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# Policy Framework to Improve Mobility Efficiency and Electrify Transportation in Tonga

Caley Johnson, Prateek Joshi, Dustin Weigl, and Eliseo Esparza

*National Renewable Energy Laboratory*

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**Technical Report**
NREL/TP-5400-87827
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# List of Acronyms

| | |
|---|---|
| AC | alternating current |
| BAU | business as usual |
| BEV | battery-electric vehicle |
| CCS | Combined Charging System |
| CV | conventional vehicle |
| DC | direct current |
| EOL | end of life |
| EV | electric vehicle |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| IEA | International Energy Agency |
| LDV | light-duty vehicle |
| MEIDECC | Tonga Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications |
| NREL | National Renewable Energy Laboratory |
| PCREEE | Pacific Centre for Renewable Energy and Energy Efficiency |
| P&R | park and ride |
| PV | photovoltaics |
| SRTS | Safe Routes to School |
| TEEMP | *Tonga Energy Efficiency Master Plan: 2020–2030* |
| TERMPLUS | *Tonga Energy Road Map: 2021–2035* |
| TOU | time of use |
| V2G | vehicle-to-grid |
| V2H | vehicle-to-home |
| VKT | vehicle kilometers traveled |
| VRU | vulnerable road user |

# Executive Summary

The Kingdom of Tonga has requested a policy framework that benefits its land transportation sector by saving cost and time, increasing resilience, and reducing petroleum and greenhouse gas (GHG) emissions. This framework was developed by building on prior work, namely the *Tonga Energy Efficiency Master Plan: 2020–2030* (TEEMP), the *Tonga Energy Road Map: 2021–2035* (TERMPLUS), and the *Regional Electric Mobility Policy for Pacific Island Countries and Territories* developed by the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE). The strengths, weaknesses, opportunities, and threats to Tonga's land transportation system were identified at stakeholder working group meetings in Tonga in June 2023. The working group discussed and refined a set of appropriate policies that have been effective in relevant jurisdictions. The resulting 27 policies are listed in Figure ES-1 and defined according to intended outcomes, relationships to other proposed policies, applications in other relevant jurisdictions, hurdles to implementation, resilience impact, equity impact, and government revenue impact. Some of the policies are also accompanied by implementation recommendations.

Two policies (feebate and parking strategies) are foundational because they provide funding and induced demand for alternative modes of transportation to enable the other policies. The remaining 25 policies can be grouped by their intended outcomes. Mode diversification policies reduce per-capita vehicle kilometers traveled by enabling more Tongans to travel by foot, bicycle, shuttle bus, ride-share, or other modes of travel. Policies with the intended outcome of safe electric vehicles (EVs) and charging help ensure that EVs and charging infrastructure in Tonga are safe to humans, infrastructure, and the environment. Policies for accessible EVs and charging aim to make a variety of EVs accessible in Tonga, along with convenient charging infrastructure. Affordable EVs and charging policies aim to bring down the costs of EVs in order to stimulate market growth. Policies that enable EV charging as a grid asset aim to manage the new electrical load so that the electrical grid becomes more resilient as a result. Policies within each group are divided into chronological phases, with the latter phases building upon earlier ones.


**Figure ES-1. Policy options supporting key intended outcomes and goals.**

Source: Fred Zietz, NREL.

The proposed policies also support the goals laid out in TEEMP and TERMPLUS, and have been tracked accordingly. Most policies are scalable to ensure that Tonga's sustainable transportation targets can be reached. A business-as-usual (BAU) scenario projected that GHG emissions from land transportation in Tonga would increase 35% between 2021 and 2050. However, meeting Tonga's suite of land transportation efficiency and electrification goals will reduce GHG emissions in the sector by 60% below the BAU scenario by 2050, as shown in Figure ES-2. These policies will also have substantial benefits to the resilience of Tonga's land transportation system. The mode diversification policies can decongest evacuation routes, EV safety and reliability standards could ensure that equipment can withstand extreme weather events, EV accessibility and affordability policies would make transportation less vulnerable to curtailments of petroleum imports, and utilizing EVs as a grid asset can make the grid more flexible and robust. Overall, the policies have successful track records in other jurisdictions and are deemed feasible by the Tonga land transportation working group. Once implemented, the policies can make Tonga's land transportation safer, less congested, more equitable, more resilient, and reduce GHG emissions in the sector by 60% compared to the BAU scenario. Furthermore, this policy framework could be applicable to other Pacific Island nations and tailored to their specific transportation systems. Collaboration with organizations such as PCREEE, the Local2030 Islands Network, NREL, or others could further support application of this policy analysis framework and policy implementation with other island partners.

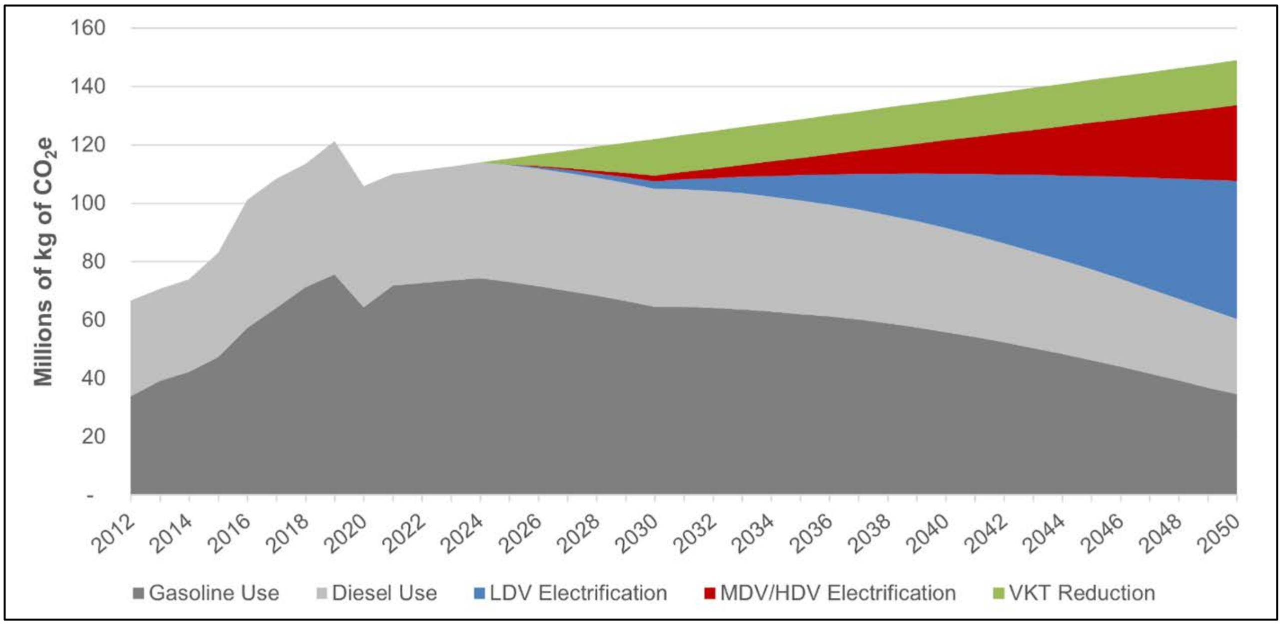


**Figure ES-2. Projected impact of proposed transportation policies on Tonga's land transportation GHG emissions.**

$CO_2e$: carbon dioxide equivalent; HDV: heavy-duty vehicle; LDV: light-duty vehicle; MDV: medium-duty vehicle; VKT: vehicle kilometers traveled.

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# 1 Introduction

## 1.1 Context for This Report

The Kingdom of Tonga, like many small island developing states, is heavily dependent on imported fossil fuels to meet its current energy needs, especially for transportation. Gasoline-based fuel imports present a financial burden to the Tongan economy, expose the country to large fluctuations in global oil prices, and contribute significantly to Tonga's greenhouse gas (GHG) emissions. As a result, the government of Tonga is actively working to reduce its fuel imports and GHG emissions by transitioning toward a more sustainable and resilient transportation system.

The previous phase of collaboration between the National Renewable Energy Laboratory (NREL) and the Tonga Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC) identified global and regional trends for transportation efficiency and electric vehicles (EVs), highlighted key policies and initiatives from select case studies, and summarized the current state of transportation in Tonga (Joshi et al. 2023). NREL and MEIDECC then jointly held a Tonga Land Transportation Stakeholder Meeting in June 2023 so that the perspectives of numerous road users in Tonga could be incorporated. This analysis, which describes and evaluates policy options for MEIDECC to improve mobility efficiency and electrify transportation, is informed by those collaborative efforts and other ongoing initiatives in Tonga and the Pacific Island region.

The rest of this section discusses relevant attributes of Tonga's current transportation system, including business-as-usual (BAU) projections for fuel imports and GHG emissions (Section 1.2), and describes the methodology used in selecting the policy options (Section 1.3).

The report then assesses policy options to achieve five overall intended outcomes, which were informed by stakeholder consultation, as well as policy options that are foundational and enable all the other policies (Section 2). The overall intended outcomes are: Mode Diversification (Section 3), Safe EVs and Charging (Section 4), Accessible EVs and Charging (Section 5), Affordable EVs and Charging (Section 6), and EV Charging as a Grid Asset (Section 7).

Section 8 then compares these policy options with those proposed in previous Tongan plans, explaining which policies were included, excluded, or combined with others in this report. Section 9 concludes by synthesizing these options into a proposed policy framework that outlines the sequencing of policies and their estimated impacts on reducing fuel imports and GHG emissions.

## 1.2 Attributes of Current Transportation System and BAU Projection

Tonga's historical (2012–2021) and projected (2022–2050) consumption of gasoline and diesel for land transportation is shown in Figure 1, and the associated historical and projected GHG emissions from this fuel consumption is shown in Figure 2. This BAU projection forms the basis for assessing progress toward goals by tracking reductions in fuel use and GHG emissions based on the policy options. Details on how these BAU projections were developed can be found in

Appendix A, and further background information on Tonga's transportation system and relevant policies can be found in Joshi et al. (2023).

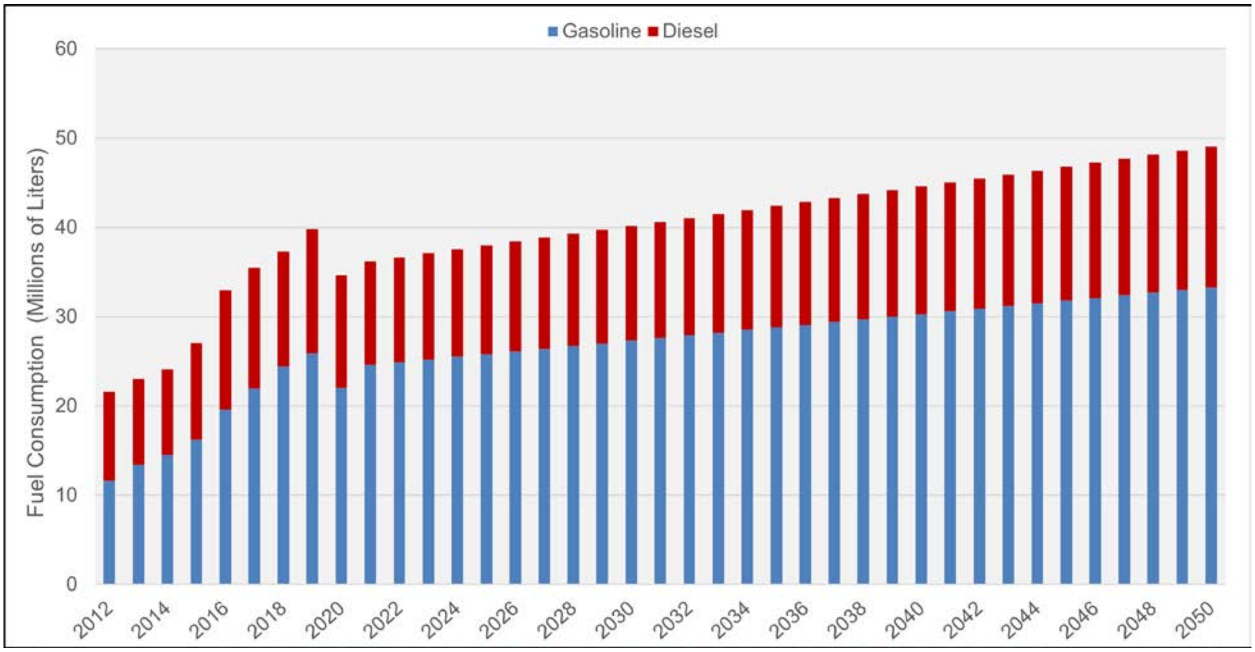



**Figure 1. Historical and BAU projected gasoline and diesel fuel consumption for land transportation in Tonga (2012–2050).**

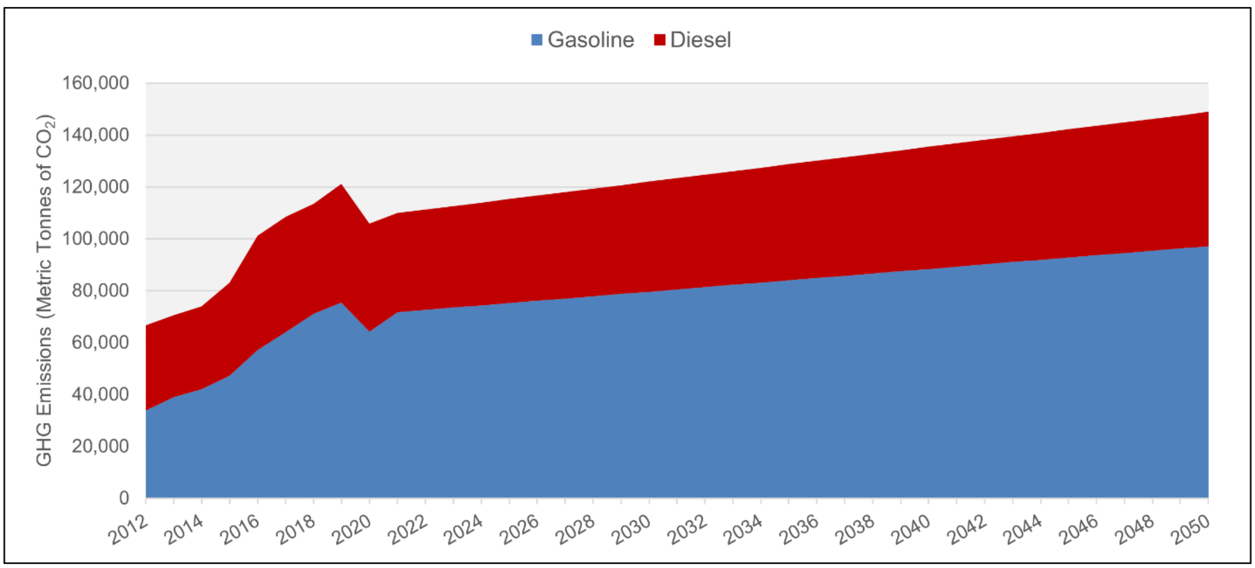



**Figure 2. Historical and BAU projected GHG emissions from gasoline and diesel fuel consumption for land transportation in Tonga (2012–2050).**

Note: This assumes emissions factors of approximately 2.9 kg $CO_2$/liter and 3.3 kg $CO_2$/liter for gasoline and diesel, respectively. These are the same assumptions used in the 2020 *Tonga Energy Efficiency Master Plan*.

This BAU model was updated from the previous analysis done for the *Tonga Energy Efficiency Master Plan: 2020–2030* (TEEMP). Comparing the findings to TEEMP's provides an indication of the changes in fuel use since then, as well as how projections have changed for Tonga. The first major difference is the availability of historical data. TEEMP used historical fuel use data from 2012–2015, while this report updated those data through 2021. This resulted in an overall decrease in the total projection compared to the previous analysis. In TEEMP, the 2050 projected fuel use reached around 58 million liters combined (about 32 million liters of gasoline and 26 million liters of diesel). In this analysis, the 2050 projected fuel use reached around 49 million liters combined, consisting of 33 million liters of gasoline and 16 million liters of diesel (Figure 1).

This drastic change in the proportion of diesel versus gasoline in overall fuel consumption is likely due to the historical data that were available. In 2013, there was a shift from gasoline being the dominant fuel to diesel being the dominant fuel. Because TEEMP relied on only 3 years of historical data, this shift had a significant impact on the projections, resulting in a model where diesel fuel was consumed at a higher rate than gasoline. More recent historical data shows that while diesel fuel still comprises a large portion of transportation fuel consumption and emissions in Tonga, it has increased at a much lower rate compared to gasoline. However, it is important to note that the overall rate of increase in Tonga's fuel use is similar in both analyses due similar assumptions about gross domestic product (GDP) per capita growth.

## 1.3 Methodology

The methodology for selecting policy options builds upon prior work, including TEEMP, the *Tonga Energy Road Map: 2021–2035* (TERMPLUS)*,* the Pacific Centre for Renewable Energy and Energy Efficiency's (PCREEE's) electric mobility program (Campbell et al. 2020b), and the previous phase of collaboration between NREL and MEIDECC (Joshi et al. 2023). The project team extracted an initial list of policies from these sources and subsequently added, adjusted, or removed policies based on Tonga's specific transportation needs and other available literature. A stakeholder working group in Tonga provided input on these draft policy options, which MEIDECC and others also reviewed.

The policies are categorized based on the following overall intended outcomes, which were informed by stakeholder consultation: Mode Diversification (Section 3), Safe EVs and Charging (Section 4), Accessible EVs and Charging (Section 5), Affordable EVs and Charging (Section 6), and EV Charging as a Grid Asset (Section 7). Policies are also discussed that are foundational and enable all five overall intended outcomes (Section 2).

For each policy, this report describes its details, intended results, relationship to other existing or proposed policies (including those in TEEMP, TERMPLUS, and the PCREEE program, among others), application in other relevant jurisdictions, hurdles to implementation, resilience impact, equity impact, and government revenue impact. Finally, the project team estimated the fuel import and GHG emissions reductions of these policies through 2030 and 2050 based on a suggested sequencing and implementation time frame (Section 9). To summarize the relationship of this effort with other ongoing efforts in Tonga and the region, this policy framework applies the PCREEE regional program to Tonga in order for the country to reach the various transportation goals outlined in TERMPLUS.

# 2 Foundational Policies

The following two policies, a feebate and a comprehensive parking strategy, are foundational to this policy framework. The funding generated from these programs, as well as the induced demand for both efficient mobility options and electrified transportation, enable all five of the overall intended outcomes.

## 2.1 Feebate

A feebate is a vehicle registration fee that increases with the fuel consumption or the GHG emissions of the vehicle, paired with a rebate for highly efficient vehicles. A fee coupled with a rebate allows for a greater cost differential between the highest- and lowest-emitting vehicles, compared to what would be economically or politically feasible with just a fee. The relative costs and emissions for New Zealand's feebate program, their Clean Car Programme, are shown in Figure 3 for new vehicles and Figure 4 for used vehicles. The solid line shows how emissions impact the fee or rebate for new or used vehicles registered after July 1, 2023. The cost differential between the maximum fee and the maximum rebate for used vehicles is not as large, which has equity implications discussed in Section 2.1.7.

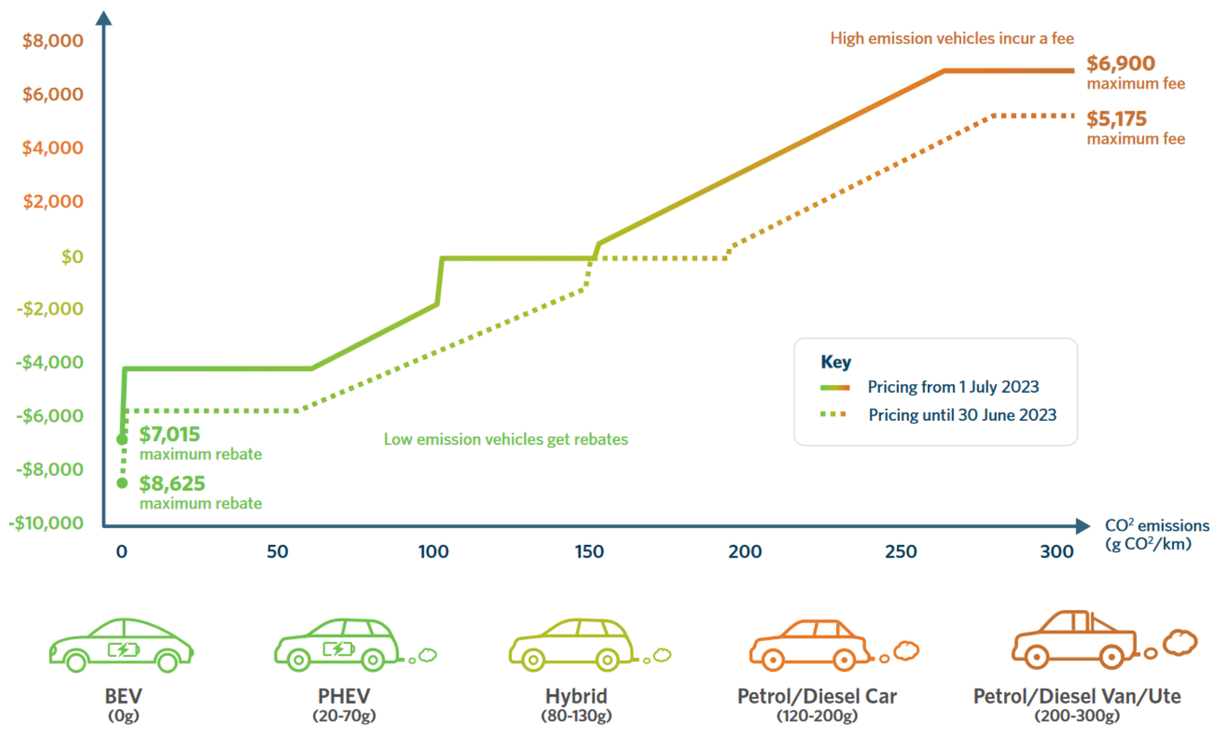



**Figure 3. Feebate curves for New Zealand's Clean Car Programme (new vehicles).**

Source: NZ Transport Agency (2023a).

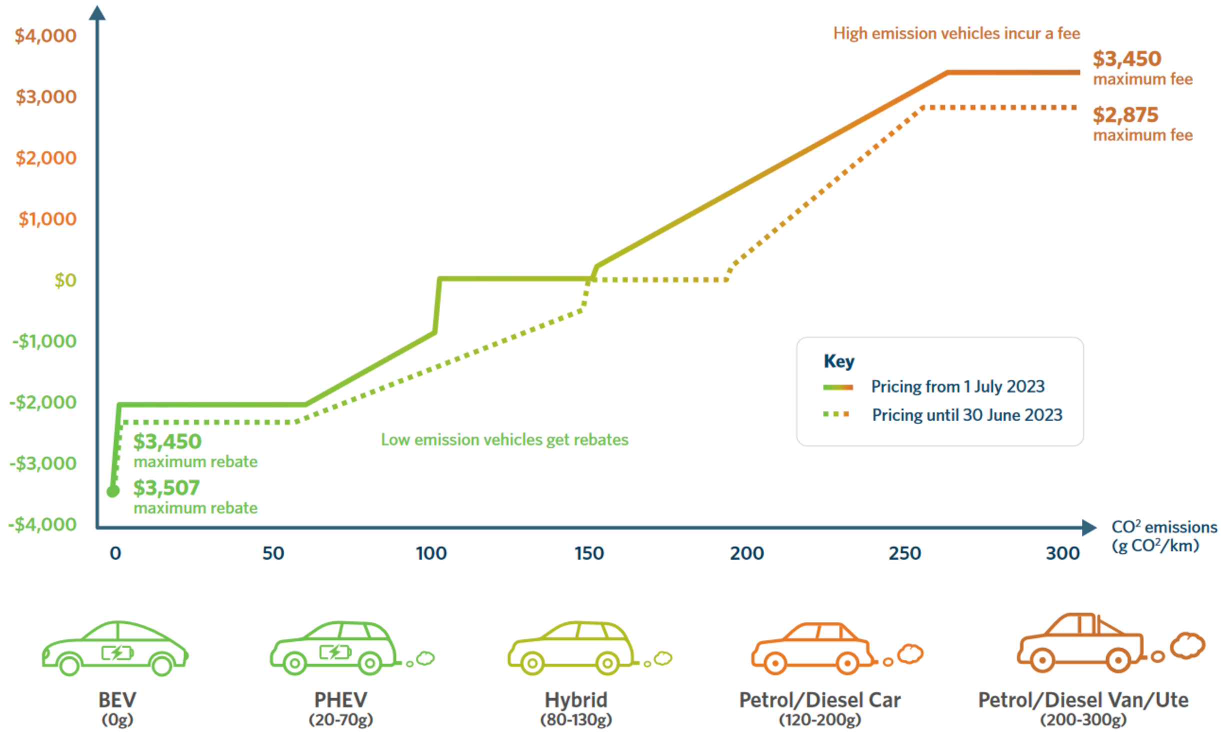



**Figure 4. Feebate curves for New Zealand's Clean Car Programme (used vehicles).**

Source: NZ Transport Agency (2023a).

### *2.1.1 Policy Details*

The first step in developing a feebate policy is to determine the fuel economy or GHG emissions for individual gasoline vehicles (make, model, and model year). It would be ideal to test vehicles on a Tonga-specific drive cycle in order to determine the GHG emissions per kilometer. However, this would be a cumbersome and expensive process. It is advisable to use the GHG emissions ratings recorded in New Zealand's Fuelsaver database (New Zealand Energy Efficiency & Conservation Authority 2023). This database reports the Worldwide Harmonized Light Vehicles Test Procedure, and because there is such strong overlap in vehicle availability between Tonga and New Zealand, this is the most applicable database to Tonga. There should be a requirement that these fuel economy numbers are posted on the car window at the point of sale so that potential buyers know the fuel economy of the vehicle, which is a proposal made in TEEMP.

The second step is to determine how to treat EVs and their associated electricity sources. Many feebate programs, including New Zealand's, ignore the GHG emissions from power plants providing EVs with electricity and therefore count EVs as zero emissions based solely on tailpipe emissions. This has the advantage of simplicity but the disadvantage of inaccuracy and does not create incentives for more efficient EVs. For example, New Zealand's scheme does not encourage someone to purchase a more efficient Nissan Leaf (0.19 kWh/km) over a Ford F150 Lightning (0.30 kWh/km). As shown in Figure 5, there are differences between the two vehicles' emissions (approximately 6 kg $CO_2e$ per 100 km) at Tonga's 2022 capacity mix of 46% renewables (International Renewable Energy Agency 2023).[1]

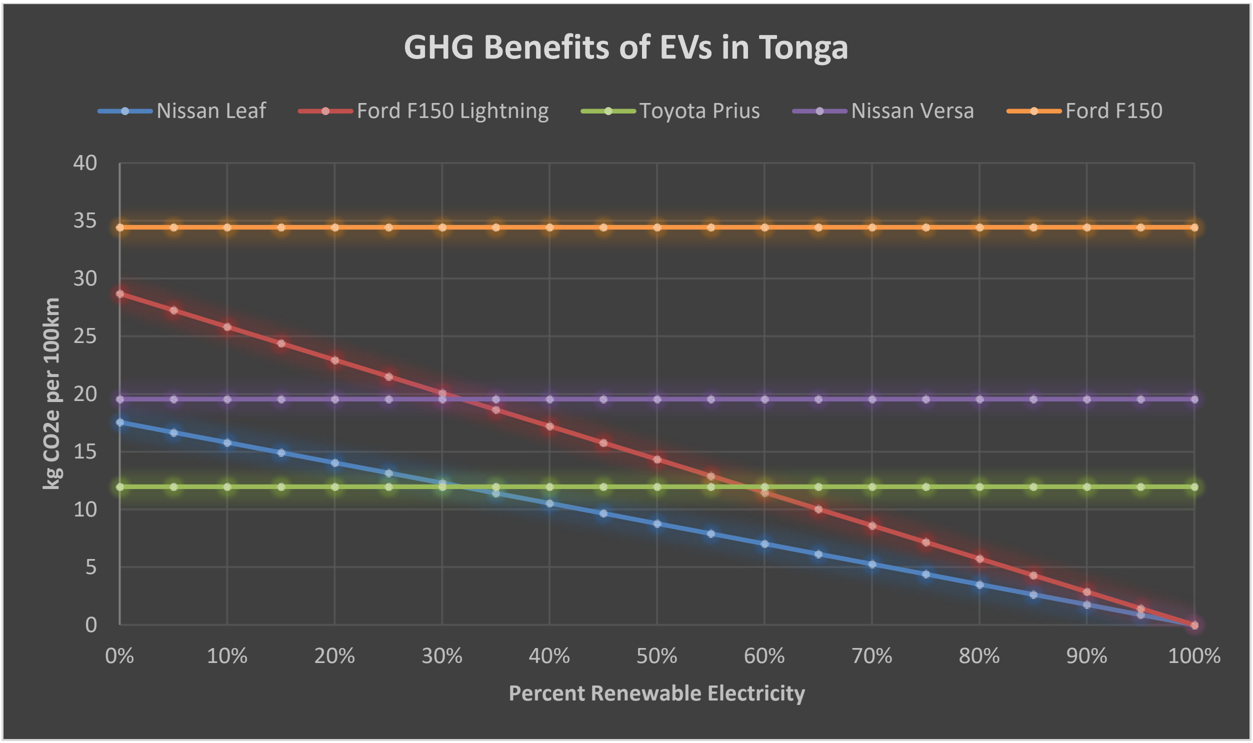



**Figure 5. GHG benefits of EVs in Tonga at various levels of renewable generation.**

Source: NREL's EV Emissions on Islands Model.

Another option for architects of a feebate policy would be to take Tonga's electricity grid fuel mix into account, including the different fuel sources and their heat rates. Two assumptions are available when calculating an EV's emissions using this method: the 2022 power capacity mix of 46% renewables or the 2025 goal of 70% renewables (Global Green Growth Institute 2022). As shown in Figure 5, assuming 70% renewables would assume greater emissions benefits from EVs and therefore provide greater incentives for purchasing EVs. However, it would provide less incentive to purchase a more efficient EV (e.g., Nissan Leaf) rather than a less efficient one (e.g., Ford F150 Lightning). Either way, calculations are needed to convert an EV's efficiency (per the Fuelsaver database) into its GHG emissions. The EV Emissions on Islands Model was used to provide both calculations below:

$$Y = 0.5095X \tag{1}$$

**Equation 1.** Conversion from EV efficiency to GHG emissions on the Tonga grid with 46% renewables (per 2022 capacity mix). Calculated using NREL's EV Emissions on Islands Model. Note: $Y$ is GHG emissions, measured in kg $CO_2e$/100 km, and $X$ is the electricity consumption rate, measured in kWh/100 km.

[1] Capacity, rather than generation, is used because it is assumed that EVs have the flexibility to charge when renewable production is happening.

$$Y = 0.2831X \quad (2)$$

**Equation 2.** Conversion from EV efficiency to GHG emissions on the Tonga grid with 70% renewables (per 2025 capacity goal). Calculated using NREL's EV Emissions on Islands Model. Note: $Y$ is GHG emissions, measured in kg $CO_2$e/100 km, and $X$ is the electricity consumption rate, measured in kWh/100 km.

After GHG emissions rates are assigned to all vehicles, the fee needs to be set by taking Tonga's vehicle fleet and economy into account. The International Council on Clean Transportation has developed a feebate simulation tool to help estimate the emissions impact of various fees and rebates (International Council on Clean Transportation 2023). It is important to note that the quantity of the fee and rebate will need to be adjusted over the years to provide the targeted amount of revenue for the government.

### 2.1.2 Intended Result

A well-calibrated feebate should increase sales of low-emitting vehicles and reduce sales of high-emitting vehicles. Over time, this will increase the average efficiency and decrease the average emissions rate of the Tonga fleet. This can be done in a cost-effective manner and deliver a specified level of revenue to the government.

### 2.1.3 Relationship to Other Proposed Policies

Revenues from this policy can be used to fund many of the other policies, incentives, and projects listed in this report. Furthermore, the feebate creates the framework that the policies for affordable EVs and charging (Section 6) can operate within.

### 2.1.4 Application in Other Relevant Jurisdictions

France was the first country to implement a feebate in 2008 (Wappelhorst 2022). Their system has an emissions component and a weight component in order to incorporate both environmental and road surface damage. At first, consumers in France were more responsive to this program than expected, resulting in large emissions reductions but also revenue shortfalls. Singapore, Sweden, Mauritius (Ally 2016), and New Zealand have also implemented feebates. The latter two have particularly relevant lessons for Tonga. Lessons from Mauritius are applicable because it has a per-capita GDP that is closer to Tonga's compared to any of the other aforementioned countries (The World Bank 2023a). Mauritius, like France, had an unexpected response to their feebate policy, resulting in lower revenues and subsequent adjustments. Policymakers found that a labeling scheme was a necessary first step in order to inform consumers about a vehicle's fuel economy. New Zealand's feebate system is also relevant because most of Tonga's cars come from New Zealand (after being manufactured in other countries), and they have developed a database of vehicle efficiencies that is applicable to Tonga (New Zealand Energy Efficiency & Conservation Authority 2023).

### 2.1.5 Hurdles to Implementation

The people who register the least efficient gasoline vehicles could view this policy unfavorably, and it could garner resistance. Implementation must be paired with a messaging campaign letting the public know that, on average, fees were not raised (if Tonga chooses to keep government revenues the same as before). The messaging must also let the owners of the inefficient vehicles know that the upfront increase in registration fees is significantly less compared to the extra fuel costs that they are incurring due to their inefficient vehicles.

#### 2.1.6 Resilience Impact

More efficient vehicles can get more work done compared to less efficient vehicles using the same amount of fuel. Therefore, if faced with a fuel shortage due to a supply chain disruption, a more efficient vehicle fleet in Tonga can better fulfill transportation needs and thus increase the sector's resilience. This principle also applies to EVs, which in the United States are 4.4 times more efficient than their conventional counterparts (Singer et al. 2023). Even when considering the electricity grid's fuel use, EVs are more efficient and lower-emitting than their gasoline counterparts (Figure 5). The resilience of EVs will be discussed in greater detail throughout the report.

#### 2.1.7 Equity Impact

This policy would raise the upfront registration costs for some of the highest-emitting, oldest, and least expensive vehicles. If assessing the policy based solely on upfront cost, it could be perceived as inequitable. However, old inefficient vehicles often appeal to low-income purchasers due to a low upfront cost, but cost the consumers much more when accounting for their life cycle costs that include fuel. By increasing the upfront costs of such vehicles and making them less alluring to low-income residents, this policy could actually save consumers money over the long term. Furthermore, the policy treats used and new vehicles separately so that Tonga can make the fee for used vehicles lower than that of new vehicles. When formulating this policy, efforts need to be made to ensure that generous rebates are given to those purchasing inexpensive and used, yet highly efficient vehicles, including motorcycles. This is how low-income residents could benefit the most, by receiving a large rebate and locking in low fuel costs into the future.

#### 2.1.8 Government Revenue Impact

This policy is expected to generate revenue that can fund the government and other policies and projects listed in this document. Policymakers can target a certain revenue level and adjust their fees and rebates accordingly. However, both France and Mauritius were surprised that the policy had more uptake (and was thus more effective at reducing emissions), and therefore generated less revenue from fees than originally anticipated. It is therefore recommended to target greater revenues than needed when setting the fees and rebates in case Tonga's experience with a feebate policy follows this same trend and actual revenues are less than expected.

## 2.2 Nuku'alofa Comprehensive Parking Strategy

Free parking in downtown Nukuʻalofa, Tonga's capital, currently leads many commuters to drive their under-occupied vehicles to town and occupy valuable parking spots all day, free of charge. This is detrimental to businesses in downtown Nukuʻalofa because short-term parking is not available to shoppers, and curb spots are less available for passenger drop-offs/pickups and goods suppliers. Furthermore, the free parking results in many cars driving to Nukuʻalofa during rush hour, causing traffic congestion, excess fuel consumption, and GHG emissions. Finally, a single-occupancy vehicle is not an optimal use of a well-located parking spot compared to, for example, a van with eight people that is relegated to far-off parking. This hypothetical situation could result in eight of nine total people walking farther distances compared to one of nine.

A comprehensive parking strategy can incentivize carpooling, buses, biking, motorcycles, micromobility, and other alternative forms of transportation. It is technology-agnostic, allowing local innovation to find solutions to minimize overall transportation costs. However, this parking strategy can be paired with other policies and projects that make it more convenient to use these alternative forms of transportation. Paid parking can be a major source of revenue for the government. Some of this revenue should be used in popular projects that make alternative forms of transportation more attractive and make the entire strategy politically acceptable.

### 2.2.1 Policy Details

Details of this policy need to be developed in an iterative process in order to determine the appropriate price of parking in various locations. Payment equipment is an important component, and a good option is a payment system that has smart kiosks on every block and allows multiple forms of payment (including cash, card, and mobile apps). These kiosks can be easier to maintain than simple meters because there are fewer of them, and weather-resistant versions are available and currently in use at beach parking lots in numerous locations around the world. Furthermore, the "smart" aspects of these systems enable discounted and free parking, which form the basis of other policies promoting carpooling and EVs.

### 2.2.2 Intended Result

The intended result of this policy is to allocate parking spots to the most valuable uses. Value is allocated to various parkers based on cumulative time savings and the increase in economic activity enabled by parking. Paid parking saves more cumulative time because the best parking spaces (i.e., where time is saved) would be disproportionately used by vehicles with multiple passengers, as those passengers could pool their money for paid parking. Pro-carpooling policies such as a ride-share coordination website (Section 3.6) can be paired with the parking system to further reinforce the intended result that close parking spots go to vehicles with higher occupancy. A paid parking policy would also allocate the best spaces disproportionately to short-term users that park, conduct business quickly, and leave. A time element to this policy can thus enhance its value; for example, certain spots can be free for 15-minute pickups or drop-offs. This would result in many more customers being able to use a given parking spot over a certain period of time, increasing the value of the spot based on the number of cars that are able to park there.

### 2.2.3 Relationship to Other Proposed Policies

A paid parking system is a bedrock that supports many of the other proposed policies. It creates a financial incentive for all other policies that reduce vehicle kilometers traveled (VKT) around Nuku'alofa. It also provides funding to support other policies and projects. Furthermore, this policy is related to charging station incentives (Section 6.4), which include free parking for EVs at charging stations.

### 2.2.4 Application in Other Relevant Jurisdictions

The best parking policy for Nuku'alofa to emulate could be the one implemented in Auckland, New Zealand. This policy is described in the 2015 *Auckland Transport Parking Strategy* (Auckland Transport 2015) and further refined in the 2022 *Draft Auckland Parking Strategy*

(Auckland Transport 2022). By considering the many provisions laid out in the 2022 draft strategy, Nukuʻalofa can benefit from Auckland's years of iterative strategy development. While Auckland and Nukuʻalofa differ in many ways, they have some important commonalities. These include (1) similar population densities of 1,250 (±50) people/km$^2$ (World Population Review 2023; New Zealand Government 2023); (2) access to similar Pacific market equipment vendors; (3) ingress/egress that is constrained by the ocean, creating traffic bottlenecks; (4) similar climates impacting people's willingness to walk and bike; and (5) both are major port cities, with associated impacts on traffic.

Some high-level lessons to be learned from Auckland's parking strategies include the following:

1. Use smart parking stations rather than simple meters. Auckland used smart stations from the company Global Parking Solutions, so they are more likely to offer service in the Pacific region.
2. Do not treat all areas the same. It is best to have zones depending on the types of businesses in the zone and the demand for parking. Different zones have different prices and time limits.
3. Keep the public informed about the benefits of paid parking and the projects that parking fees are funding. Get formal feedback from representative groups and adjust the parking strategy accordingly.
4. