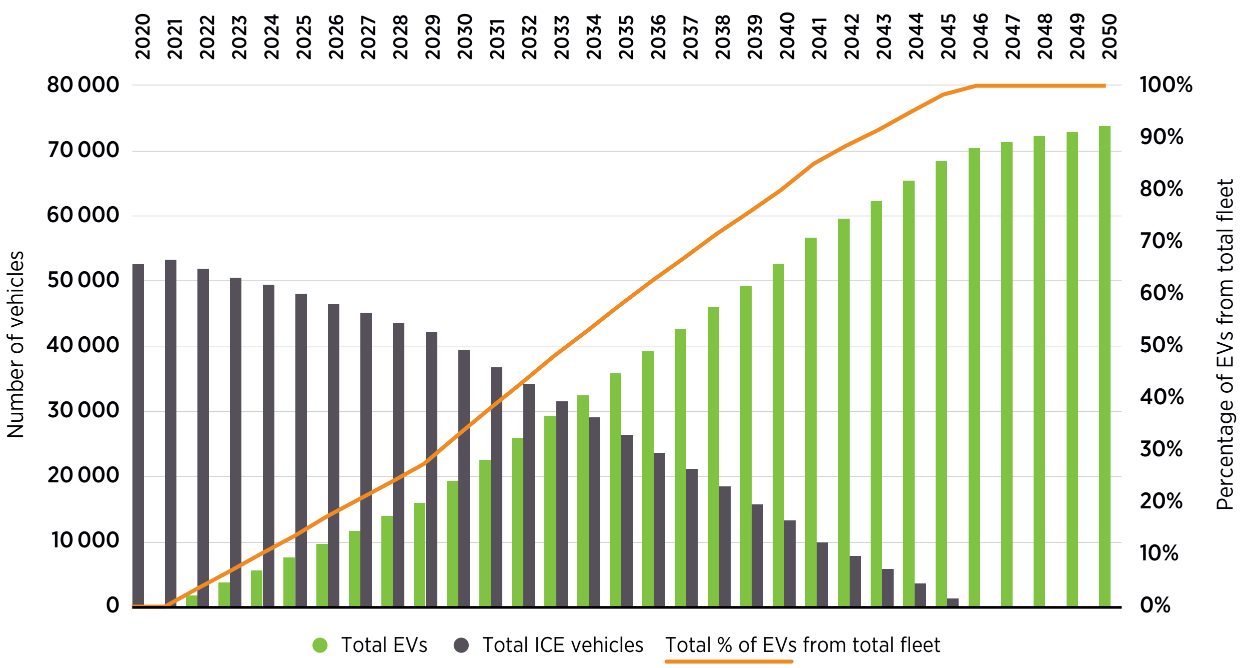
6 RESULTS AND FINDINGS

The transition to a fully electric vehicle (EV) fleet in the island of Antigua is feasible and can be powered by renewable energy and achieved by 2046. The number of vehicles on Antigua's roads is projected to increase from 52 537 in 2020 to 73 693 in 2050.

6.1 ADOPTION OF ELECTRIC MOBILITY

Figure 7 presents the computed trends in the total number of internal combustion engine (ICE) vehicles and EVs as well as the electrification rate from 2020 to 2050. The results show that it is possible to achieve a 100% EV fleet by 2046. Additionally, the figure shows an increase in the electrification rate from 2030, when ICE vehicles become unavailable for purchase, and aging models must thus be replaced by their EV equivalent.

Figure 7 Number of total ICE and EV vehicles, and percentage of EVs in total vehicle fleet (solid line), 2020-2050



Note: EVs = electric vehicles; ICE = internal combustion engine.

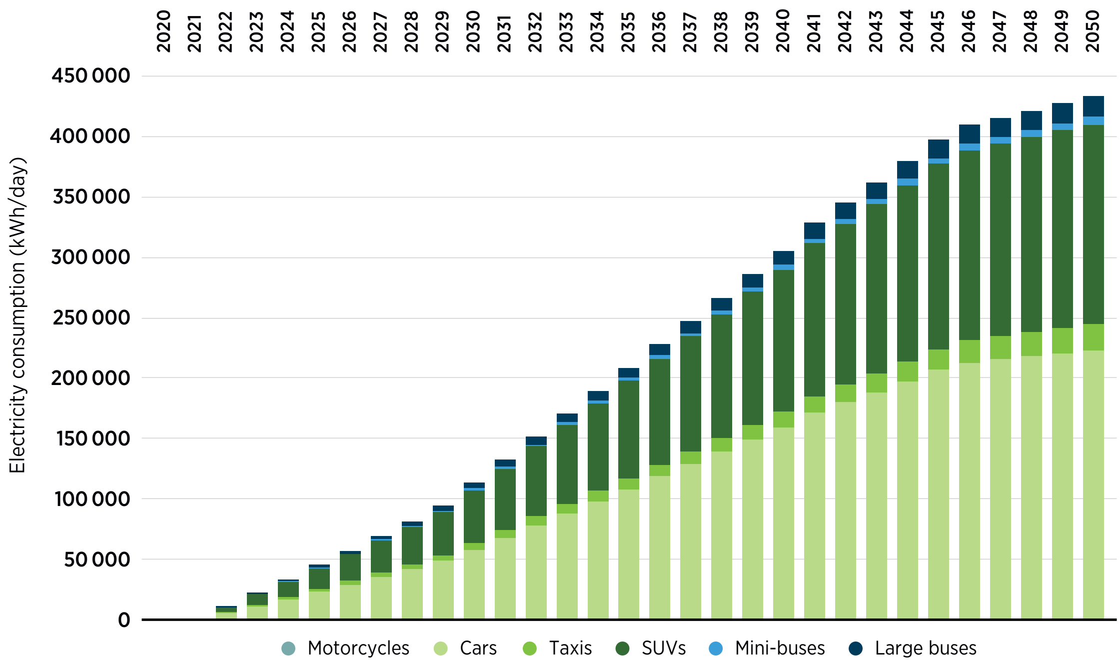
6.2 FOSSIL FUEL REDUCTION

The estimated annual fuel consumption of the ICE road vehicle fleet is projected to increase from 68 million litres in 2020 to 95 million litres in 2050 in the absence of fleet electrification. If the entire fleet is electrified by 2050, fuel consumption decreases to zero, and total annual electricity generation required to power the EV fleet is estimated at 182.4 GWh, with the majority of demand associated with cars and sports utility vehicle (SUV) types.

The demand for electricity and fuel is expected to change with a shift from ICE vehicles to EVs. By 2050, the total electricity generation required to power the EV fleet is estimated to be 182.4 GWh, of which 158 GWh corresponds to actual electricity fed into the EVs and 24 GWh to the T&D losses. In the technology plan, the fuel consumption is zero by 2046 where no ICE vehicles are in service on Antigua. In the baseline case, where no EVs are deployed and all vehicles are ICE, annual fuel consumption is forecasted to increase from 68 million litres in 2020 to 95 million litres in 2050.

