Advancing Transportation Efficiency and Electric Vehicles in Tonga: A Review of Relevant Trends and Best Practices

Prateek Joshi, Bonnie Powell, Dustin Weigl,
Caley Johnson, and Derina Man

National Renewable Energy Laboratory

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5R00-84078
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Suggested Citation
Joshi, Prateek, Bonnie Powell, Dustin Weigl, Caley Johnson, and Derina Man. 2023. *Advancing Transportation Efficiency and Electric Vehicles in Tonga: A Review of Relevant Trends and Best Practices*. Golden, CO: National Renewable Energy Laboratory. NREL/ TP-5R00-84078. https://www.nrel.gov/docs/fy23osti/84078.pdf.

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National Renewable Energy Laboratory
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Acknowledgments

This work was sponsored by the U.S. Department of State, in partnership with the U.S. Department of Energy.

The National Renewable Energy Laboratory (NREL) team thanks members of Tonga's Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC) including Feauini Veikoso Laumanu, Samiuela Matakaiongo, and ‘Eliate Laulaupea'alu, along with Solomone Fifita and Sosefo Siuta Tofu from the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE), for providing vital information and data used in this report. NREL also appreciates ongoing collaboration with the Local2030 Islands Network to facilitate peer-to-peer exchange to identify and implement best practice solutions across islands worldwide. Furthermore, the NREL authors thank the following colleagues for their thoughtful feedback: Will Rolston (Global Green Growth Institute), Kaylyn Bopp, Jacob Holden, Alicen Kandt, John Barnett, and Mike Callahan, as well as Katie Wensuc for her editorial assistance.

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List of Acronyms

AC	alternating current
BESS	battery energy storage system
BEV	battery electric vehicle
BNEF	Bloomberg New Energy Finance
CAD	Canadian dollar
CCS	Combined Charging System
CTCN	Climate Technology Centre and Network
DC	direct current
DOE	U.S. Department of Energy
EECA	Energy Efficiency and Conservation Authority
EV	electric vehicle
FJD	Fijian dollar
GDP	gross domestic product
GGGI	Global Green Growth Institute
GHG	greenhouse gas
HEV	hybrid electric vehicle
ICE	internal combustion engine
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ITA	International Trade Administration
LEDS	Low-Emission Development Strategy
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
NDC	Nationally Determined Contribution
NREL	National Renewable Energy Laboratory
NZD	New Zealand dollar
OECD	Organisation for Economic Co-operation and Development
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PHEV	plug-in hybrid electric vehicle
PICT	Pacific Island Country and Territory
TEEMP	Tonga Energy Efficiency Master Plan
TOU	time-of-use
TPL	Tonga Power Limited
USD	U.S. dollar
VKT	vehicle kilometers traveled

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1 Introduction

The purpose of this report is to provide Tonga's Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC) with a wide range of information on electric vehicles (EVs) and transportation efficiency. Specifically, Section 2 discusses transportation efficiency and EV trends, both globally and regionally. Section 3 includes select case studies from different regions of the world, highlighting key policies and actions to promote sustainable transportation systems. Section 4 focuses on the land transportation sector in Tonga to assess its EV readiness. Section 5 concludes with insights to inform the next steps of this technical assistance project and future work that might be undertaken by the Government of Tonga. This report does not provide policy recommendations or an analysis of the impacts of different policies. Policy analysis might be considered in future stages of the project. This report provides a review of relevant trends and select best practices that are tailored to Tonga's geographic, economic, and environmental context.

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2 Transportation Energy Efficiency and Electric Vehicle Trends

The transportation sector is going through significant changes worldwide. The Paris Agreement set an international goal to limit global warming to well below 2°C, preferably to 1.5°C, compared to preindustrial levels (United Nations 2022). Commitments by various countries and subnational governments to comply with the Paris Agreement's goals and achieve net-zero greenhouse gas (GHG) emissions by 2050 have spurred additional efforts and investments to decarbonize the transportation sector, which is one of the largest contributors of GHG emissions. At the United Nations Climate Change Conference in 2021, known as COP26, 39 national governments and a host of other subnational governments, companies, and organizations signed a declaration aiming to achieve 100% sales of zero-emission cars and vans by 2040 and by no later than 2035 in leading markets (U.K. Government 2022). By understanding detailed global and regional trends for transportation energy efficiency and EVs within this context, MEIDECC can proactively plan for a resilient and sustainable transportation system.

2.1 Global Outlook

This section primarily focuses on trends that exist globally and in the largest vehicle markets (e.g., China, Europe, and the United States), which are expected to impact and expand to satellite markets.[1] Section 2.2 discusses the regional outlook and focuses on the markets that Tonga imports vehicles from.

2.1.1 Global Electric Vehicle Stock Trends

Global sales of EVs are growing rapidly and have been concentrated in certain markets. In 2021, sales of electric passenger cars doubled from the previous year, reaching 6.6 million and accounting for 9% of global sales (BNEF 2022a). As a result, 16.7 million electric passenger cars were on the road in 2021, primarily in China, Europe, and the United States (Figure 1). Aside from passenger cars, approximately 180,000 electric commercial vehicles were on the road in 2021 (1% share of annual sales), along with 685,000 electric buses (44% share of annual sales), and 275 million electric two- and three-wheelers (42% share of annual sales) (BNEF 2022a).[2] The projection of two- and three-wheeler sales includes vehicles such as motorcycles, mopeds, and scooters.

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[1] *Europe* refers to the 27 member nations of the European Union, Iceland, Liechtenstein, Norway, Switzerland, and the United Kingdom.

[2] Commercial vehicles consist of light-, heavy-, and medium-duty commercial vehicles.

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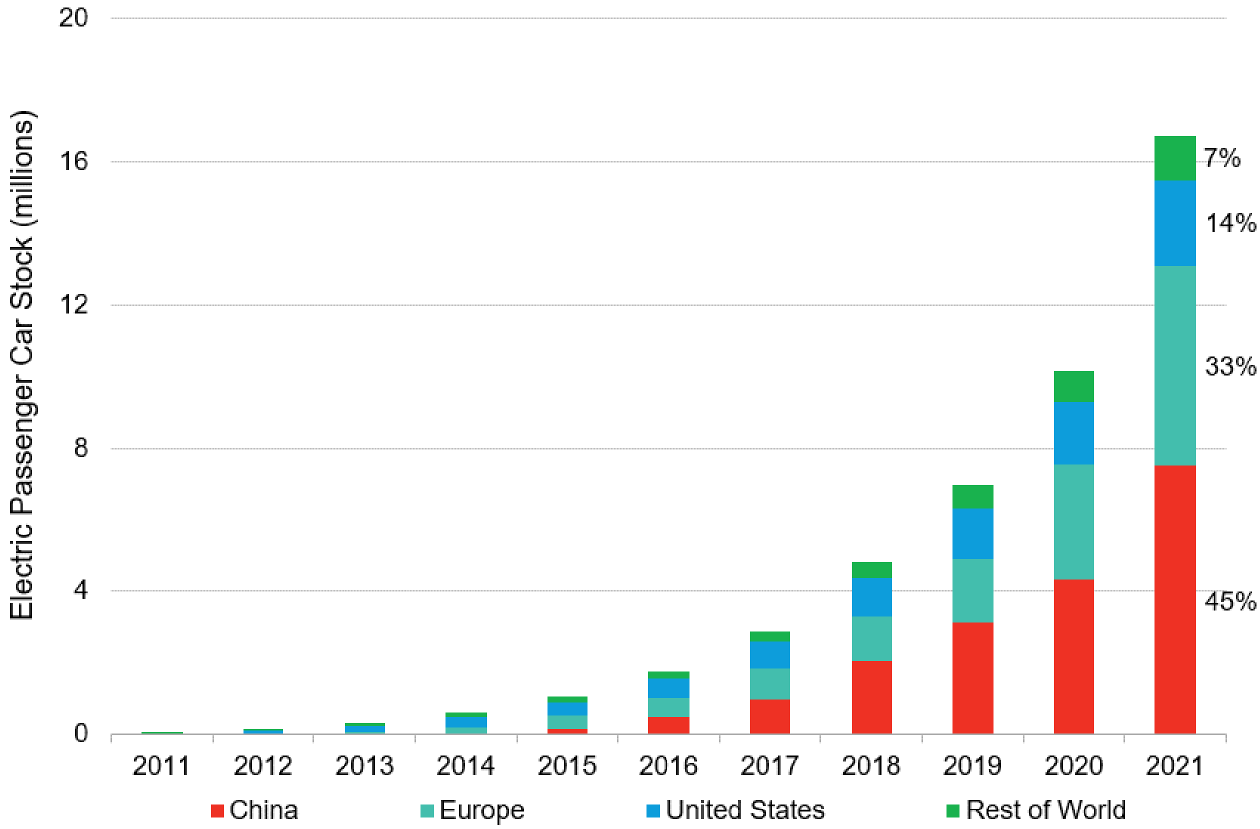

Figure 1. Global electric passenger car stock, 2011–2021

Figure adapted from BNEF *Electric Vehicle Outlook 2022* data (BNEF 2022a). Data include BEVs and PHEVs.

Bloomberg New Energy Finance (BNEF) developed EV stock and sales projections through 2040 for an Economic Transition scenario, which reflects existing policies and measures, is primarily driven by techno-economic trends and market forces, and assumes that no new policies or regulations are enacted (2022). The projection for electric passenger cars, which can be interpreted as an "existing policies" scenario, is shown in Figure 2. BNEF projects there to be 727 million electric passenger cars on the road by 2040 (75% share of annual sales), along with 15.5 million electric commercial vehicles (54% share of annual sales), 1.7 million electric buses (83% share of annual sales), and 758 million electric two- and three-wheelers (83% share of annual sales).

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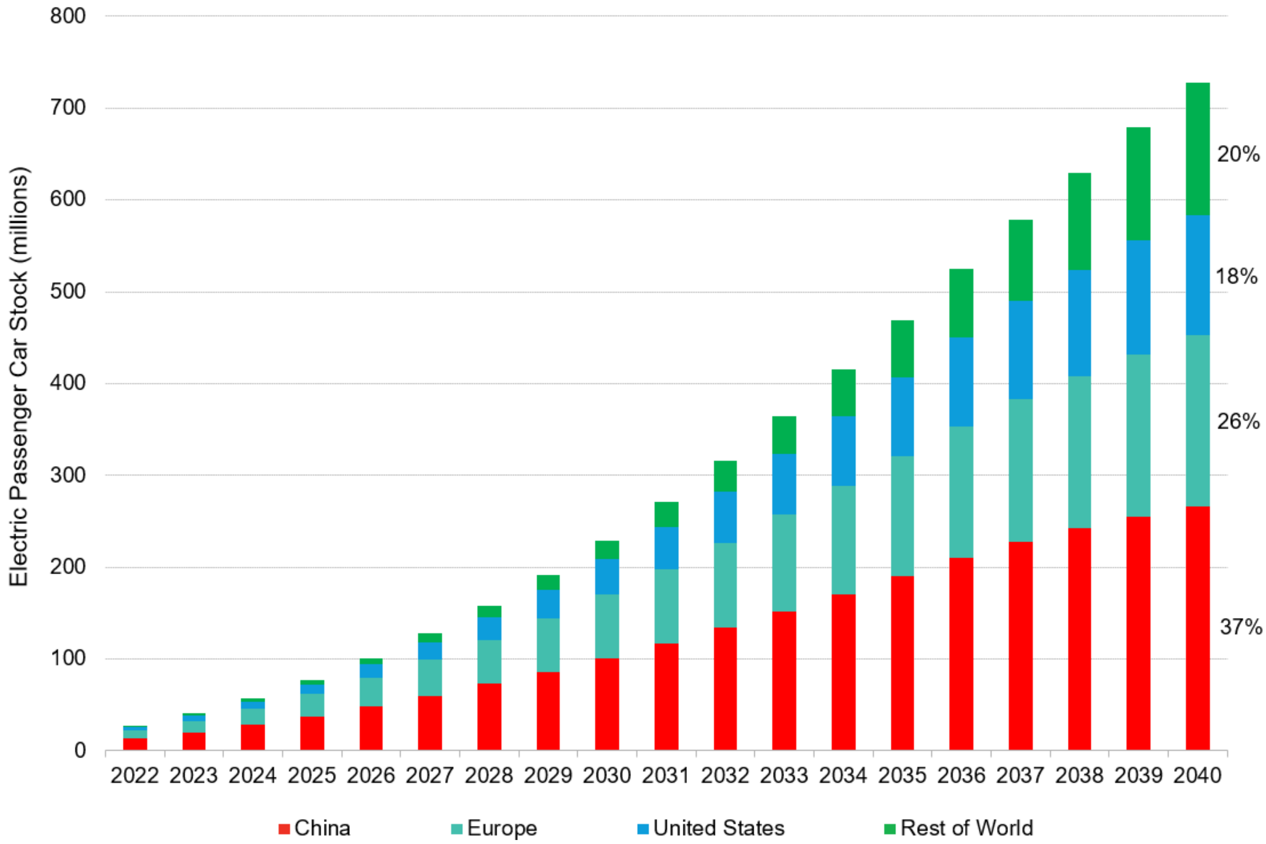

Figure 2. Global electric passenger car stock projection, 2022–2040

Figure adapted from BNEF *Electric Vehicle Outlook 2022* data (BNEF 2022a). Data include BEVs and PHEVs.

2.1.2 Global Electric Vehicle Cost Trends

The higher upfront cost of most EVs compared to their internal combustion engine (ICE) counterpart is due to the battery pack cost. Battery pack prices have fallen by 89% since 2010 (Figure 3) and are projected to fall to $58/kWh by 2030 with an assumed learning rate of 18% (Figure 4). However, due to recent supply chain issues and rising costs for raw materials, BNEF forecasts that average battery prices will increase by 2% in 2022 compared to 2021. BNEF projects that if these inflationary pressures persist, the point at which battery prices reach the $100/kWh threshold, at which EVs are expected to reach upfront price parity with ICE vehicles, could be delayed by 2 years to 2026 (BNEF 2022a). In BNEF's Economic Transition scenario, unsubsidized price parity between EVs and ICE vehicles is achieved in most vehicle segments and countries by the late 2020s. Already, the lifetime operational cost of owning a light-duty EV is typically less than its ICE counterpart due to reduced fuel and maintenance costs.

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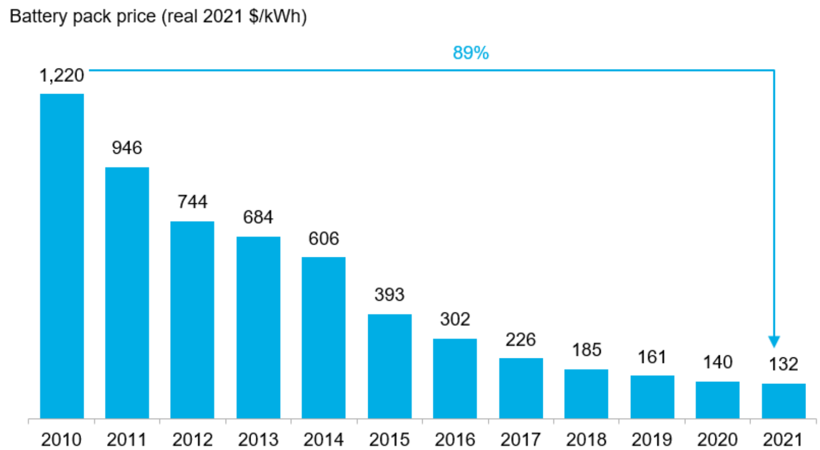

Figure 3. Decrease in price of battery packs, 2010–2021

Figure from BNEF *Electric Vehicle Outlook 2022* (BNEF 2022a).

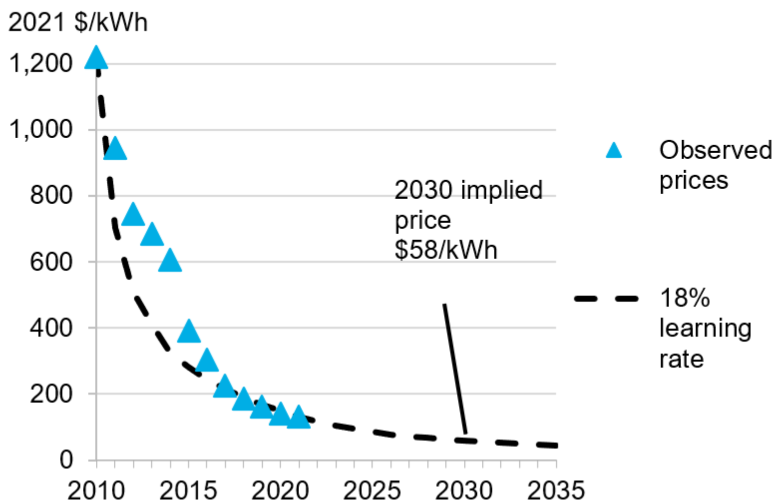

Figure 4. Projected decrease in price of battery packs, 2022–2035

Figure from BNEF *Electric Vehicle Outlook 2022* (BNEF 2022a).

2.1.3 Global Electric Vehicle Shipping Trends

Some shipping companies have banned or restricted the shipment of EVs due to safety concerns related to the batteries. For example, in March 2022 a ship named *Felicity Ace* was carrying thousands of EVs and sunk after catching on fire (Day 2022). Though the cause of the fire is not definitely known, the shipping company, Japan's Mitsui O.S.K. Lines, has since banned all shipments of used EVs, although the vehicles on the *Felicity Ace* were new. According to Mitsui O.S.K. Lines, it can be more difficult to perform safety checks on EVs prior to shipping compared to ICE vehicles (Day 2022).

Although studies have shown that EVs are less likely than ICE vehicles to catch on fire, if a fire starts, it could be more difficult to extinguish with EVs due to the thermal runaway of lithium-ion batteries (Bodine 2022; Sun et al. 2020). Due to these concerns, there is interest in new standards for ship designs and firefighting on vessels. The International Maritime Organization stated that new firefighting standards are needed to address EV safety concerns (Day 2022). One option for reducing risk could be to charge batteries to a lower capacity so there is less stored

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energy in the vehicles in the event of a fire (Osler 2022). Another option is adding detection equipment to ships so a fire can be quickly identified and extinguished before it spreads (Osler 2022). The impacts of shipping bans or restrictions are high, especially for islands that heavily rely on imports.

2.1.4 Global Efficiency Trends

Globally, overall vehicle efficiency has been increasing due to various policies, technology improvements, and manufacturing standards (Figure 5). This increase in efficiency has been primarily a result of higher fuel economy standards for ICE vehicles as well as the increasing introduction of hybrid electric vehicles (HEVs) into major automobile markets. Electric powertrains are three-to-five times more energy efficient than ICE powertrains; therefore, increasing the share of EVs in the transportation sector will simultaneously increase transportation efficiency. Studies have shown, however, that the real-world fuel consumption and carbon dioxide emissions of plug-in hybrid electric vehicles (PHEVs) are, on average, two-to-four times higher than rated values due to less frequent charging and more reliance on combustion power (International Council on Clean Transportation et al. 2020). This can be mitigated by increasing the all-electric range and frequency of charging for PHEVs, thereby decreasing petroleum fuel consumption. Pursuing battery electric vehicles (BEVs) instead of PHEVs negates this problem and increases vehicle efficiency because EVs do not need to carry a heavy ICE engine. The most developed EV markets are trending away from PHEVs and toward BEVs (Bibra et al. 2022).

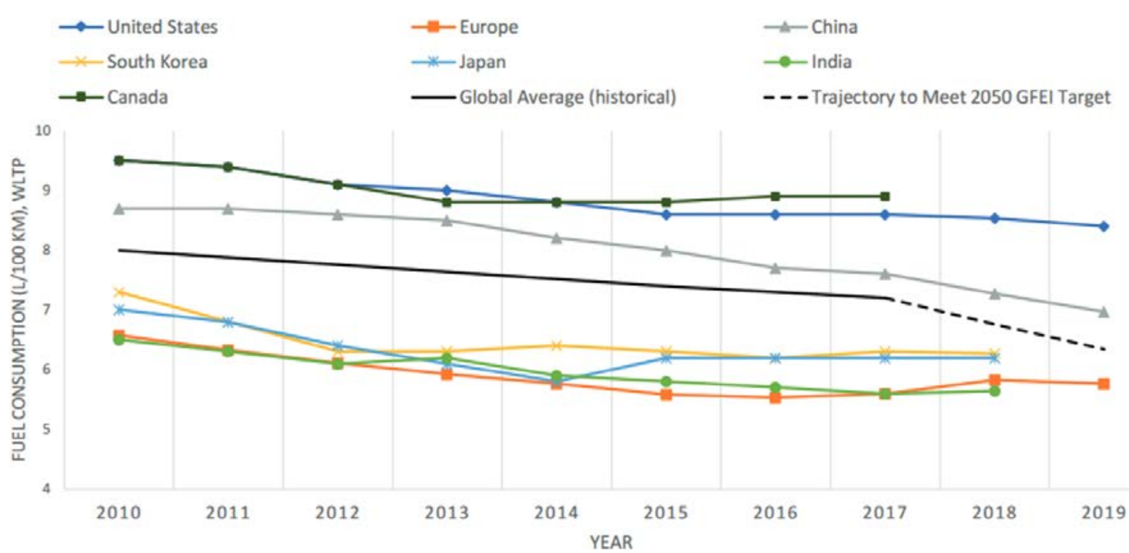

Figure 5. Increase in global vehicle efficiency (indicated by a decrease in average fuel consumption), 2010–2019

Figure from International Council on Clean Transportation et al. 2020.

2.1.5 Global Charging Trends

The International Energy Agency (IEA) *Global Electric Vehicle Outlook 2022* found that charging infrastructure is significantly expanding, with a 40% increase in publicly available charging stations between 2015 and 2021 (Figure 6). The report notes that this expansion occurred “despite a pandemic-related slowdown in construction” (Bibra et al. 2022). China, with its significant infrastructure investments, high EV adoption, and densely populated urban regions

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with limited home charging access, continues to have the largest share of public EV chargers, followed by Europe and the United States.

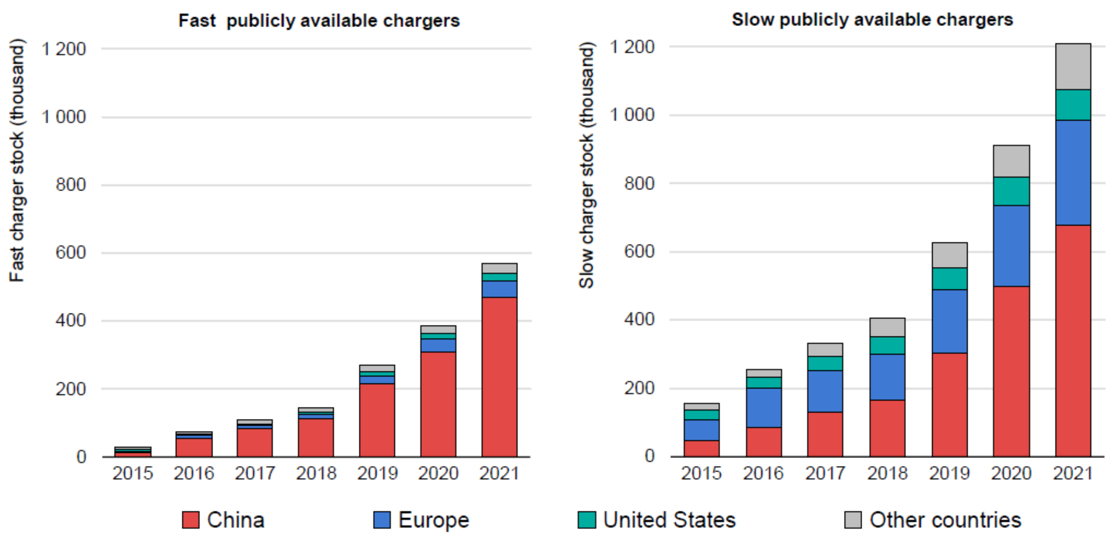

Figure 6. Publicly accessible light-duty vehicle charging ports by power rating and region, 2015–2021

Figure from IEA *Global Electric Vehicle Outlook 2022* (Bibra et al. 2022). Values shown represent the number of charging ports. According to the report, fast chargers have a power rating of more than 22 kW and can serve vehicles with power ratings of up to 350 kW, whereas slow chargers have a power rating of less than or equal to 22 kW.

The density of EVs per charging port varies by country, as shown in Figure 7. The global average as of 2021 is approximately 10 EVs per charging port. The appropriate number of charging ports per EV depends on a variety of factors that are specific to each jurisdiction, such as housing stock, vehicle stock, population density, and average trip distance.

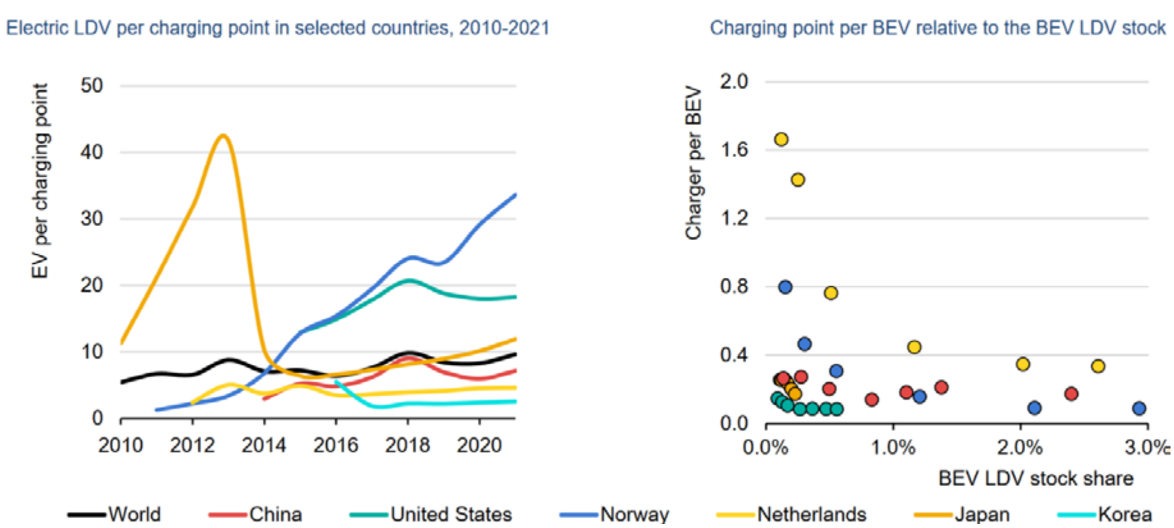

Figure 7. Ratio of electric light-duty vehicles per charger by region

Figure from IEA *Global Electric Vehicle Outlook 2022* (Bibra et al. 2022). Charging ports include only publicly available chargers, both fast and slow.

In BNEF's projections for 2040, the share of EVs with a home charger in the largest markets ranges from approximately 25% (China) to 40% (Europe and the United States). In these

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markets, BNEF also projects 30–40 EVs per public connector (including ultrafast chargers) and 100–300 BEVs per ultrafast charger (Figure 8). In general, markets with a lower share of home chargers also have a lower number of EVs per public connector and a much lower share of BEVs per ultrafast charger, indicating higher levels of public chargers and fast chargers. This general trend reflects the greater need for public access to charging in locations with reduced home charger access.

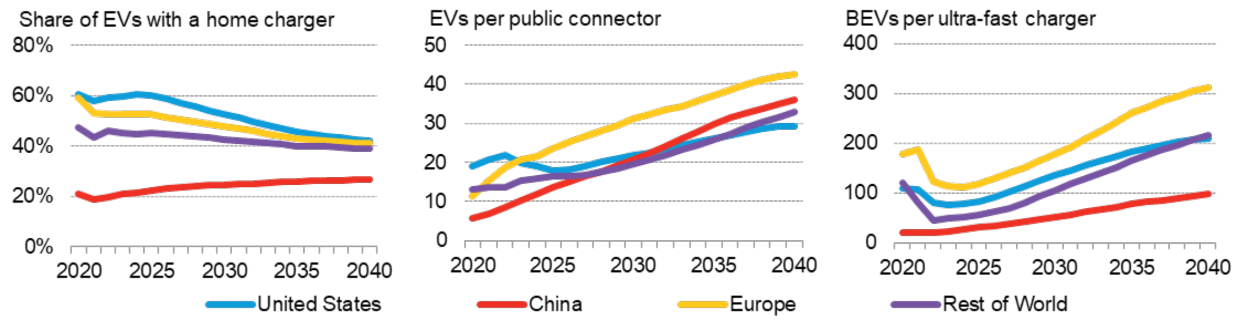

Figure 8. EV charger trends by region, 2020–2040

Figure from BNEF *Electric Vehicle Outlook 2022* (BNEF 2022a).

2.2 Regional Outlook

Pacific Island Countries and Territories (PICTs) import new and used vehicles from a variety of countries and regions, primarily Australia, China, Japan, South Korea, New Zealand, Singapore, South America, and the United States (Campbell et al. 2020c); therefore, this section focuses on these countries and regions, where data are available, in addition to PICTs. This section excludes details on markets in China, Europe, and the United States, which were featured in Section 2.1.

2.2.1 Regional Stock Trends

Data on EV sales and stock in 2021 for Australia, Brazil, Chile, Japan, New Zealand, South Korea, and Southeast Asia are disaggregated by vehicle segment in Table 1.[3] These data include BEVs, PHEVs, and fuel-cell EVs, and they cover both shared and private vehicles. Electric buses and two-wheelers are recommended to be a priority in emerging economies, which include Tonga, because buses are one of the more affordable forms of transportation and electric two-wheeler's have already achieved price parity with ICE counterparts (Bibra et al. 2022). In fact, emerging economies such as those in Southeast Asia have large two-wheeler markets, which could be due to the affordability and ease of navigation in congested urban streets. Three-wheelers are excluded from Table 1 because these vehicle types are not common in PICTs (Campbell et al. 2020c). Thus, although three-wheeler EVs could have applications in PICTs, their uptake is less likely because a market does not currently exist.

[3] *Southeast Asia* commonly refers to the following countries, which are members of the Association for Southeast Asian Nations: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam.

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Table 1. EV Stock and Sales Data in 2021 for Select Countries and Regions

Data from BNEF *Electric Vehicle Outlook 2022* (BNEF 2022a), IEA *Global Electric Vehicle Outlook 2022* (Bibra et al. 2022), and E-Bus Radar (2022).[4]

Country	Passenger Cars		Commercial Vehicles		Buses		Two-Wheelers	
	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales
Australia	41,451	20,699	3	0	195	156	45	45
Brazil	12,668	7,254	N/A	N/A	351	N/A	N/A	N/A
Chile	1,399	566	N/A	N/A	849	N/A	N/A	N/A
Japan	358,247	47,378	1,346	897	246	25	2,290	2,097
New Zealand	33,306	10,300	871	199	181	75	N/A	N/A
South Korea	286,678	123,813	42,942	32,719	2,937	1,287	46,311	17,419
Southeast Asia	69,270	12,240	N/A	N/A	533	266	4,009,531	547,219

Currently, there are small numbers of electric buses operating in Malaysia, and operations are planned for Singapore and Fiji (Nasokia 2022). PICTs also have small numbers of electric scooters, bikes, and two-wheelers, many of which are made available to tourists, as well as a small number of used electric passenger cars, mostly from Japanese manufacturers and primarily imported from New Zealand (Campbell et al. 2020c). For instance, the Cook Islands have 46 electric cars (predominantly Nissan Leaf models), 3 electric pickup trucks, 2 electric trucks, 24 electric two-wheelers, and 4 electric scooters. Papua New Guinea recently imported 3 electric commercial vans, Samoa is importing Hyundai Kona EVs through a pilot project supported by the government-run Electric Power Corporation, and Tuvalu is awaiting the arrival of 12 electric scooters from China (Campbell and Fifita 2022).

Projections for EV sales and stock are not available for Brazil, Chile, and New Zealand; however, New Zealand's EV-related targets and policies are covered in a case study in Section 3, and this information can provide a general sense of where the New Zealand EV market is heading. BNEF's Economic Transition scenario has projections for Australia, Japan, South Korea, and Southeast Asia, which are displayed for 2030 in Table 2.

[4] Data for Australia, Japan, South Korea, and Southeast Asia are from the BNEF *Electric Vehicle Outlook 2022* (BNEF 2022). The BNEF data do not include commercial vehicles for Southeast Asia. Data for Brazil, Chile, and New Zealand are from the IEA *Global Electric Vehicle Outlook 2022* (Bibra et al. 2022). The IEA data do not cover two-wheelers and do include vans and trucks, which are assumed to be part of the commercial vehicles category. E-Bus Radar has electric bus stock data from April 2022 for Chile and Brazil.

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Table 2. EV Stock and Sales Projections in 2030 for Select Countries and Regions

Data from BNEF *Electric Vehicle Outlook 2022* (BNEF 2022a).[5]

Country	Passenger Cars		Commercial Vehicles		Buses		Two-Wheelers	
	Stock	Sales	Stock	Sales	Stock	Sales	Stock	Sales
Australia	1,059,126	250,625	32,346	9,858	9,243	1,629	7,088	2,386
Japan	4,056,072	1,022,886	1,454,812	347,555	7,625	2,069	213,253	59,946
South Korea	4,031,159	650,896	644,567	111,934	24,111	3,284	377,377	67,007
Southeast Asia	847,289	248,013	N/A	N/A	43,448	13,881	17,614,048	3,966,297

The Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) has an electric mobility program that has proposed regional targets for 2030 and 2050, along with 38 policy actions to support these targets within the categories of: Central Policy and Administration, Standards and Guidelines, Awareness and Promotion, and Demonstration and Upscale (Campbell et al. 2020a). Proposed 2030 targets include having 10 different models of mainstream EVs available in Pacific Island markets and public awareness of EVs. Proposed 2050 targets include making EVs an integral and significant component of transportation systems. The program's guidance is that low-voltage mobility, such as electric two-wheelers, are relevant in all PICTs; electric passenger cars are relevant in PICTs with quality roads; electric buses are relevant in PICTs with major cities, such as Suva (Fiji) and Port Moresby (Papua New Guinea); and developments in electric trucks should be monitored. For instance, the initial adoption of electric trucks could have applications in government emergency response activities before widespread consumer adoption.

Multiple automakers around the world have made EV commitments. European vehicle manufacturers have the most ambitious goals, such as Volkswagen's commitment of selling 70% EVs by 2030 and Stellantis' goal of 100% EVs by the same year (Bibra et al. 2022). In China, most top automakers have also made pledges. These include selling 50% to 85% EVs by 2030 or 2035 (Bibra et al. 2022). In the United States, Ford and General Motors have both committed to selling only zero-emission vehicles by 2035.

The Government of Japan has a target of 100% "clean energy vehicles", which include hybrid vehicles, sold by 2035 (ITA 2021). This is particularly relevant for Tonga because Japanese-made vehicles are common in the country. Japanese automakers have varying commitments that have lagged other manufacturers. Toyota recently committed to EVs constituting 40% of annual sales by 2030 (Adler 2022), and Nissan committed to 50% sales from EVs and hybrids by the same year (Nikkei 2021). Hybrid vehicles remain a priority for many Japanese automakers, and EV commitments have been slow and cautious compared to the commitments of other automakers (Dooley and Ueno 2021).

[5] The BNEF projections do not include commercial vehicles for Southeast Asia.

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2.2.2 Regional Cost Trends

Due to their high utilization and ability to accrue more operational cost savings over increased kilometers driven, taxi and ride-hailing services are likely to be more cost-effective applications of electric passenger cars in PICTs, as is the case throughout the world (Campbell et al. 2020c). Ride-hailing services could also include on-demand public transit vehicles as opposed to fixed-route systems. Further, the shorter travel distances required in PICTs make it possible to use electric buses with smaller battery capacities, which is an opportunity to further reduce the upfront costs of these vehicles. These batteries could also be used to power smaller buses based on the needs and demands of local routes. Price parity with a diesel-powered bus might be achieved for a "right-sized" electric bus by 2030 in PICTs (Campbell et al. 2020c). The PCREEE program also notes that PICTs could consider setting tax levels to encourage the import of desired goods, such as EVs or other efficient vehicles, which could help reduce the incremental upfront costs for consumers (Campbell et al. 2020b).

2.2.3 Regional Efficiency Trends

Most emerging economies have limited or no regulations governing imported used vehicles. If regulations exist, they might be poorly enforced, resulting in an inefficient vehicle stock (International Council on Clean Transportation et al. 2020). Regulations that could be implemented by countries that predominantly rely on importing used vehicles include import bans, age restrictions, import tariffs or registration fees that favor smaller or more efficient vehicles, and vehicle labeling campaigns to transparently display the fuel efficiency and emissions associated with different vehicle models. These actions could favor more efficient vehicles, such as HEVs, PHEVs, and BEVs. Given the growing stock of EVs in countries that PICTs import vehicles from, regulations and policies governing imported vehicles can help accelerate the transition to a fuel-efficient domestic fleet.

For instance, Mauritius, an Indian Ocean island nation, adopted a fee and rebate program to import more fuel efficient vehicles, helping to result in an improvement in fuel economy by 16% from 2005 to 2015. In subsequent years, the measure was changed to incentivize EVs in addition to more efficient ICE vehicles and gasoline hybrids (International Council on Clean Transportation et al. 2020).

Japan's automobile industry, a significant source of vehicles in Tonga, has heavily invested in HEVs. Hybrids, including PHEVs, accounted for almost 44% of passenger car sales in Japan in 2021. Further, Japan's target for all new car sales to be electric-powered vehicles by 2035 includes hybrids, which the automobile industry is hoping can still be carbon neutral with the introduction of synthetic zero-emission fuels, which still have not become commercially mass produced for vehicles (Yamazaki 2022). However, most major automakers have pledged significant transitions beyond hybrid vehicles and toward battery electric models (Section 2.2.1).

2.2.4 Regional Charging Trends

Because PICTs import vehicles from a wide range of jurisdictions (e.g., Australia, China, Japan, South Korea, New Zealand, Singapore, South America, and the United States), different charging standards might fragment the market (Campbell et al. 2020c); thus, the PCREEE program highlights the need for charging infrastructure standards based on those that already exist in other countries. The geographic distribution of charging standards for countries where such data are available is shown in Figure 9. New Zealand, a source for many of Tonga's used vehicle imports, has adopted Combined Charging System (CCS) 2 standards. Despite the existence of these standards, some connector types are still varied. For example, CHAdeMO connectors operate across the United States, and a separate Tesla connector operates in most major markets except Europe.

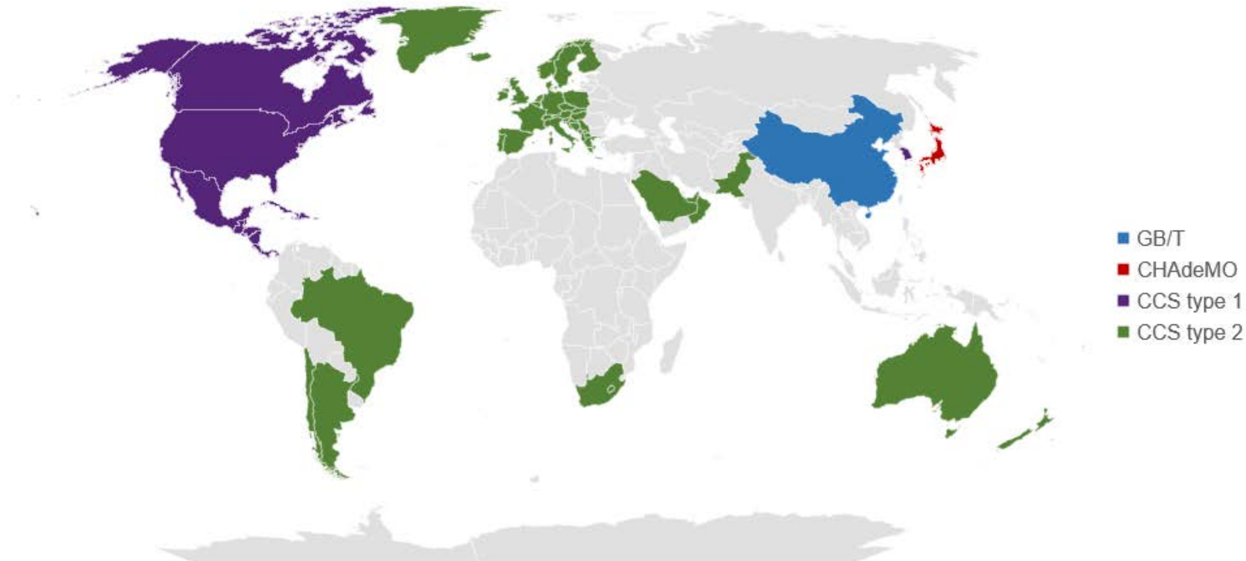

Figure 9. Predominant DC fast charging connector standards by location

Figure adapted from Kane (2021) and populated with additional data.

The regional PCREEE program notes that time-of-use pricing and managed charging for EVs can greatly reduce strain on the grid and facilitate the use of renewables in PICTs. Managed charging is defined as the capability of the electricity supplier to control when or at what rate the vehicle charging occurs, whereas time-of-use pricing is defined as a pricing program that incentivizes customers to shift electricity demand to periods that are beneficial to the electric grid. Specifically, PCREEE's electric mobility program proposes that 50% of EVs are charged through devices that can manage charging by 2030 and 90% by 2050 (Campbell et al. 2020a). Managed charging could be promising because the battery capacity on new EVs will likely be underused in PICTs due to the lower average driving distances. Battery swapping businesses, such as those in the Philippines or Taiwan, are also viewed as viable in PICTs for low-voltage mobility, such as two-wheelers (Campbell et al. 2020b; Toll 2022). Draft proposed EV charging guidelines developed by a PCREEE program list safety considerations, including that the charging equipment be labeled by the manufacturer with its electricity supply requirement, public charging stations be inspected annually and have a switch to isolate the equipment from all live conductors, and that sockets that have been inspected and meet charging requirements be labeled with standardized signage (Campbell 2022).

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3 International Case Studies

The following case studies for transportation efficiency and EVs focus on select island nations and regions chosen for their progress in EV adoption and attributes relevant to Tonga. Although best practices will be identified, it is difficult to generalize these findings across all PICTs because various context-specific factors can affect EV uptake, such as urbanization, relative wealth, road infrastructure, existing vehicle fleet, electricity sources, and fuel supplies (Campbell et al. 2020c). A common best practice is to ensure equity in any measures to increase EV uptake. Interest-free loans for qualifying customers and grants for commercial vehicles, which can facilitate the development of a secondhand EV market, are examples of measures that can reduce the EV adoption gap between wealthy and non-wealthy communities (Caulfield et al. 2022). Further, some policies and incentives discussed in this section also apply to HEVs, in addition to EVs, as a way to further increase transportation sector efficiency. The case study locations are shown in Figure 10, and a summary of the case studies is shown in Table 3.

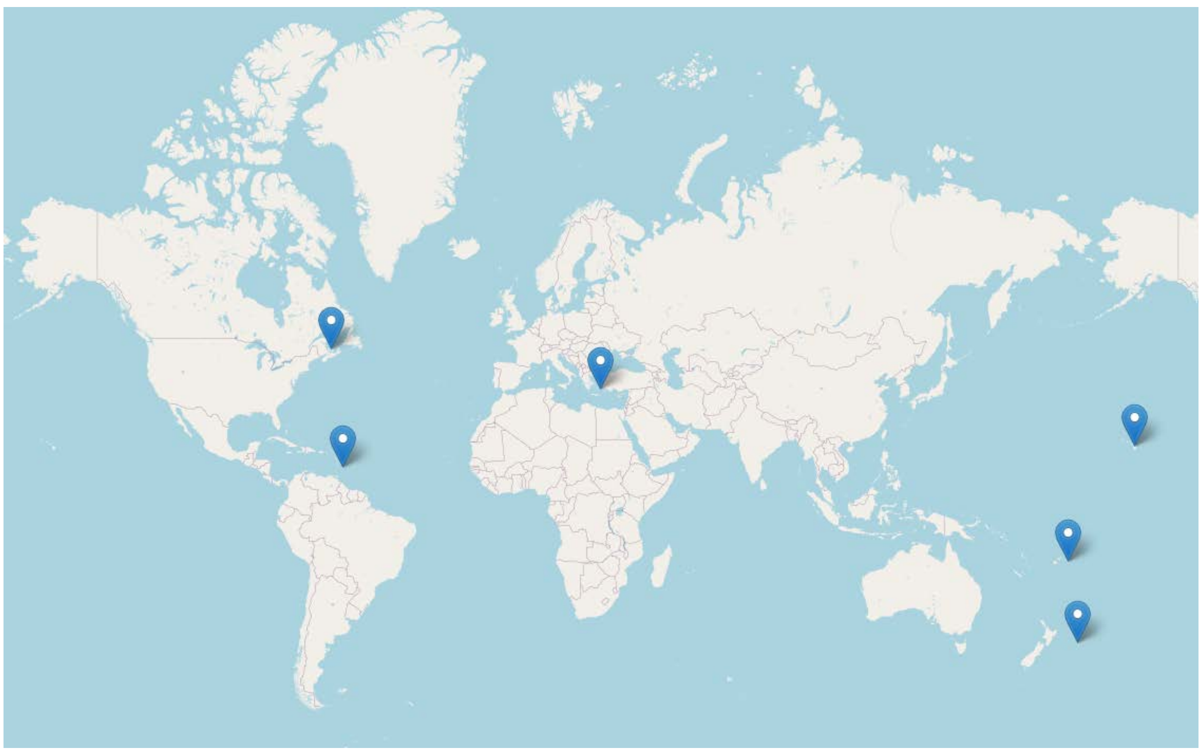

Figure 10. Locations of case studies around the world

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Table 3. Summary of Key Statistics and Insights for Case Study Locations[6]

Jurisdiction	Population	GDP per Capita (USD)	Land Area (km^2)	Key Takeaways
Tonga	100,300	$4,024	749	- See Section 4 for detailed information.
Astypalaia	1,334	$20,277	97	- Emphasis on mode-shifting and shared mobility - Plans to pilot EVs in government fleets - Initiative to scrap conventional ICE vehicles.
Barbados	287,708	$17,034	430	- Studying how to replace fuel tax revenues - Developing EV maintenance courses - Plans to reuse EV batteries for storage systems.
Cook Islands	15,200	$19,193	237	- Government is purchasing EVs for select use - Certification encourages businesses to adopt EVs - Electric bicycles introduced for tourists and locals.
Fiji	888,400	$4,274	18,333	- Reduced import duties and taxes on EVs - Enacted import requirements for efficient vehicles - Electric grid not equipped for large EV growth.
Hawaii	1,455,271	$67,299	28,412	- Rebate program to build charging stations - EVs eligible for free parking and high-occupancy vehicle lanes - Dealers required to recycle old car batteries.
New Zealand	5,122,600	$48,802	263,310	- Seeks to also reduce personal vehicle travel - Rebate and fee program based on emissions - Emissions and efficiency labeling program.
Prince Edward Island	170,688	$36,212	5,686	- Purchase or lease subsidies for new and used EVs - Free Level 2 charger provided to EV owners - Registration fee waiver for EVs.

3.1 Astypalaia, Greece

3.1.1 Trends and Targets

Astypalaia, a small island in Greece, set ambitions not only to electrify its vehicles and power them using clean electricity but also to reduce the total number of vehicles on the island by one-

[6] Data for Tonga, Fiji, and the Cook Islands are from 2018 and are contained in Campbell et al. (2020c). Astypalaia population data are from the 2011 census, land area data are from the Encyclopedia Britannica, and gross domestic product (GDP) per capita data are for all of Greece for the year 2021 and are from the World Bank. Population, GDP per capita, and land area data for Barbados and New Zealand are for 2021 and are from the World Bank. Hawaii population data are for 2020 and are from the U.S. Census Bureau. Hawaii GDP per capita data are for 2022 and are

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third by 2026 (Metzger 2021). Stakeholders first conducted a study to gauge residents' views toward electric mobility and identify barriers to change. This study found that 65% of Astypalaia residents were willing to switch to an EV if the proposed purchase grants were included. It also found that 50% would consider giving up their personal vehicle with the arrival of new planned mobility services, such as EV ride sharing, on-demand shuttles, electric bus lines, electric scooters, and electric bikes (Pappas 2022; Volkswagen Group 2022).

3.1.2 Policies and Actions

The Government of Greece began by piloting EVs for use by the police department, airport authority, and municipal government, along with providing purchase subsidies for residents. These subsidies amount to 40% of the pretax retail price for EVs that cost up to €50,000, with the maximum subsidy capped at €12,000 (Volkswagen 2022). Under this program, vehicles priced from €30,000 to €50,000 receive the maximum subsidy of €12,000. These incentives do not apply to gasoline hybrid vehicles. The island also launched an initiative to remove conventional ICE vehicles and send the scraps to Athens to be recycled (Kokkinidis 2022). Volkswagen, which is supplying the EVs in Astypalaia, also has plans to recycle and reuse the EV batteries at the end of the vehicle's life (Neves 2022).

3.2 Barbados

3.2.1 Trends and Targets

Barbados has the highest number of EVs per capita in the Caribbean, with more than 430 EVs on the road and a population of approximately 287,000 (Masson and Perez 2021). In 2018, 1.28% of new car sales and 0.33% of registered vehicles were electric (Viscidi et al. 2020). The transportation sector in Barbados represents 33% of its fossil fuel consumption, and the government is hoping to significantly reduce its oil imports. The island also has 45 public chargers and 200 private EV chargers (Viscidi et al. 2020).

Barbados has ambitious targets that set the overall tone for transportation efficiency and EV adoption in the country. The country has a target to achieve a 49% reduction in fossil fuel consumption nationwide by 2023, 100% renewable energy for electricity by 2030, and economy-wide carbon neutrality by 2030 (Masson and Perez 2021). To meet part of these 2030 goals, the Government of Barbados plans to electrify 100% of its buses and public fleets by 2030 and study how biofuels can be used in existing ICE vehicles (Viscidi et al. 2020).

3.2.2 Policies and Actions

To meet its ambitious transportation targets, Barbados has enacted several policy measures. First, the government has reduced duties and taxes on EVs compared to ICE vehicles. The import duty has been reduced from 45% to 10%, and the excise tax has been reduced from 46.95% to 20% (Viscidi et al. 2020). On August 1, 2022, a 24-month excise tax and value-added tax holiday was

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from the U.S. Bureau of Economic Analysis. Hawaii land area data are from Encyclopedia Britannica. Prince Edward Island population data are from Statistics Canada for July 1, 2022, and GDP per capita data are from Statistics Canada for 2019, converted from Canadian dollar (CAD) to U.S. dollar (USD) based on average 2019 exchange rates. Prince Edward Island land area data are also from Statistics Canada.

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enacted for EVs. The tax holiday does not apply to hybrids, though import duties for HEVs were also reduced (Madden 2022).

The government is also studying how to reduce its dependence on fuel tax revenues, which will dramatically decline due to electric mobility. This is an important consideration for all countries reliant on fuel tax revenue. According to data from the Organisation for Economic Co-operation and Development (OECD), fuel taxes comprised almost 3% of Barbados' total tax revenue in 2019 (OECD 2022). Other jurisdictions have studied levying taxes based on vehicle kilometers traveled to make up for this forgone income. To address the issue of public awareness, Barbados is deploying pilot projects and working with the Samuel Jackman Prescod Institute of Technology to develop EV maintenance courses for technicians in training (Viscidi et al. 2020). Thus, Barbados is addressing a critical gap in workforce development and preparing for an EV-dominated automotive industry.

Barbados has supported a significant buildout of charging stations, which outnumber gas stations on the island, by allowing independent companies, such as Megapower, to operate EV charging infrastructure. In many other Caribbean nations, narrow legal interpretations prevent outside entities from providing this service because the utility is the sole provider of electricity. However, the Barbadian government views EV charging as an access service, and it is not considered electricity delivery, which remains the domain of Barbados Light & Power Company (Viscidi et al. 2020). Megapower has also received a grant from the Caribbean Export Development Agency to reuse EV batteries for storage in solar photovoltaic systems and plans to buy back old batteries from EV customers as part of its business model (Ellsmoor 2018). If EV penetration significantly increases, however, reuse of batteries in domestic storage systems might not be sufficient in dealing with the waste stream if it is the only solution.

3.3 Cook Islands

3.3.1 Trends and Targets

In the Cook Islands, the land transportation sector accounted for an average of 39% of annual emissions from 2007–2014, which was the largest subsector analyzed (Government of the Cook Islands 2019). The government views EVs and associated charging infrastructure as priority technology areas to mitigate these emissions (Government of the Cook Islands 2020). The country is a leader in EV adoption among Pacific Island nations. According to a recent estimate, it has 46 electric cars, 3 electric pickup trucks, 2 electric trucks, 24 electric two-wheelers, and 4 electric scooters (Campbell and Fifita 2022).

3.3.2 Policies and Actions

To promote the use of EVs, the Cook Islands government has purchased EVs for its prime minister and other senior ministers and is planning to further incorporate EVs into the government fleet (Pacnews 2019). The government is also planning to promote and seek funding for the following technologies, as outlined in its Technology Needs Assessment report: public service passenger vehicle fleet, solar photovoltaic off-grid charging stations for EVs, conventional electric buses for the private sector, workplace charging stations at government buildings and businesses, and smart chargers for electric bicycles (Government of the Cook Islands 2020). The Tourism bureau's eco-certification program, Mana Tiaki, also encourages businesses to purchase and operate EVs to satisfy the program's requirements. Mana Tiaki has

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incentivized hotels and resorts to offer EV fleets and electric bicycles, and approximately 50 businesses have achieved the eco-certification thus far (Cook Islands Tourism Corporation 2020).

3.4 Fiji

3.4.1 Trends and Targets

Fiji's Low-Emission Development Strategy 2018–2050 views EVs as an important tool to meet emissions targets, and therefore EVs are a significant component of future scenario modeling (Campbell et al. 2020a). In Fiji's business-as-usual scenario, EVs consist of 20% of new cars sold in 2030 and 20% of the light-duty vehicle fleet by 2050. In Fiji's high ambition scenario, EVs consist of 80% of new cars in 2030 and 100% of the light-duty vehicle fleet by 2050 (Broughton et al. 2019). The overall fuel economy of Fiji's vehicle stock improved by 12% from 2012–2018 partly due to an influx of hybrid used vehicles and despite an increase in vehicles with larger engine sizes (International Council on Clean Transportation et al. 2020).

As a result of reduced excise duties and value-added tax since 2013, used hybrids are reportedly the most popular cars in Fiji. Although Fiji has a recycling plant for lead acid batteries, the country currently does not have recycling facilities for the vast quantity of batteries (primarily lithium-ion chemistries) in its aging hybrid vehicle fleet. Although the batteries in HEVs are smaller than in PHEVs or BEVs, waste management is still an issue. Battery recycling and repurposing capacity have thus been identified as significant gaps in Fiji's transition to EVs (Kaufmann and Kaufmann 2020).

3.4.2 Policies and Actions

To encourage the import of EVs, Fiji has reduced import duties and taxes on EVs and has a requirement that vehicles must be less than 5 years old at the time of entry. In its 2022–2023 budget, the Government of Fiji increased the subsidy for capital investments in EV charging infrastructure from 5% to 10% for stations that cost more than $50,000 Fijian dollars (FJD) (previously $100,000 FJD). Further, the government will provide a subsidy of $5,000 FJD per EV if a local business purchases five vehicles or more (HLB 2022). One company, Leaf Capital, Ltd., was established in Fiji in 2021 and plans to deploy EV charging infrastructure that can take advantage of on-site renewables, such as solar photovoltaics, and manage the power draw based on grid capacity limits (PCREEE 2022). However, Fiji's electrical infrastructure, both in households and along highways, is not equipped to support a widespread EV fleet. Thus, Broughton et al. (2019) recommends that the government examine the feasibility of electrifying its own fleet and remove additional import duties on vehicle chargers, smart utility meters, and other grid technologies to enable transportation electrification.

3.5 Hawaii, United States

3.5.1 Trends and Targets

Hawaii's transition to EVs is motivated by the state's commitments to a zero-emission clean economy by 2045 and to eliminating its dependence on imported fuels for transportation (Hawaii State Energy Office 2022). As of July 2022, there were 1,055,870 registered passenger vehicles in the state, of which 20,240 (1.92%) were electric (PHEV and BEV). This represents a 30%

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increase in EV registrations from the previous year (Shuai 2022). Currently, there are 805 public charging ports in Hawaii to support these EVs (DOE 2022). Hawaiian Electric projects that half of all passenger cars will be fully electric by 2045 and will need to be supported by approximately 3,600 public charging ports by 2030 (Hawaiian Electric Company et al. 2019). Overall, Hawaii's state laws and regulations regarding zero-emission vehicles do not prioritize gasoline hybrid vehicles.

3.5.2 Policies and Actions

To support the buildout of public charging infrastructure, Hawaii has established a rebate program that covers up to $4,500 for a new alternating current (AC) Level 2 charging station with at least two ports, $3,000 to upgrade an existing charging system to an AC Level 2 charging station with at least two ports, $35,000 for a new direct current (DC) fast charging system, and $28,000 to upgrade an existing charging station to a DC fast charging system. EVs are also eligible for free parking at state and county facilities and have access to high-occupancy vehicle lanes, in addition to requirements that certain public parking spaces be reserved for EVs (Hawaii State Energy Office 2022). Car dealers in Hawaii are required by state law to accept and recycle old car batteries, and Maui County's Junk Vehicle Disposal Assistance Program also covers EVs and HEVs with no extra battery disposal fee charged (City and County of Honolulu 2022; Maui County 2022).

Lessons drawn from Hawaii's experience with EVs thus far include: the importance of an overarching objective based on a shared vision, establishing pilot projects, developing a roadmap that leverages initial experiences, evaluating the effectiveness of actions, having close regulatory oversight, and encouraging stakeholder participation (Carrillo and Lave 2021).

3.6 New Zealand

3.6.1 Trends and Targets

As discussed in Section 2.2, New Zealand had EV sales of 10,574 vehicles and an EV stock of 34,358 vehicles in 2021, with the breakdown among passenger cars, buses, and trucks displayed in Table 1. New Zealand's Emission Reduction Plan seeks to both promote EVs and reduce personal vehicle travel. The Emission Reduction Plan focuses on supporting walking, cycling, and the use of public transportation while also rapidly adopting low-emission personal vehicles and decarbonizing heavy transportation (Briggs 2022). To meet these high-level goals, the government has set four specific targets:

1. Reduce the light-duty vehicle fleet's vehicle kilometers traveled (VKT) by 20% by 2035 through improved urban design and better travel options, particularly in the largest cities.
2. Increase zero-emission vehicles to 30% of the light-duty vehicle fleet by 2035.
3. Reduce emissions from freight transportation by 35% by 2035.
4. Reduce the emissions intensity of transportation fuel by 20% by 2035.

Transportation currently accounts for approximately 17% of New Zealand's GHG emissions. To meet the Emission Reduction Plan target for zero-emission vehicles, the EV fleet needs to be approximately 1.5 million vehicles by 2035 (Briggs 2022). Currently, the New Zealand highway system has public EV chargers every 75 kilometers; however, charging availability is still viewed as a major impediment to increased EV adoption, and the number of chargers and

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electrical generating capacity will need to scale dramatically to support 1.5 million EVs (Briggs 2022).

3.6.2 Policies and Actions

To incentivize the adoption of zero- or low-emission vehicles, the New Zealand Transport Agency has developed a Clean Car discount program consisting of rebates and fees depending on the emissions characteristics of a vehicle. For instance, a zero-emission vehicle can quality for a $7,500 New Zealand dollar (NZD) rebate if it is new and a $3,000 NZD rebate if it is used. New and used vehicles with emissions less than 146 grams carbon dioxide per kilometer (e.g., PHEVs and HEVs) can qualify for a reduced rebate. Vehicles above this limit must pay a fee, which is capped at $4,500 NZD for new vehicles and $2,500 NZD for used vehicles (New Zealand Government 2022). Overall, the program is designed to be cost-neutral to the government, with collected fees intended to directly fund rebates (New Zealand Minister of Transport n.d.).

To help meet its Emission Reduction Plan targets related to overall transportation sector efficiency (e.g., shifting from personal vehicles to bikes or public transit) and EV charging infrastructure, New Zealand's Energy Efficiency and Conservation Authority (EECA) developed a Low-Emission Transport Fund, which has supported 1,278 EV chargers and a variety of other projects (Figure 11).

Figure 11. Activities supported by New Zealand's Low-Emission Transport Fund

Figure from New Zealand EECA.

Vehicle emissions and energy economy labels, which transparently display the environmental and efficiency attributes of a vehicle, are also required on vehicles that weigh 3.5 metric tons or less, which empowers customers to select vehicles that match their budgets and preferences (Briggs 2022).

The New Zealand EECA has also provided funding to support the Battery Industry Group, which has proposed a "product stewardship scheme" with the following steps (EECA 2021):

1. Upon arrival in New Zealand, batteries are registered with the nonprofit in charge of running the "product stewardship scheme".
2. Ownership of batteries will be tracked throughout their lifetime.
3. When the battery is no longer suitable for a vehicle, it can be repurposed for another use.
4. Once the battery has reached its end of life, it will be sent to a recycling facility, and the materials and chemicals will be extracted for reuse.

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3.7 Prince Edward Island, Canada

3.7.1 Trends and Targets

Prince Edward Island has led other Canadian provinces in relative growth of EVs. Registrations of EVs on the island have increased from 166 in 2019 to 494 in 2021 (198% increase), and 86 EVs were registered in the first quarter of 2022 compared to 41 EVs in the first quarter of 2021 (Yarr 2019). To support this growth in EVs, Prince Edward Island has installed 49 public charging ports (45 Level 2 chargers and 4 DC fast chargers) (Figure 12).

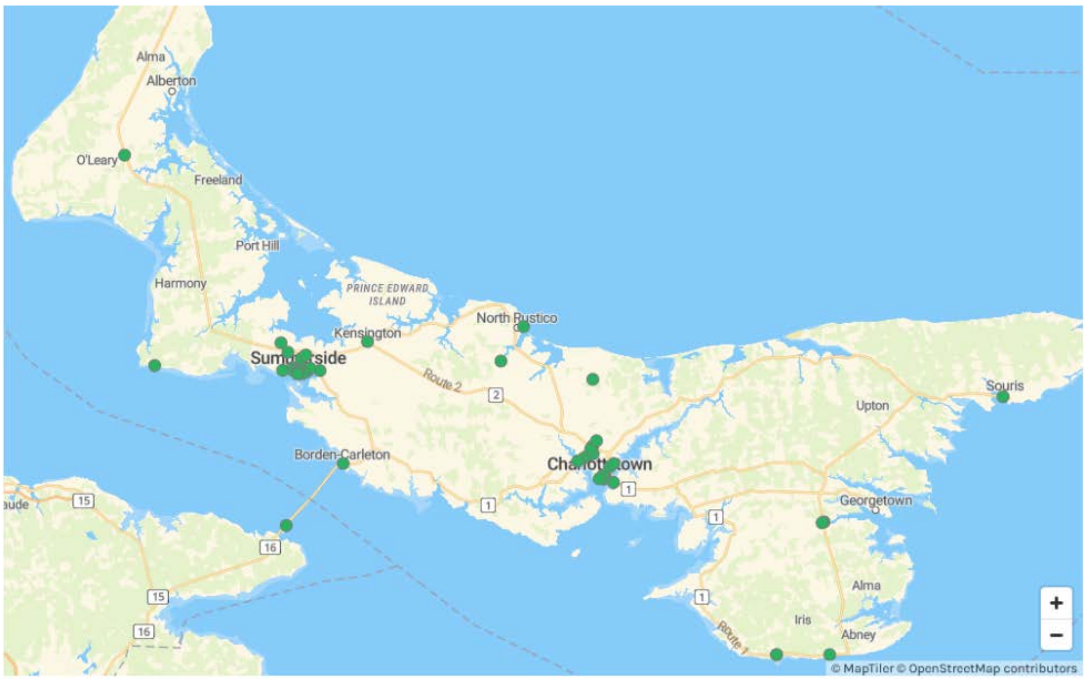

Figure 12. Distribution of EV charging stations across Prince Edward Island

Figure from DOE (2022).

3.7.2 Policies and Actions

The Prince Edward Island government offers significant incentives to residents who purchase or lease EVs: $5,000 Canadian dollars (CAD) is provided for new or used BEVs and $2,500 CAD for new or used PHEVs if the vehicle has a sticker price of $55,000 CAD or less and is no older than 7 model years at the time of purchase. HEVs are excluded from this incentive program. Vehicles must be purchased from licensed island dealerships, purchasers must own the vehicle for at least 1 year, and incentives are applied directly to the bill of sale or lease agreement. Eligible vehicles are listed on the government's website. Leased vehicles can qualify for the full BEV or PHEV incentive if the lease is for 48 months or longer; shorter leases result in smaller incentive values (McPhee 2022). These provincial incentives can be paired with federal incentives, resulting in a maximum possible rebate of $10,000 CAD. Prince Edward Island provides a free Level 2 EV charger upon vehicle purchase, though customers are responsible for any installation costs. The registration fee is waived for EVs in Prince Edward Island, resulting in an annual savings of $100 CAD (Maritime Electric 2022). As of August 2022, the province has no recycling program for EV batteries, and this gap is a current focus area for the director of sustainability at the Department of Environment, Energy and Climate Action (Wright 2022).

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4 Current State in Tonga

The research team reviewed existing policies, technical reports, and studies related to energy in Tonga to establish a baseline for land transportation and initial EV activities.

4.1 Current State of Transportation

Tonga is a collection of 170 islands, 36 of which are populated. As of 2021, there were 18,847 private households. The capital island of Tongatapu contains most of the population, with 73% of the private households. The country is prone to natural disasters, such as earthquakes and tropical cyclones, and has been identified as one of the most vulnerable countries in the world to natural hazards and climate change (MEIDECC 2018). A 2010 study estimated that the entire urban population and 80% of the rural population has access to electricity (CTCN, NREL, and PCREEE 2020).

Tonga has one primary electric utility, Tonga Power Limited (TPL), which is vertically integrated. Four of the islands (Tongatapu, Vava'u, Ha'apai, and 'Eua) have TPL-operated grid systems. Four additional islands have grids not operated by TPL, and the rest are off-grid, using household diesel generators and solar systems (CTCN, NREL, and PCREEE 2020). The 2020 *Tonga Energy Efficiency Master Plan* (TEEMP) identified two weekday peak electricity demand periods: one in the morning corresponding to commercial uses and a second in the late afternoon corresponding to residential uses (CTCN, NREL, and PCREEE 2020). Electricity demand increased by 3.6% between June 2019 and June 2020 (TPL 2021). TPL began installing smart meters at residences in 2020 to replace the need for frequent meter reading (TPL 2021). These smart meters are a prerequisite for most forms of managed EV charging and time of use pricing.

As of October 2022, TPL's installed capacity consisted of 17.7 MW of diesel generators and 6.9 MW of renewable energy, primarily solar photovoltaics (TPL 2022). Despite the large share of diesel generators, however, EVs still emit fewer GHGs per kilometer traveled compared to ICE vehicles, and this disparity will only increase as the electricity mix becomes less dominated by fossil fuels (CTCN, NREL, and PCREEE 2020). In fiscal year 2019–2020, 13% of total generation (GWh) came from renewable sources (TPL 2021). All petroleum is imported, making Tonga sensitive to fuel price volatility.

In addition to electricity generation, imported petroleum is used for transportation. Transportation has been identified as the highest-emitting sector, comprising 40% of national GHG emissions (CTCN, NREL, and PCREEE 2020) and 62% of total energy consumption (MEIDECC and GGGI 2021). With goals of 70% and 100% renewable energy for electricity by 2025 and 2035, respectively, Tonga's reliance on imported petroleum will decrease, and further decreases are possible from a transition to EVs.

A vehicle inventory was performed in the 2021 census that identified a total of 22,121 household vehicles in the country, the majority of which are listed as cars, trucks, and vans (Table 4). These data might exclude commercial vehicles, such as taxis, rental cars, and heavy-duty trucks. As of 2019, 59% of households own at least one car (MEIDECC 2021). Only 1% of vehicles in the 2021 census were identified as motorcycles, and motorcycle ownership between 2011 and 2021 decreased by 67% (CTCN, NREL, and PCREEE 2020; Tonga Statistics Department 2022). According to interviews with representatives from MEIDECC, the reasons for this decline could

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be an abundance of loose dogs that chase motorcyclists and bicyclists, large families that cannot all fit on a two-wheeled vehicle, and safety concerns related to riding on poorly maintained narrow roads.

Table 4. Tally of Household Vehicles in Tonga by Type as of 2021

Data from the Tonga 2021 census.

Vehicle Type	Number of Vehicles	Percentage of Total Vehicles
Car	12,369	56%
Van	7,454	34%
Truck	1,980	9%
Motorbike	230	1%
Bus	88	0.4%
Total	**22,121**	**100%**

Ninety-five percent of registered vehicles are owned by individuals or private organizations, with buses constituting less than 1% (MEIDECC and GGGI 2021). The vast majority (86%) of vehicles are on the island of Tongatapu, and light-duty pickup trucks alone comprise 42% of all land transportation modes (Figure 13).

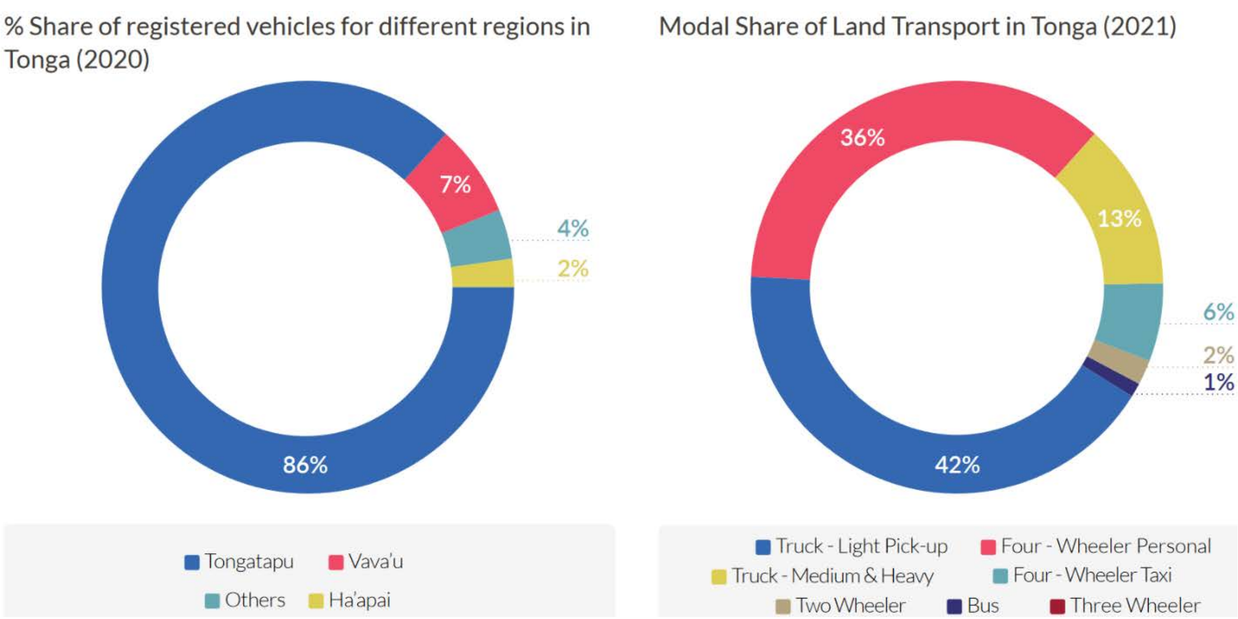

Figure 13. Share of registered vehicles by region (left) and modal share of land transportation (right)

Data from *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021).

In 2021, there were 2,511 new registrations for vehicles in Tonga, presumably either new or used imported vehicles, according to data provided by MEIDECC. This primarily consisted of light-goods vehicles (49%), private motor vehicles (37%), heavy-goods vehicles (5%), and taxis and rental cars (4%). The VKT between various locations on Tongatapu were estimated in 2016 and are shown in Table 5. As of 2016, VKT was estimated at 2,289 VKT per capita.

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Table 5. Traffic Counts, Traffic Destinations, and Daily VKT on Tongatapu in 2016

Figure from *Tonga Energy Efficiency Master Plan 2020–2030* (CTCN, NREL, and PCREEE 2020).

Road	Counter Location	VEH's/day	Destination A	Kilometres to A	Vehicles to A	Daily VKT	Destination B	Km's to B	VEH's to B	Daily VKT
Taufa'ahau Road	Fanga	21,528	Tofoa	1.2	15,837	**19,111**	Havelu & Vaoloa	0.5	5,691	**3,022**
Bypass Road	MOI	9,822	Western suburbs	2.5	4,911	**12,169**	Hihifo district	10.0	4,911	**48,991**
Fatafehi Road	OE	7,319	Intra-Nuku traffic	2.5	7,319	**18,135**	-	-	-	-
Taufa'ahau Road	Pasilika	10,866	Intra-Nuku traffic	2.5	10,866	**26,924**	-	-	-	-
Vaha'akolo Road	Queen State College	7,175	Sopu	2.5	7,175	**17,779**	-	-	-	-
Matealona road	THS	10,830	Western suburbs	1.2	5,415	**6,535**	Hihifo District	10.0	5,415	**54,019**
Tupoulahi	Ngele'ia	7,162	Intra-Nuku traffic	2.5	7,162	**17,746**	-	-	-	-
Vuna	Chinese Embassy	15,600	Ma'ufanga and peninsula	2.5	15,600	**38,655**	-	-	-	-
Fatafehi Road	TDB	5,558	Intra-Nuku traffic	2.5	5,558	**13,772**	-	-	-	-
Wellington	Perma&Sons	5,381	Intra-Nuku traffic	2.5	5,381	**13,333**	-	-	-	-
Tuku'aho	Pelehake	2,781	Fua'amotu, Lavengatonga, and coast towns in between	5.3	2,781	**14,766**	-	-	-	-
Taufa'ahau Road	Malapo	4,039	Tatakamotonga	4.8	2,020	**9,748**	NE coast towns	13.0	2,020	**26,320**

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Vaini-Longoteme Rd	Vaini	1,252	Accounted for in Pea line	-	-	-	-	-	-	-
Taufa'ahau Road	Vaini Police Stn	9,298	Accounted for in Pea line	-	-	-	-	-	-	-
Vaini-Longoteme Rd	Sei'uhila	554	Accounted for in Pea line	-	-	-	-	-	-	-
Folaha Road	Nualei	1,012	Accounted for in Pea line	-	-	-	-	-	-	-
Taufa'ahau Road	Pea	12,400	Viani	7.2	10,550	**76,387**	Folaha*	10.5	1,566	**16,378**
Fonongahina	Pea	4,451	West on Taufa'ahau	6.4	4,451	**28,647**	-	-	-	-
Vaha'akolo	Tofoa	7,988	Pea	1.6	4,451	**7,162**	-	2.5	3,537	**8,821**
Taufa'ahau	Tofoa	13,201	Pea	1.6	12,400	**19,952**	-	2.5	801	**1,998**
Intra-Hihifo trips	No Counters**	-	-	4.8	5,000	**24,135**	-	-	-	-
Intra-Hahake trips	No Counters**	-	-	4.0	5,000	**20,113**	-	-	-	-
Total Daily VKT on Tongatapu		**545,531**								

*284 of these cars are assumed to continue 3.2 km past Folaha on to Vietongo and Coast
** There were no counters in the Hihifo or Hahake districts. See text for how the vehicle numbers were estimated.

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In addition to vehicle use, cycling and walking are additional forms of transportation. Approximately 26% of households own a bike (CTCN, NREL, and PCREEE 2020).

Smartphone ownership can be relevant to transportation because mobile applications can be used for locating a charging station, ride hailing, ride sharing, or other on-demand transit systems. According to the 2021 census, 62% of the population age 10 or older owns a cell phone, and 91% of cell phone owners have access to the internet through their mobile devices (Tonga Statistics Department 2022).

4.2 Transportation Projections

The 2020 TEEMP projected transportation fuel usage in a business-as-usual scenario where no reduction attempts are modeled. This was done by first projecting a GDP increase and then using transportation data for other countries with similar GDP values.

Annual VKT were projected to increase from 2,289 VKT/person in 2016 to 5,103 VKT/person in 2050 (including freight) (CTCN, NREL, and PCREEE 2020). This assumes a compounded annual growth rate in VKT (and fuel use) of 2.4% per year and a constant population. The projected fuel usage and associated GHG emissions are shown in Figure 14 and Figure 15.

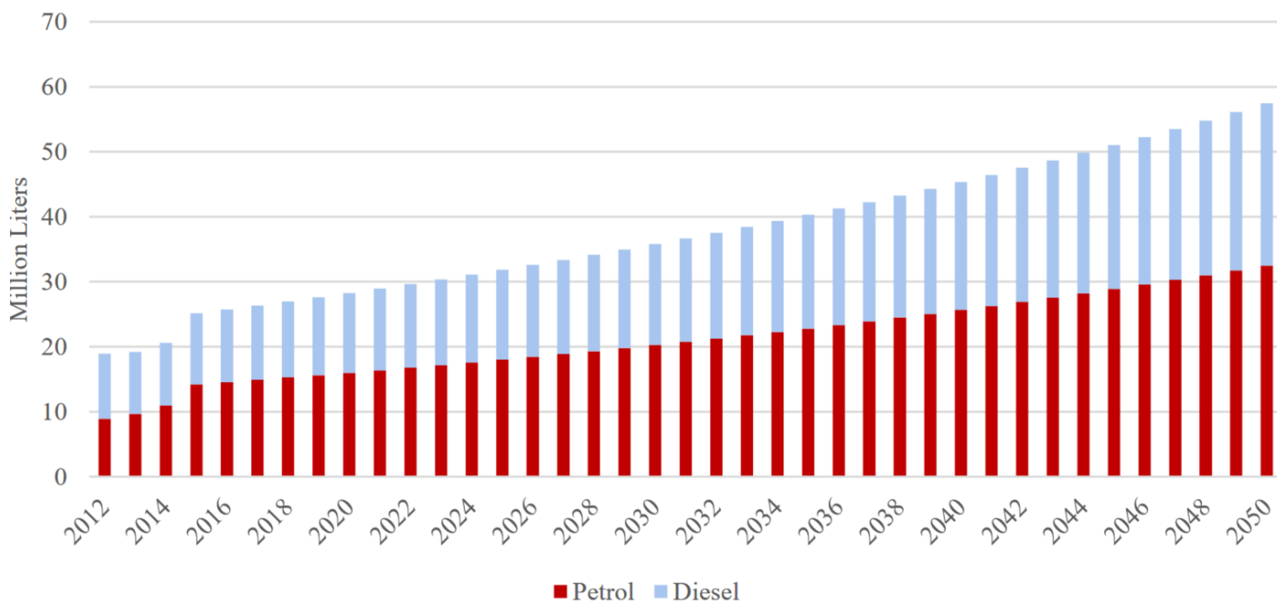

Figure 14. Tonga business-as-usual transportation diesel and petrol fuel usage projections

Figure from *Tonga Energy Efficiency Master Plan 2020–2030* (CTCN, NREL, and PCREEE 2020).

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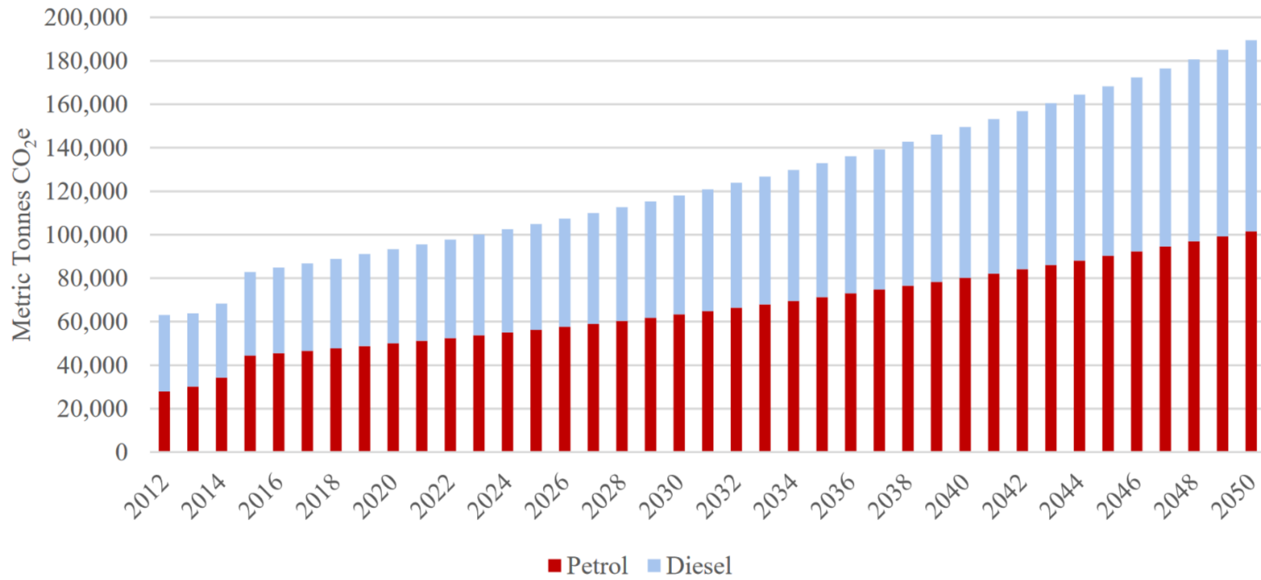

Figure 15. Tonga business-as-usual land transportation GHG projections

Figure from *Tonga Energy Efficiency Master Plan 2020–2030* (CTCN, NREL, and PCREEE 2020).

The *Tonga Energy Road Map 2021–2035* estimated that the number of vehicles in Tonga will grow at a rate of 1.3% between 2021 and 2035, using the World Bank population growth assumption of 0.2% compound annual growth rate (MEIDECC and GGGI 2021); however, the report notes that "vehicle registration has been rising and declining over the past 10 years, which makes it difficult to comment on future trends" (MEIDECC and GGGI 2021, 58).

4.3 Country Policy

Tonga has implemented multiple policies, legislation, and regulations relevant to the transportation sector. An overview of these is included in Section 4.3.1, with greater discussion of particular policies and studies in sections 4.3.2, 4.3.3, and 4.3.4.

4.3.1 Relevant Policy

Relevant energy policies, legislation, and regulations for the transportation sector are outlined in the *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021). Many of these relate directly to EV adoption. Those relevant to land transportation are summarized in the Table 6.

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Table 6. Relevant Transportation Policies, Legislation, and Regulations

Source: Adapted from the *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021).

Year	Policy	Relevance to Land Transportation
2012	*National Spatial Planning and Management Act, 2012*	Includes infrastructure planning and implementation.
2013	*National Infrastructure Investment Plan, 2013–2023*	Outlines infrastructure plans and priorities, including improving road infrastructure and improving the resilience of transportation systems to climate change.
2015	*Tonga Strategic Development Framework, 2015–2025*	Goal of more reliable, safe, and affordable transportation infrastructure and services on each island.
2016	*Customs Act—Revised, 2016 Edition*	Specifies customs duty shall be paid on imported goods, including motor vehicles, but does not specifically reference EVs.
2016	*Tonga Climate Change Policy*	Includes 20 targets, including "a transport system that is not reliant on fossil fuels" and "100% renewable energy".
2018	*Joint National Action on Climate Change Adaptation and Disaster Risk Management 2, 2018–2028*	Aligns with the Tonga Climate Change Policy and includes the transportation sector.
2020	*Road Act, 2020*	Establishes a fund for the building and maintenance of public roads, stemming from vehicle registrations and grants.
2020	*Tonga Energy Efficiency Master Plan (TEEMP), 2020*	Includes a section on transportation and policies to achieve GHG reductions from this sector via various measures.
2020	*Tonga Energy Bill, 2020*	Establishes an Energy Commission to regulate petroleum, electricity, and renewable energy.
2020	*Tonga's Second Nationally Determined Contribution (NDC)*	Target of 13% reduction in GHG emissions from the combustion of fossil fuels by 2030 compared to 2006 and a 2% efficiency increase per year in new light-duty vehicles.
2020	*Traffic Act, 2020*	Contains vehicle registration and permitting provisions.
2021	*Tonga Energy Road Map, 2021–2035*	Provide the basis for Tonga's national energy policy and outlines plan to reach 70% and 100% renewable electricity.
2021	*Tonga Low-Emission Development Strategy, 2020–2050*	Considers Tonga's development through 2050 in terms of phasing out greenhouse gas emissions, alleviating poverty, and enhancing resilience to climate change.
2021-2022	*Tonga Budget Statements, 2021–2022*	Provides direction for development work and impacts road infrastructure development and maintenance.

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4.3.2 Nationally Determined Contributions

Tonga's 2020 Nationally Determined Contribution (NDC), which represents its commitment to reduce its GHG emissions under the Paris Agreement, targets a 13% reduction in GHG emissions from energy by 2030 compared to 2006. As a strategy to meet this objective, Tonga proposes "mandatory vehicle standards and/or incentives through taxes, fees, and import tariffs" (MEIDECC 2020). The 2020 NDC includes interview notes with various Tongan agencies. The Department of Transport emphasizes the lack of sufficient infrastructure for nonmotorized transportation and a preference for car travel over other modes, as well as concern that engine and fuel standards might increase costs for owners already struggling to pay for fuel.

4.3.3 Tonga Energy Efficiency Master Plan

Tonga has proposed GHG emissions reduction targets for the transportation sector, and these were analyzed through a wedge analysis in the 2020 TEEMP. Goals included:

- A 20% reduction in VKT for light-duty vehicles compared to the business-as-usual scenario.
- A 30% improvement in fuel economy for new light-duty vehicles.
- Reducing heavy-duty vehicle idle time by 1 hour per day.
- Using a 10% biodiesel blend for all road transportation.
- 10% of new light-duty vehicle sales to be electric by 2030.

The TEEMP includes policies that would help Tonga achieve these goals. These policies fall into the following categories: increased vehicle efficiency, reduced VKT, reduced idle time, increased biodiesel use, electric and hybrid vehicle promotion, and improved traffic flows.

The 2020 TEEMP identifies and prioritizes policies and projects that could reduce GHG emissions from the transportation sector. Three of these are related to EVs, including:

1. Sending a mechanic to HEV/EV maintenance training in Japan or New Zealand.
2. Providing rebates on HEV/EVs (including electric scooters).
3. Providing rebates on public EV charger installations.

Vehicle energy-efficiency policies, such as adjusting the vehicle registration tax and implementing import tariffs based on metrics such as vehicle weight and fuel economy, were also identified in the 2020 TEEMP. Some policies have already been implemented, including switching to 10 ppm diesel fuel in 2018. Reducing the emissions associated with diesel fuel by using a 10% biodiesel blend and reducing idle time through various idle reduction technologies were also analyzed.

Some proposed policies and projects focused on decreasing VKT. First, bicycling and walking were incentivized through a safe bicycle crossing law, providing safety reflectors and lights to school children, and installing rumble strips and painted lines on roads. Other policies focused on tracking and coordinating buses using the NextBus platform, instituting a water taxi across the Tongatapu laguna, and building a park-and-ride lot and associated bus stop at the intersection of Taufa'ahau Road and Loto Road. Note that the GHG emissions reductions from adopting EVs highly depend on the amount of renewable energy in the electric grid. Tonga currently has goals of 70% and 100% renewable energy for electricity by 2025 and 2035, respectively (GGGI 2022).

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Projected GHG emissions for various EV models based on Tonga's grid mix were calculated in the 2020 TEEMP and are shown in Figure 16, along with Tonga's percentage of renewable electricity in 2020 (IRENA 2022).

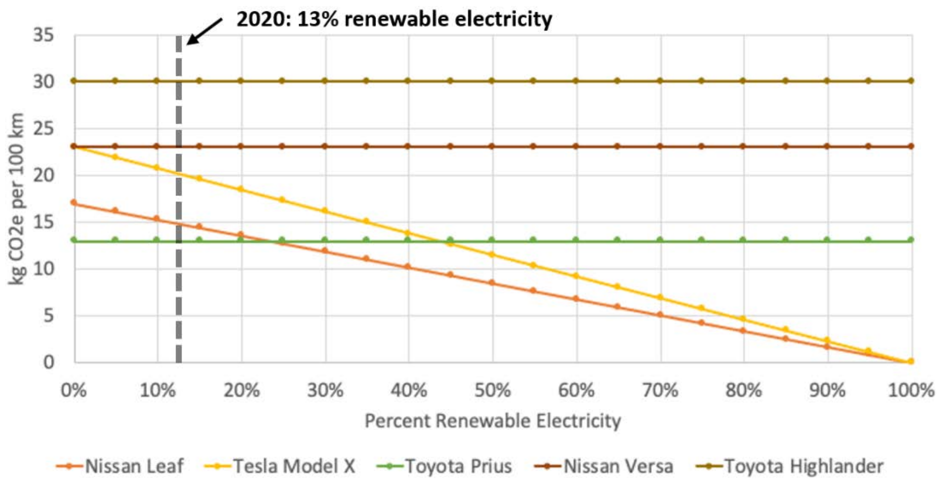

Figure 16. Impact of renewable electricity share on GHG emissions for different vehicles in Tonga

Figure from *Tonga Energy Efficiency Master Plan 2020–2030* (CTCN, NREL, and PCREEE 2020).

4.3.4 Low-Emission Development Strategy and Tonga Energy Road Map

The *Tonga Low-Emission Development Strategy* (LEDS) identifies nine transportation sector pathway actions (MEIDECC 2021). These are shown in Figure 17.

Figure 17. Nine transportation sector pathway actions for Tonga

Figure from MEIDECC (2021).

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A timeline suggesting when these actions could be implemented in the next 30 years is included in the LEDS (Figure 18). The first introduction of EVs is proposed to be in the government fleet, followed by 50% public adoption 5 years later.

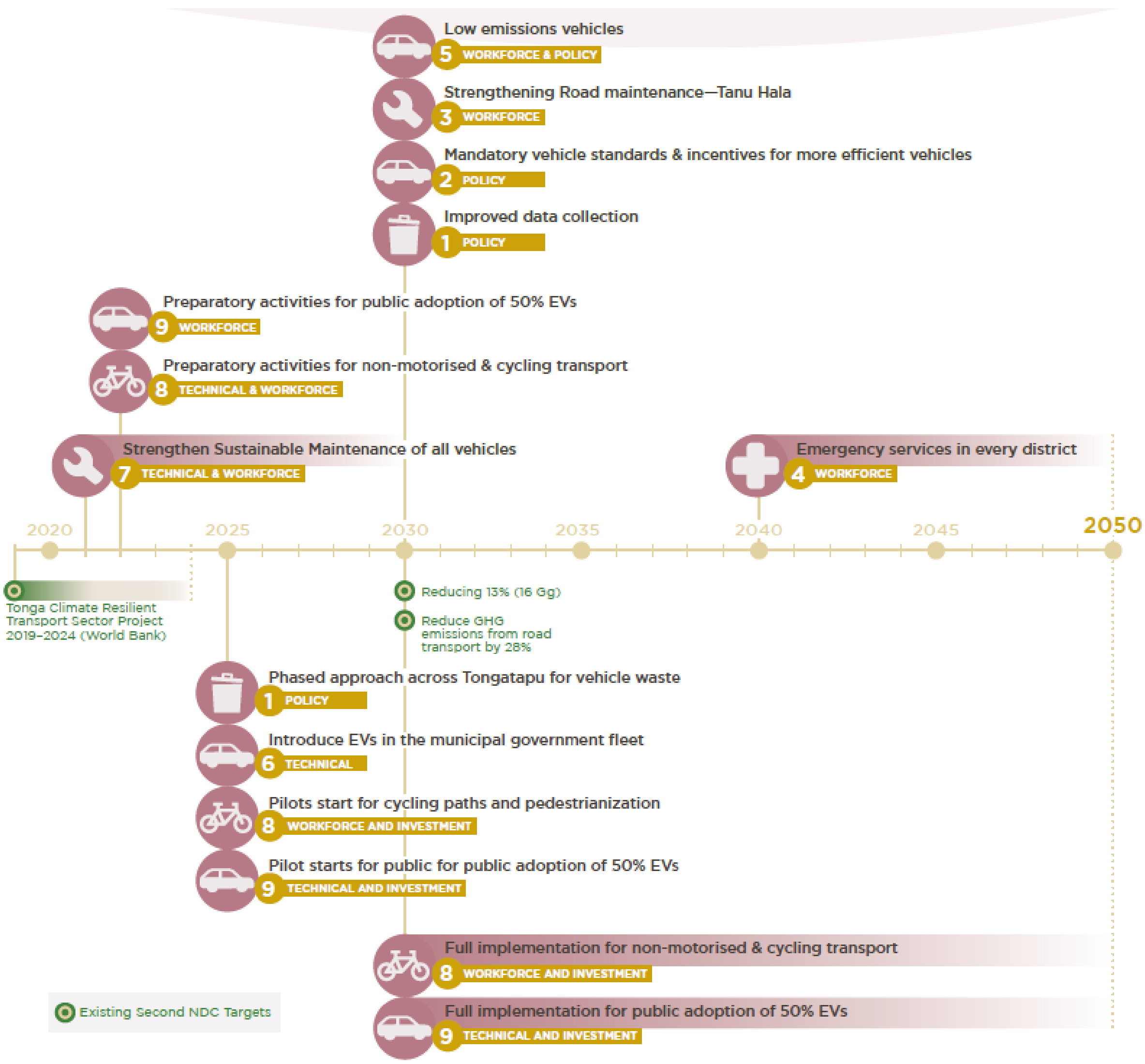

Figure 18. A timeline of Tonga's nine transportation sector pathway actions

Figure from MEIDECC (2021).

Greater detail regarding each of the nine pathways is as follows:

1. **Improve transportation data collection and waste management.** The Government of Tonga has proposed creating a central scrapping facility for ICE vehicles that are replaced by EVs and plans to collect data on waste classification and transportation preferences. The government might enact incentive mechanisms to scrap the deregistered ICE vehicles as well.

2. **Establish vehicle standards and incentives.** Although there are no current vehicle standards, the Government of Tonga has instituted a 10-year age limit on imported

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vehicles and is considering imposing further restrictions (MEIDECC 2021). The goal is to increase vehicle energy efficiency because newer vehicles are generally more efficient than older ones. To increase consumer demand for EVs, various types of financial incentives shall be considered by the government to make EVs more affordable, even for lower income households. Specific incentives—such as interest-free loans, top-up subsidies, rebate programs, and tax credits—might be considered.

3. **Strengthen road maintenance.** Repairing potholes and resurfacing roads can increase cycling and walking and reduce the braking and accelerating required from conventional vehicles, which helps improve transportation efficiency.

4. **Decentralize services from urban to rural areas to decrease traffic congestion.** In general, conventional vehicles operate more efficiently in less congested traffic when they do not need to stop and accelerate as frequently.

5. **Incentivize low-emission vehicles.** Imposing vehicle standards for new light-duty vehicles is discussed as well as incentivizing low-emission vehicles through taxes, fees, and import tariffs.

6. **Introduce EVs into the municipal government fleet.** Tonga has identified the government fleet as the first ICE vehicles to replace with EVs, and a pilot project is currently underway. The LEDS proposes developing an EV proposal by 2022, with the goal that 100% of the government fleet is EVs by 2027.

7. **Strengthen the sustainable maintenance of all vehicles.** This includes performing safety inspections on vehicles every 3 years as well as providing specialized trainings for local mechanical engineers and electricians on vehicle maintenance.

8. **Implement nonmotorized and cycling transportation options.** The focus of this action is primarily on Nuku'alofa Island. The specific projects include adding bicycle lanes, implementing pedestrian-only city center areas, removing import duties on bicycles, performing awareness campaigns on the health benefits of cycling and walking, reactivating linkages to walking culture, and providing incentives for ministries and companies to provide cyclist commuter facilities, such as showers and bicycle parking. The *Tonga Energy Road Map 2021–2035* notes that "despite limited and lack of safe infrastructure for nonmotorized transport, most daily trips are made on foot, which indicates that Tonga has huge potential to promote walking" (MEIDECC and GGGI 2021).

9. **Achieve public adoption of 50% EVs.** Following the adoption of EVs in the government fleet, the goal is for the public to subsequently adopt EVs and to use electric public transportation, such as buses and taxis. Rebates for vehicles and charging stations, designated parking spaces, shared EVs, and trainings are identified as specific actions that work toward this goal.

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The *Tonga Energy Road Map 2021–2035* outlines key challenges related to transportation (MEIDECC and GGGI 2021). Many of these connect to the nine pathways listed here. These challenges include a high demand for private vehicles, leading to traffic congestion, increased dependence on fossil fuels as VKT increases, poor traffic management and road infrastructure, and poor public transit services (including limited and inconsistent operation and a lack of bus terminals). The report also mentions the potential of shared mobility (especially in Tongatapu) through ride sharing or hailing, rental bicycles or scooters, and shuttles.

A multicriteria analysis of the measures that could be implemented was performed in the *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021). The results of this analysis are shown in Figure 19, with the size of each bubble corresponding to the potential GHG savings. Switching ICE passenger vehicles to EVs was identified as having the greatest GHG mitigation potential. The top three interventions regarding GHG emissions reduction potential are vehicle electrification of private passenger vehicles, freight vehicles, and commercial taxis, respectively.

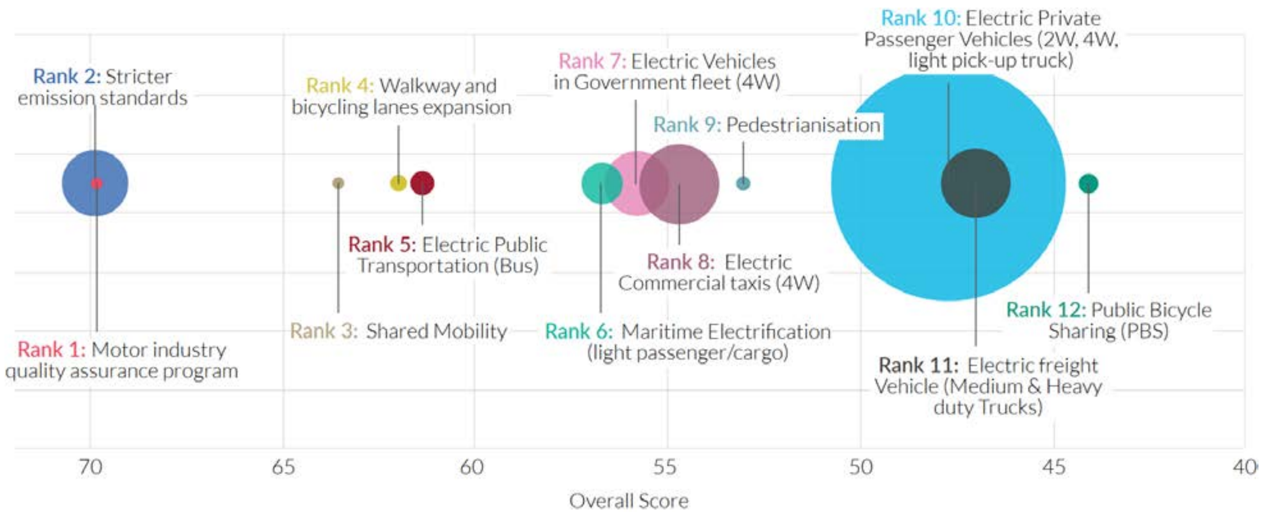

Figure 19. Multicriteria analysis of transportation interventions

Figure from *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021). The size of the bubble corresponds to the GHG mitigation potential of the intervention.

A transportation roadmap was also identified in the *Tonga Energy Road Map 2021–2035*, with short-, medium-, and long-term targets and key stakeholders for various interventions (MEIDECC and GGGI 2021). For the electric private passenger vehicle intervention, 10% of passenger vehicle imports are targeted to be EVs by 2025, 25% by 2030, and 35% by 2035. The emissions mitigation potential for various electrified transport modes is shown in Table 7.

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Table 7. GHG Emissions for Various Low-Emission Vehicles

From *Tonga Energy Road Map 2021–2035* (MEIDECC and GGGI 2021). Gms: grams, Pax-km: passenger-kilometer.

Activities	Emission/pax-km for ICE (gms/Pax-km)	Emission/pax-km for EV (gms/Pax-km)	CO_2e mitigation / pax-km (gms/Pax-km)	Total mitigation (by 2035)
Electric Private Passenger Vehicles	2W: 69	2W:16	2W: 53	129,541 tons CO_2e
	4W Personal:141	4W Personal: 52	4W Personal: 89	
	Truck – Light pick-up: 132	Truck –Light pick-up: 90	Truck – Light pick-up: 42	
Electric Public Transportation	29	19	10	1,704 tons CO_2e
Electric Commercial Taxis (4W)	141	52	89	13,534 tons CO_2e
Electric Vehicles in Government fleet (4W)	141	52	89	9,663 tons CO_2e
Electric Freight Vehicle	342	125	217	8,409 tons CO_2e

4.3.5 Tonga Climate Resilient Transport Project

Tonga is currently working with the World Bank on the Tonga Climate Resilient Transport Project (P161539). The project goal is to improve the climate resilience of the transportation sector and to respond to eligible emergencies (World Bank 2018). The first component focuses on planning tools and includes traffic modeling and upgrading the Transport Management System information technology. The second component addresses infrastructure, including road rehabilitation, maintenance, footpath upgrades, and maritime and aviation sector-specific rehabilitation. The third component includes regulatory support for road and maritime management, and the final component includes an avenue for the reallocation of project funds for emergency response, if needed. This project does not include a component on EVs, but the road and footpath maintenance pieces are relevant to vehicle efficiency and the potential reduction of VKT, respectively.

4.4 Electric Vehicle Readiness

The adoption of EVs requires cohesive policy, technical, financial, and educational interventions. Policy measures can include phasing out personal ICE vehicles, EV purchase incentives, EV sales incentives for vehicle manufacturers, tax restructuring, import incentives, parking policies, low-emission vehicle zones, and vehicle standards. Shipping and customs policies will have a large impact on EVs because all these vehicles will likely be imported in Tonga. There are multiple electric grid considerations as well, and EV charging strategies vary based on renewable energy penetration and type. Tongatapu has been identified as well suited for EVs due to its flat terrain and small size (60 km by 30 km). Furthermore, the Government of Tonga is gaining significant experience with EVs through its demonstration project in Tongatapu.

4.4.1 Electric Grid Considerations

EV charging strategies differ based on the electric grid mix. A 2020 technical paper prepared as a follow-up to the Fourth Pacific Regional Energy and Transport Ministers Meeting in September 2019 outlined the value and fit of various charging solutions based on different penetrations of renewable energy (Campbell et al. 2020c). These are shown in Table 8.

Table 8. Assessment of the Value and Fit of EV-Electricity Supply Combinations With Various PICT Electricity Supply Types

Table adapted from PCREEE 2020 *Technical Background Paper* (Campbell et al. 2020c). Cells colored green indicate a perceived good fit, red a perceived poor fit, and amber somewhere between the two. BESS: battery energy storage system.

Integrated EV Solution	Dispatchable RE	Intermittent RE	Future Grid with BESS	Local and Off-Grid
Vehicle -to- Grid	Possible future goal if technology becomes both available and affordable, but advantages are far less where dispatchable RE is available.	Has the potential to increase RE penetration and utilize any excess RE. However, BESS provides an easier and lower cost option for same outcome without including EV costs.	Potential to increase RE penetration with smaller BESS but does not offer any cost advantage in the short term.	Not applicable, as V2G requires high numbers of EVs to share the high start-up costs.
Vehicle -to- Home	Little advantage with dispatchable RE apart from customer and personal backup, disaster relief, or on-site reliability.	Only useful from GHG point of view if excess RE exists and it is used with managed charging to capture this RE. BESS could provide similar services for a lower cost, unless the grid supply was also unreliable.	Has potential to add battery storage to the grid at reasonable unit cost compared with BESS but requires charging to be managed for GHG benefits to be realized.	Has the potential to provide useful backup or to support local grid battery storage.
Grid Managed Charging	Potential for significant benefits to be realized by the electricity supplier, with potential for sharing cost savings with the EV customers.	Potential to make good use of intermittent RE generation and potential to, at least marginally, increase RE penetration.	Potential to make good use of intermittent RE generation and potential to, at least marginally, increase RE penetration.	Not applicable.
On-Site Managed Charging	Little advantage and therefore little incentive to introduce.	Only of use if RE is distributed, in which case it has the potential to better utilize a customer's RE resource. Has the potential to marginally increase RE penetration.	Only of use if RE is distributed, in which case it has the potential to better utilize a customer's RE resource. Has the potential to marginally increase RE penetration.	Has the potential to significantly increase the proportion of RE on a local grid and maximize the use of any excess RE generated.
Time-of-Use (TOU) Pricing	Potential for good cost benefits to the electricity supplier and customer and the capability is close to deployment in Samoa.	Potential to better manage the diesel generation fleet and RE generation, with greater benefit if the TOU pricing is dynamic.	Potential to better manage the grid, with greater benefit if the TOU pricing is dynamic.	Currently not applicable as TOU pricing is a management tool for larger grids.
Low Voltage, Local Grid Supply	Low need for off-grid and low-voltage local grid options.	Low need for off-grid and low-voltage local grid options.	Low need for off-grid and low-voltage local grid options.	Could provide a very useful and significant option for increasing mobility and access to electricity, particularly in remote areas.

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Between June 2019 and June 2020, electricity demand across the four main island groups in Tonga increased by 3.6% (TPL 2021). Increased electricity demand due to GDP and population growth should be considered in addition to increased electrification. There are various other grid-related considerations, such as peak demand, rate structure, and grid stability.

4.4.2 Tonga Electric Vehicle Demonstration Project

The Government of Tonga launched an EV demonstration project in 2021 that will include the testing of an EV on Tongatapu. The demonstration project covers institutional, political, technical, financial, and educational spheres. The project includes a focus group, the development of an EV roadmap, the creation of a charging standard, a marketing campaign for EVs, and the proposal of EV charging business models. A secondhand Nissan Leaf and data logger will be acquired, and a Level 2 charging station will be installed to aid the testing.

The EV demonstration project plans to share its finding with PCREEE, which is committed to the exchange of electric mobility ideas among PICTs. PCREEE held a virtual webinar in February 2022 and an in-person workshop in November 2022 to discuss electric mobility in the region with various stakeholders and partners.

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5 Conclusion

Tonga is facing a transportation sector characterized by ICE private passenger vehicles, poorly maintained roads and walkways, and an inadequate public transit system. Replacing ICE passenger vehicles with EVs, along with measures to reduce VKT—such as adding bicycling lanes, walking paths, and increasing the reliability of the bus network—are all interventions that can reduce GHG emissions in the transportation sector.

Jurisdictions leading in EV adoption have implemented policies such as reducing taxes on EVs compared to ICE vehicles, providing subsidies and rebates for EV charger installation, instituting an age limit on imported ICE vehicles, and developing EV maintenance courses to expand the skill set of current automotive technicians. As has been done in many of the regions evaluated in these case studies, the Government of Tonga also plans to lead the way by adopting EVs in municipal fleets and has enacted a wide range of policies to promote transportation efficiency. Furthermore, an EV demonstration project is currently underway on the island of Tongatapu.

At a PCREEE virtual webinar on February 23, 2022, common success themes among countries starting EV programs were presented. These include:

1. A vision of the desired future
2. A specific government, public, or industry group responsible for developing an EV sector
3. An agreed upon roadmap for all parties
4. Clear and actionable targets
5. Well-thought-out incentives
6. Quality information and marketing
7. Robust supporting policy

Although there are key challenges and barriers to widespread EV adoption in Tonga, multiple studies have researched potential political, technical, financial, and educational interventions and GHG emissions reduction potential. These can be adapted to Tonga's specific context. The PCREEE 2020 *Technical Background Paper* reported data on various PICTs, including key vehicle, fuel, and electricity sector statistics. In future work, Tonga's profile—in terms of population, land area, urbanization, registered vehicles, and fuel consumption, etc.—could be directly compared to other PICTs that have tried to increase EV adoption because much can be learned from other jurisdictions with similar demographics and goals as Tonga.

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