Figure 8 shows EVs' daily consumption of grid electricity, by vehicle type, between 2020 and 2050. As noted earlier, the majority is associated with cars and SUVs. In 2050, the forecasted consumption of the EV fleet totals 433 MWh/day without considering T&D losses.

Figure 8 Daily electricity consumption, by EV type, 2020-2050



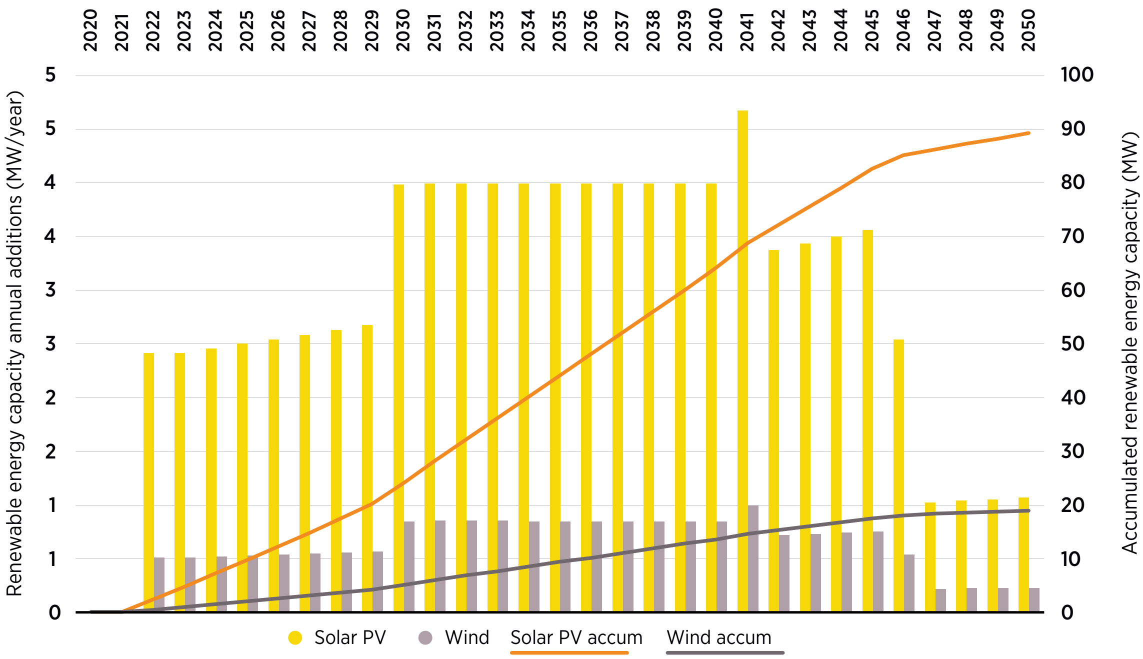
Note: kWh = kilowatt hour; SUVs = sports utility vehicles.

6.3 RENEWABLE ENERGY INTEGRATION

By 2050, a fully electrified road vehicle fleet would require total renewable energy capacity of 89 MW solar photovoltaic (PV) and 19 MW onshore wind. The majority of renewable energy capacity additions should be implemented between 2022 and 2046, when the shift from ICE vehicles to EVs occurs.

Figure 9 shows the required annual capacity additions of renewable energy (solar PV and wind) and the resulting total accumulated capacity. The majority of capacity is to be installed between 2022 and 2046, when the shift from ICE vehicles to EVs occurs. From 2046 to 2050, the additional renewable capacity installed covers the rise in electricity demand associated to the increase in the vehicle fleet.

Figure 9 Renewable energy capacity annual additions and accumulated installed capacity required to power the Antigua EV fleet, 2020-2050



Note: MW = megawatt; PV = photovoltaic.

6.4 ELECTRIC MOBILITY INFRASTRUCTURE

The total number of EV chargers peaks in 2031 with approximately 4 000 units, and then declines to slightly more than 1 500 units in 2050. The installed capacity of EV chargers reaches 74 MW in 2041 and declines to 64 MW in 2050. Level 1 and Level 2 chargers dominate the market for EV charging stations. Between 2022 and 2050, the total accumulated battery capacity will increase continuously, reaching a total of 6 470 MWh for EV batteries.

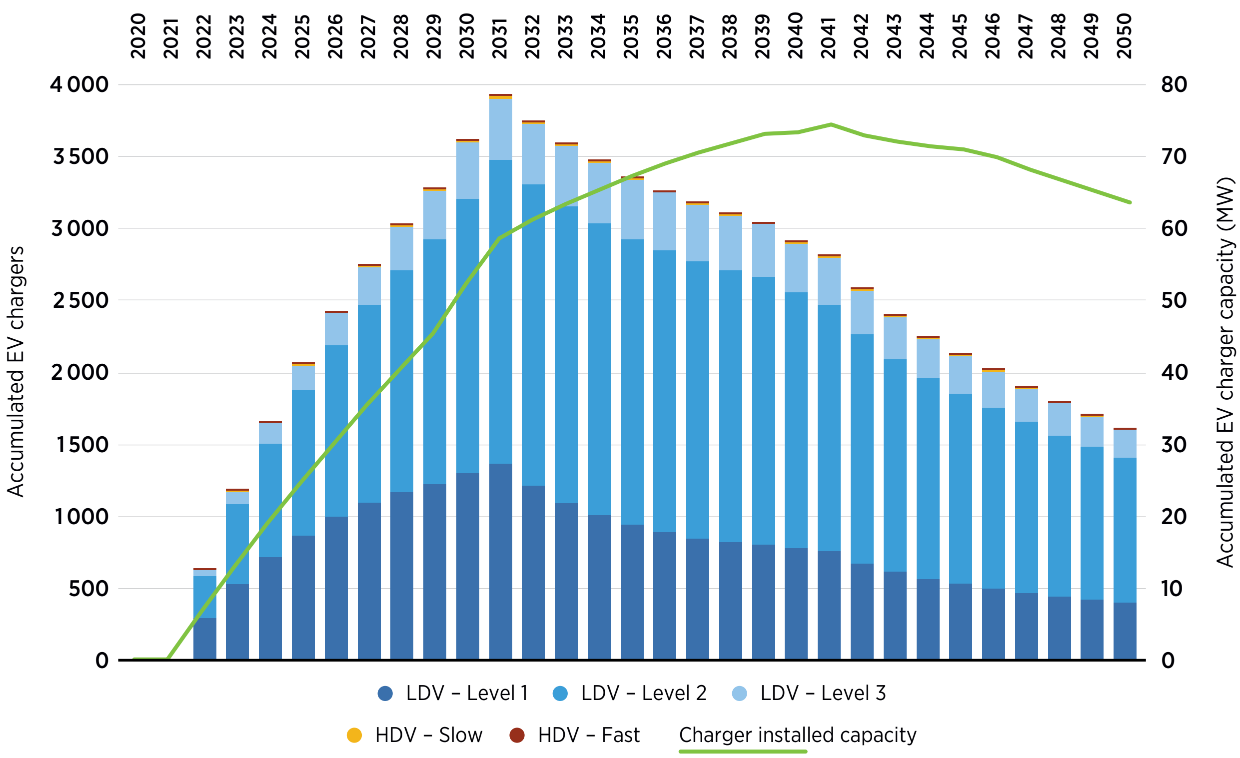
EV charger units and capacity

The number and type of chargers required to power the EV fleet and equivalent installed capacity in the 2022-2050 period are plotted in Figure 10. The total number of EV chargers shows two different trends: from 2022 to 2031, there is a rapid increase, peaking in 2031 with a total number of EV chargers close to 4 000; and from 2032 to 2050, there is a continuous decrease in the number of EV chargers, stabilising at just over 1 500 in 2050. Throughout the entire period of analysis, the types of EV chargers are dominated by Level 1 and Level 2. The equivalent EV charger installed capacity shows a similar trend as the EV charger units, with the difference that the peak in capacity of 74 MW is reached in 2041. By 2050, the total EV charger installed capacity is forecasted to be 64 MW.

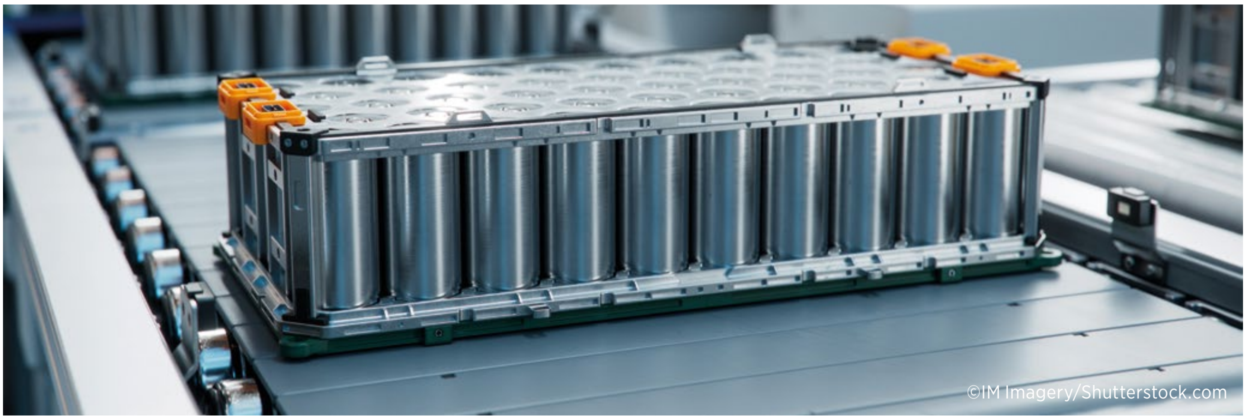
Trends in EV charger units and equivalent capacity are estimated using the following assumptions:

- **Lifespan of EV chargers.** The lifespan of EV chargers is set to ten years. Increasing the lifespan of EV chargers delays the year when the number and capacity of EV charger units peaks.
- **EV charger rated power.** The rated power of the EV chargers is assumed to increase by 60% between 2020 and 2030 and by 150% between 2030 and 2050. This translates into a lower number of EV chargers required for a given electricity demand in the future. It also explains the decrease in the number of EV charger units observed from 2032, when the first EV chargers installed in 2022 are retired.
- **The utilisation rate of EV chargers.** The utilisation rate of EV chargers is assumed to increase from 5% in 2020, to 10% in 2030 and 30% in 2050. A higher utilisation rate lowers the required number and capacity of chargers to meet a given electricity demand. The peak in EV charger capacity is reached in 2041, when the increase in the EV charger utilisation rate overcomes the rise in EVs and associated electricity demand, leading to a reduction in the EV charger capacity required in the system.

Figure 10 Accumulated number and capacity of EV chargers on Antigua, by type, 2022-2050



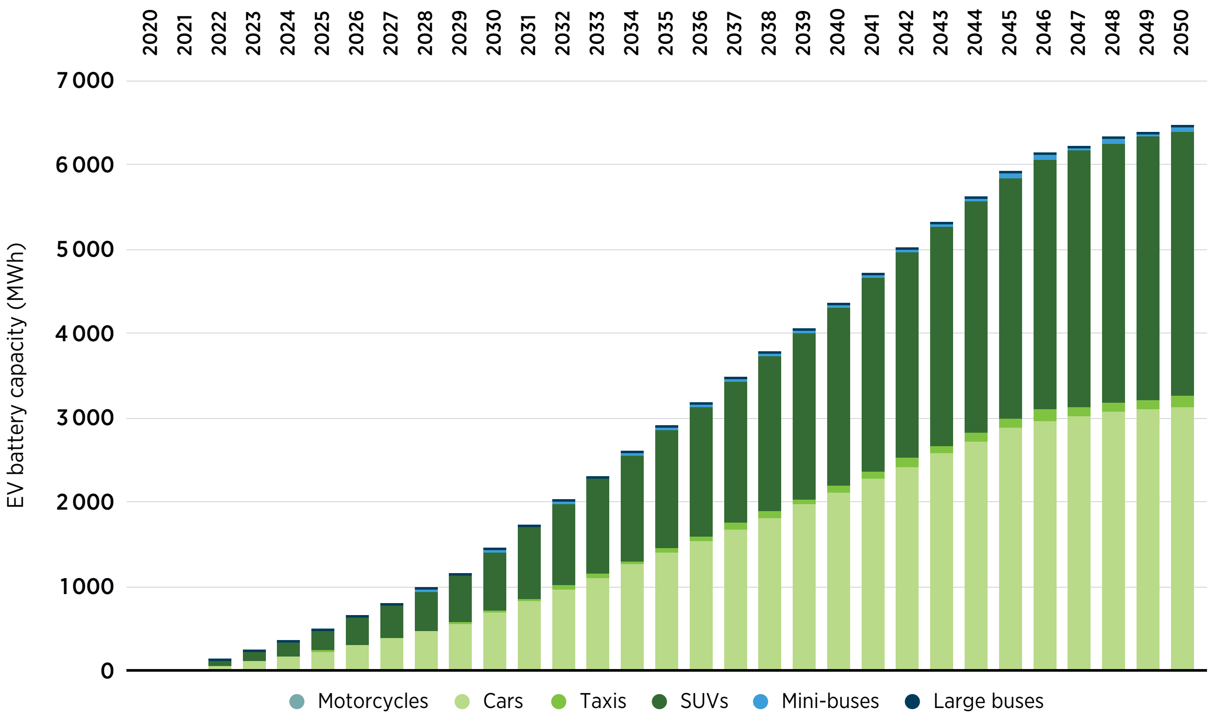
Notes: EV = electric vehicle; HDV = heavy-duty vehicle; LDV = light-duty vehicle; MW = megawatt.



EV battery capacity

The EV battery capacity trend in the analysed period naturally follows the changes in the number of EVs shown in Figure 11, in addition to the expected increase of battery capacity in EVs between 2020 and 2030 presented in Section 4.7 EV battery capacity constantly increases throughout the analysed period and is dominated by cars and SUVs. The total accumulated EV battery capacity in 2050 is estimated at 6 470 MWh.

Figure 11 Accumulated EV battery capacity on Antigua, by vehicle type, 2022-2050



Note: EV = electric vehicle; MWh = megawatt hour; SUVs = sports utility vehicles.

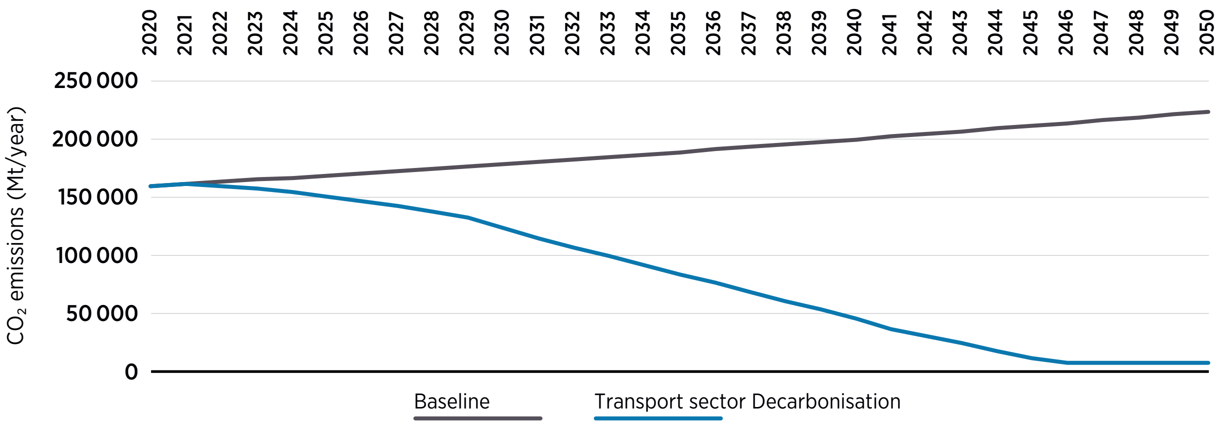
6.5 CLIMATE CHANGE MITIGATION POTENTIAL

By 2050, annual carbon dioxide (CO_2) emissions associated with a road transport fleet comprised entirely of EVs are projected to decrease to 7 310 tonnes/year compared to the baseline; an equivalent ICE-based road transport fleet could reach 223 000 tonnes/year. The electrification of road transport vehicle fleets can reduce annual CO_2 emissions by 97%. In addition, complete electrification of the road vehicle fleet can reduce annual particulate matter (PM_{10}, $PM_{2.5}$) and nitrogen oxide (NOx) emissions by 90%, 95% and 99%, respectively.

Carbon dioxide

Figure 12 shows the annual CO_2 emissions directly associated to the operation of a vehicle fleet with and without renewable-based transport in 2020-2050.[5] With a 100% EV fleet, in 2050, the annual CO_2 emissions associated to the road transport are forecasted to be 7 310 tonnes/year. The EV emissions in 2050 are not zero since there is still a fraction of electricity generated with heavy fuel oil. By comparison, in the baseline case where no EVs are implemented, the CO_2 emissions associated to the road transport reach 223 000 tonnes/year by 2050. A 100% EV fleet results in a -97% reduction in CO_2 emissions compared to a case with no EVs implemented.

Figure 12 Annual CO_2 emissions directly attributed with the use of a road fleet with and without renewable-based EVs, 2020-2050

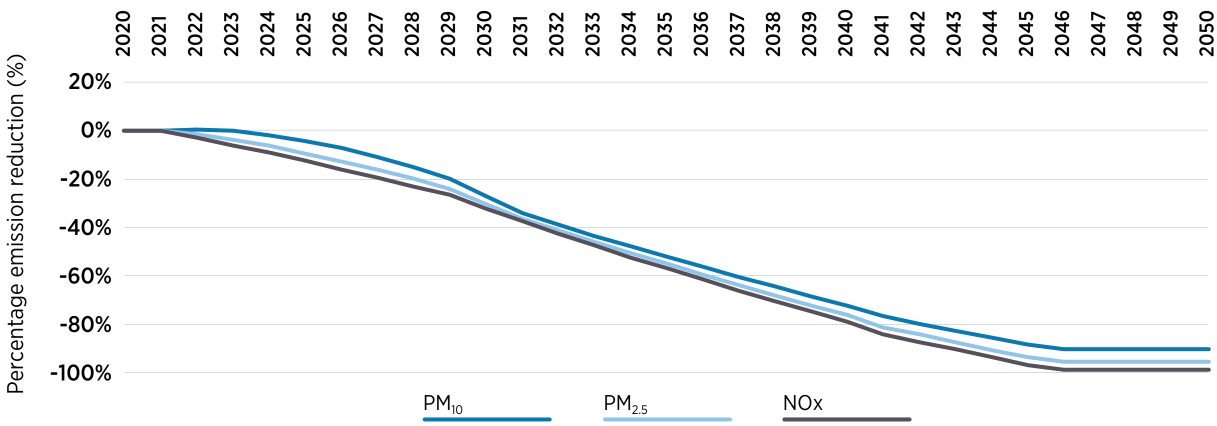


Note: CO_2 = carbon dioxide; Mt = million tonnes.

Particulate matter and other emissions

Figure 13 shows the reduction in PM_{10}, $PM_{2.5}$ and NOx emissions directly linked to the use of vehicles fuelled by renewable-based energy, compared to the baseline. By 2050, the annual reduction in the emissions of PM_{10}, $PM_{2.5}$ and NOx are -90% (4 tonnes), -95% (7 tonnes) and -99% (411 tonnes), respectively.

Figure 13 Reduction in PM_{10}, $PM_{2.5}$ and NOx emissions associated with the use of a fleet with and without renewable-based EVs, 2020-2050



Note: NOx = nitrogen oxides; PM = particulate matter.

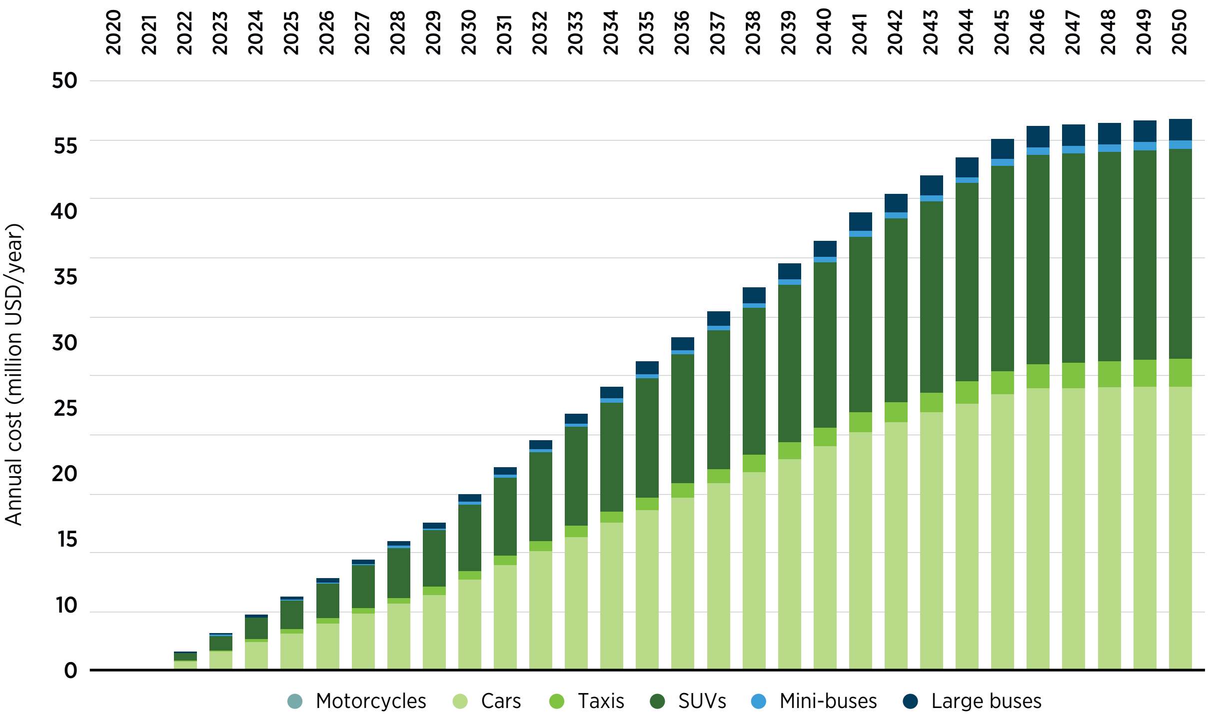
5 *For example, it does not include inefficiencies of EV chargers and T&D losses for the EVs, or conversion and transport of petrol for ICE vehicles.*

6.6 INVESTMENT REQUIREMENTS

The major costs associated with decarbonising the transport sector are electricity, EV chargers and electric vehicles, as well as upgrading the grid and interconnection infrastructure. By 2050, electricity costs for charging EVs are anticipated to exceed USD 45 million annually compared to a baseline in which over USD 600 million will be spent on fuel for vehicles alone. In 2050, it is anticipated that the total accumulated investment costs associated with EV chargers and EVs will be USD 54.2 million and USD 3 568 million, respectively. Cars and SUVs account for the majority of both annual electricity and accumulated investment costs.

Figure 14 shows the annual electricity retail cost of powering an all-EV fleet by vehicle type. As expected, most annual costs correspond to cars and SUVs.

Figure 14 Breakdown of annual electricity costs to power an all-EV fleet, by vehicle type, 2020-2050



Note: SUVs = sports utility vehicles.

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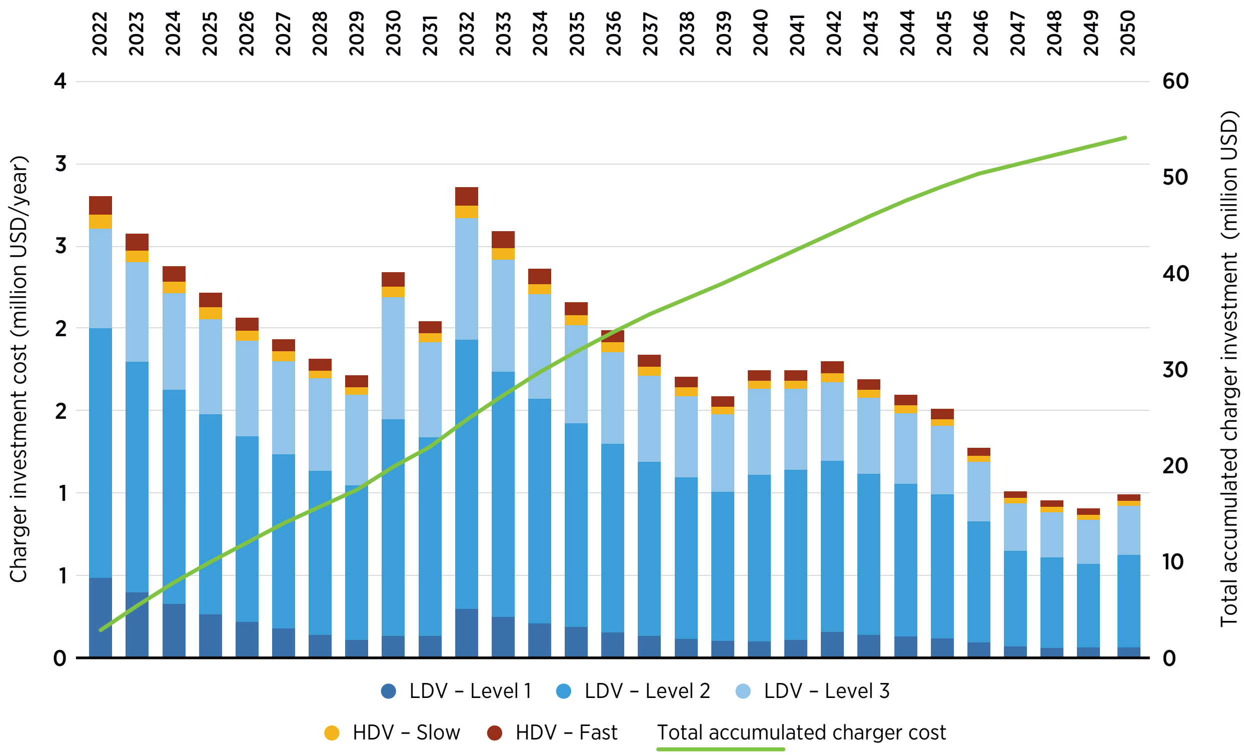
Figure 15 shows the forecasted annual and accumulated investment cost to acquire the number of EV chargers required to transition towards a 100% EV fleet. The set lifespan for the EV chargers is the source for the local peaks in annual costs located in 2032 and 2042. The total accumulated cost associated to EV chargers in 2050 is forecasted to be USD 54.2 million.

Figure 15 Annual and accumulated investment cost of EV chargers, 2020-2050



Notes: EV = electric vehicle; HDV = heavy-duty vehicle; LDV = light-duty vehicle; MW = megawatt.

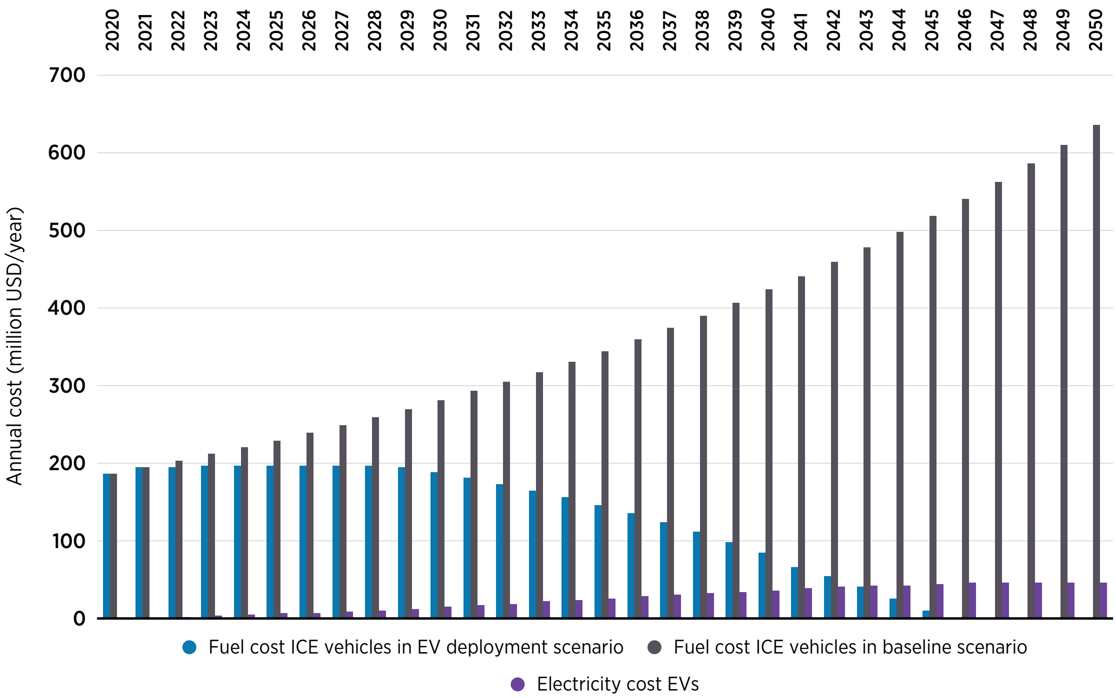
In terms of the annual and accumulated investment cost of EVs and ICE vehicles under the technology plan for the electrification of transport with renewables, the total accumulated investment cost of EVs in 2050 is forecasted to be USD 3 568 million. The accumulated cost of ICE vehicles considers the initial stock of ICE vehicles on the island of Antigua and does not present any growth from 2030 since no more ICE vehicles would be allowed to be purchased.

6.7 ECONOMIC SAVINGS

Total transport electrification would result in annual energy cost savings of USD 590 million. It would also reduce annual external costs by USD 22.6 million, of which 81.5% are related to CO_2.

Figure 16 shows the annual costs of electricity and fuel forecasted by the technology plan versus the baseline. In the technology plan, the trends in electricity and fuel consumption are in line with those of EVs and ICE vehicles in section 6.1. The total annual cost of electricity in 2050 to power a 100% EV fleet is forecast to be about USD 47 million. By contrast, if no EVs were implemented and the entire vehicle fleet were to run on petrol, the equivalent annual fuel cost in 2050 would be USD 637 million. Annual energy cost savings would be USD 590 million that same year.

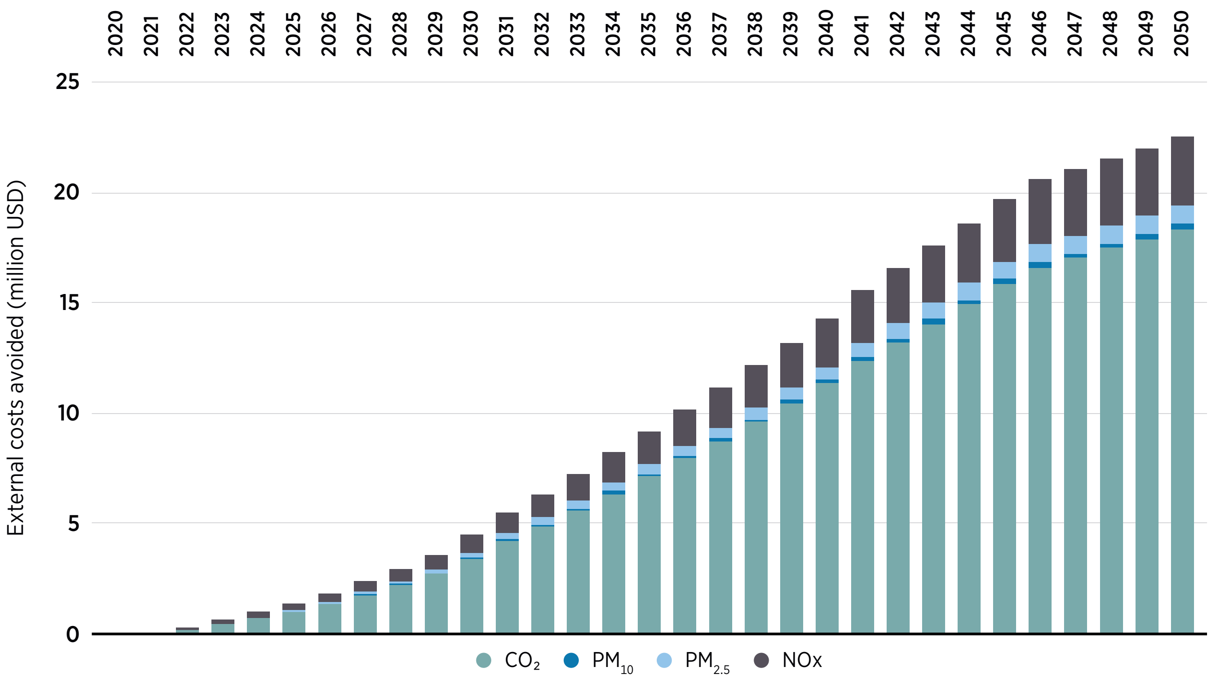
Figure 16 Annual fuel and electricity costs with and without renewable-based EVs, 2020-2050



Note: EV = electric vehicle; ICE = internal combustion engine.

Figure 17 shows the evolution of the annual external costs associated to the CO_2, PM_{10}, $PM_{2.5}$ and NOx emissions resulting from the technology plan between 2020 and 2050. By 2050, the forecasted total annual external costs avoided are USD 22.6 million, of which CO_2 accounts for 81.5%.

Figure 17 Breakdown of external costs avoided relating to CO_2, PM_{10}, $PM_{2.5}$ and NOx emissions with and without renewable-based EVs, 2020-2050



Note: EV = electric vehicle; ICE = internal combustion engine.

7 DISCUSSION

This section describes the primary outputs of the Electric Mobility Infrastructure (EMI) tool, as well as the results of a sensitivity analysis that focuses on alternative scenarios defined to understand the implications of two important model parameters. In addition, it discusses the significance of deploying electric vehicles (EVs) and renewable power generation simultaneously.

7.1 OUTPUTS

The analysis reveals the results presented in Table 15.

Table 15 CAPEX considered for EV chargers, 2020

OUTPUT DESCRIPTION	OUTPUT RESULT 2030	OUTPUT RESULT 2050
Number of existing ICE vehicles	39 482	0
Number of existing EVs	19 328	73 693
Number of ICE vehicles retired annually	2 627	0
Number of EVs retired annually	0	3 286
Number of EVs purchased annually	3 286	6 626
Number of existing EV chargers	3 621	1 611
Number of retired EV chargers annually	0	295
Number of purchased EV chargers annually	499	158
Percentage reduction CO_2 emissions relative to no-EV implementation case	-31%	-97%
Percentage reduction PM_{10} emissions relative to no-EV implementation case	-27%	-90%
Percentage reduction $PM_{2.5}$ emissions relative to no-EV implementation case	-30%	-95%
Percentage reduction NOx emissions relative to no-EV implementation case	-32%	-99%

OUTPUT DESCRIPTION	OUTPUT RESULT 2030	OUTPUT RESULT 2050
Reduction of associated external costs (million USD)	4.5	22.5
Petrol demand from ICE vehicle fleet (million litres)	51	0
Electricity generation to power EV fleet (MWh)	49 345	182 370
Battery storage capacity associated to EV fleet (MWh)	1 432	6 470
Charger capacity associated to EV fleet (MW)	52	64
Additional renewable energy capacity required to power the EV fleet (MW)	24 (Solar PV) 5 (Wind)	89 (Solar PV) 19 (Wind)
Costs/savings associated to changes in electricity and fuel consumption (million USD)	267	590
Accumulated investment costs associated to EVs (million USD)	682	3 568
Accumulated investment costs associated to EV chargers (million USD)	19.8	54.2
Accumulated investment costs associated to additional renewable energy capacity (million USD)	20	61

Note: CO_2 = carbon dioxide; EV = electric vehicle; ICE = internal combustion engine; MWh = megawatt hour; NOx = nitrogen oxides; PM = particulate matter; PV = photovoltaic.

7.2 SENSITIVITY ANALYSIS

Alternative scenarios were defined to understand the implications of the two important tool parameters: fleet electrification target year and fleet growth. The results presented in the previous section are based on two main assumptions:

- Growth rate of vehicle fleet on Antigua between 2020 and 2050 based on the averaged population growth trend between 2015 and 2020.
- Target for 100% electrification of the transport sector set to 2050 or earlier.

An initial sensitivity analysis has been conducted considering the following three vehicle fleet annual growth scenarios: vehicle growth lockstep with averaged population growth between 2015 and 2020 (slow growth); no growth (zero growth) and vehicle growth of 6.5% based on historic vehicle growth rates (fast growth) (GEF, 2020). The target of 100% electrification might be accomplished by 2040. In this case, a peak emission reduction of -97% to -99% relative to the internal combustion engine (ICE) baseline can be reached in 2040.

Table C.3 in Appendix C shows the resulting percentage of the vehicle fleet to be electrified, and the absolute emissions associated with the use of vehicles between 2022 and 2050, as well as the maximum reduction in emissions compared to an ICE-based case and the year in which this is achieved for the various alternative scenarios that were defined.

The effects of the three vehicle growth scenarios on the technology plan in terms of electrification and emissions have been analysed, yielding the following conclusions:

- For the zero-growth case, absolute annual emissions associated to a 100% ICE vehicle fleet remain at 159 169 million tonnes of carbon dioxide ($MtCO_2$) for the entire period analysed, compared to the 223 266 $MtCO_2$ and 1 052 802 $MtCO_2$ reached in 2050 for the slow and fast vehicle growth scenarios, respectively.
- When setting the target of 100% EV fleet by 2050 or earlier, results show that a 100% EV fleet could be achieved earlier than 2050 in the three scenarios, with the annual emissions associated to the 100% EV fleet in 2050 estimated at 7 310 $MtCO_2$, 5 210 $MtCO_2$ and 34 468 $MtCO_2$ for the slow, zero and fast growth scenarios, respectively. Compared to a 100% ICE vehicle fleet, the slow and no growth scenarios lead to a -97% reduction in emissions while in the case of fast growth the reduction reaches -99%.
- When the target of 100% EV is moved forward to 2040, results show that a 100% EV fleet can be achieved by 2040 and that annual emissions associated to the vehicle fleet are 5 210 $MtCO_2$ from 2040 to 2050 for the zero-growth case. For the slow and fast growth scenarios, emissions reach a minimum in 2040 of 6 530 $MtCO_2$ and 18 362 $MtCO_2$, respectively, and experience a small increase between 2040 and 2050.

8 RECOMMENDATIONS FOR NDC IMPLEMENTATION

Electric vehicles (EVs), combined with renewable power generation, offer the greatest potential to reduce emissions in the transport sector. Based on the current targets, as outlined in the country's first updated Nationally Determined Contribution (NDC), the transport sector of Antigua and Barbuda could achieve a 100% electric road vehicle fleet by 2046. By 2050 the total number of vehicles is expected to be 73 693 and the total electricity generation required to cover the new demand is 182.4 GWh/year, to be supplied by renewable energy capacity. The total yearly cost of electricity to power the EV fleet in 2050 will be more than ten times cheaper than if the fleet continues to run on gasoline.

A 100% EV road fleet in 2050 would reduce annual CO_2 emissions by more than 30 times. Other major pollutants such as particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen oxides would be minimised, with positive health and social implications. As a signatory to the Paris Agreement, Antigua and Barbuda agreed to make best efforts to limit global warming to 2°C over pre-industrial levels, and ideally to 1.5°C. In addition, as part of the country's first updated NDC, the Cabinet of Antigua and Barbuda presented two key climate targets for the country to implement: 86% renewable energy generation from local resources in the electricity sector by 2030, and 100% of all new vehicle sales to be EVs by 2030. In addition to the switch to EVs, decarbonisation measures include alternatives to private transport, such as car sharing and public transport.

To achieve the 2050 objective, substantial action must be taken by 2030. To shift the existing course, strong action is required, backed by political will and well-designed policy packages. Electricity will become the predominant form of energy in future clean energy systems. The direct electrification share of final energy consumption (which includes direct use of electricity but excludes indirect uses such as e-fuels) would increase from 21% in 2019 to 30% by 2030 and 50% by 2050. Transport will emerge as a significant new market for electricity (IRENA, 2022).

The transport sector is key for society and must be decarbonised to prevent the risks that climate change can bring. The shift to low-emission mobility necessitates not only the abandonment of internal combustion engine technologies, but also the re-engineering of the overall transport sector. Transitioning to renewable energy sources is the most effective strategy for reducing climate change's most serious impacts. Moreover, this path promises increased energy security, domestic resilience and a global economy that is more inclusive, equitable and climate resilient.

As a follow-up step to this technology plan, a detailed assessment of EV charging and generation profiles would increase the accuracy and resolution of estimated power, grid and EV infrastructure requirements. In addition, actions to remove market distortions and incentives for energy transition solutions will allow the necessary adjustments in funding structures. The majority of additional capital is anticipated to originate from the private sector. Nevertheless, state funding will also need to increase to stimulate private investment and foster a conducive atmosphere for a swift transition with maximum socio-economic advantages.

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APPENDIX A

This section covers the results and outcomes of the technology plan for transport electrification with renewables for a case in which decarbonisation of the transport sector begins in 2025.

The analysis reveals the results presented in Table A1.

Table A1 Electric Mobility Infrastructure tool outputs for Antigua

OUTPUT DESCRIPTION	OUTPUT RESULT 2030	OUTPUT RESULT 2050
Number of existing ICE vehicles	45 498	0
Number of existing EVs	13 312	73 693
Number of ICE vehicles retired annually	2 627	0
Number of EVs retired annually	0	3 286
Number of EVs purchased annually	3 287	14 164
Number of existing EV chargers	1 984	1 570
Number of retired EV chargers annually	0	296
Number of purchased EV chargers annually	504	168
Percentage reduction of CO_2 emissions relative to no-EV implementation case	-21%	-97%
Percentage reduction of PM_{10} emissions relative to no-EV implementation case	-19%	-90%
Percentage reduction of $PM_{2.5}$ emissions relative to no-EV implementation case	-21%	-95%
Percentage reduction of NOx emissions relative to no-EV implementation case	-22%	-99%
Reduction of associated external costs (million USD)	3	22.5
Petrol demand from ICE vehicle fleet (million litres)	59	0

OUTPUT DESCRIPTION	OUTPUT RESULT 2030	OUTPUT RESULT 2050
Electricity generation to power EV vehicle fleet (MWh)	33 920	182 370
Battery storage capacity associated to EV vehicle fleet (MWh)	1 057	6 470
Charger capacity associated to EV vehicle fleet (MW)	33	64
Additional renewable energy capacity required to power the EV fleet (MW)	17 (Solar PV) 4 (Wind)	89 (Solar PV) 19 (Wind)
Costs/savings associated to changes in electricity and fuel consumption (million USD)	53	590
Accumulated investment costs associated to EVs (million USD)	466	3 568
Accumulated investment costs associated to EV chargers (million USD)	11.7	54.2
Accumulated investment costs associated to additional renewable energy capacity (million USD)	16	61

Note: Case with decarbonisation starting in 2025. CO_2 = carbon dioxide; EV = electric vehicle; ICE = internal combustion engine; MWh = megawatt hour; NOx = nitrogen oxides; PM = particulate matter; PV = photovoltaic.

Table B1 Consumption rates for ICE vehicles

VEHICLE TYPE	CONSUMPTION RATE (litre/km)	SOURCE
Scooters	0.03	(UNEP, 2018)
Cars	0.10	(Kothari *et al.*, 2021)
Taxis	0.10	(Kothari *et al.*, 2021)
Sports utility vehicles	0.14	(US EPA, 2008)
Mini-buses	0.18	Own assumption
Large buses	0.66	(UNEP, 2018)

Table B2 Consumption rates for EVs

VEHICLE TYPE	CONSUMPTION RATE (kWh/km)	SOURCE
Scooters	0.040	(UNEP, 2018)
Cars	0.146	(UNEP, 2018)
Taxis	0.146	(UNEP, 2018)
Sports utility vehicles	0.192	(EVD, 2022; TrueCar, 2022)
Mini-buses	0.258	(EVD, 2022)
Large buses	1.150	(UNEP, 2018)

Note: km = kilometre; kWh = kilowatt hour.

APPENDIX B

Table B3 Percentage of electrification of the vehicle fleet and absolute emissions associated to the vehicle fleet for different mitigation scenarios, 2022-2050

MITIGATION CASE	DESCRIPTION	PERCENTAGE EV FLEET (%) ABSOLUTE EMISSIONS ASSOCIATED TO THE USE OF VEHICLES							
		2022	2025	2030	2035	2040	2045	2050	MAXIMUM CO_2 EMISSIONS REDUCTIONS vs BASELINE (%) (YEAR ACHIEVED)
• Baseline ICE • Slow growth	• Vehicle fleet 100% ICE vehicles – no shift to EVs. • Growth in number of vehicles in line with population trend.	0 162 801	0 168 404	0 178 175	0 188 513	0 199 450	0 211 022	0 223 266	-
• EV 2050 IRENA power mix • Slow growth	• 100% EV fleet by 2050. Generation mix based on IRENA's roadmap. • Growth in number of vehicles in line with population trend.	3 159 248	14 150 543	33 123 168	58 83 384	80 45 252	98 10 828	100 7 310	-97 2047
• EV 2040 IRENA power mix • Slow growth	• 100% EV fleet by 2040. Generation mix based on IRENA's roadmap. • Growth in number of vehicles in line with population trend.	5 157 379	21 141 142	47 98 894	74 54 156	100 6 530	100 6 909	100 7 310	-97 2040

• Baseline ICE • Zero growth	• Baseline 100% ICE vehicles • No growth in number of vehicles between 2020 and 2050.	0 159 169	0 159 169	0 159 169	0 159 169	0 159 169	0 159 169	0 159 169	-
• EV 2050 IRENA power mix • Zero growth	• 100% EV fleet by 2050. Generation mix based on IRENA's roadmap. • No growth in number of vehicles between 2020 and 2050.	3 155 696	14 142 287	33 110 447	58 70 510	83 32 021	100 5 211	100 5 211	-97 2045
• EV 2040 IRENA power mix • Zero growth	• 100% EV fleet by 2040. Generation mix based on IRENA's roadmap. • No growth in number of vehicles between 2020 and 2050.	5 153 868	21 133 402	47 88 345	74 45 726	100 5 211	100 5 211	100 5 211	-97 2040
• EV 2050 IRENA power mix • Fast growth	• 100% EV fleet by 2050. Generation mix based on IRENA's roadmap. • Growth in number of vehicles of 6.5% based on historic vehicle growth rates.	0 180 533	0 218 075	0 298 782	0 409 357	0 560 855	0 768 420	0 1052802	-
• EV 2050 IRENA power mix • Zero growth	• 100% EV fleet by 2050. Generation mix based on IRENA's roadmap. • No growth in number of vehicles between 2020 and 2050.	3 176 594	14 194 946	35 201 477	62 163 718	79 130 188	95 64 672	100 34 468	-99 2047
• EV 2040 IRENA power mix • Fast growth	• 100% EV fleet by 2040. Generation mix based on IRENA's roadmap. • Growth in number of vehicles of 6.5% based on historic vehicle growth rates.	5 174 521	21 182 772	48 163 214	75 113 516	100 18 362	100 25 157	100 34 468	-99 2040

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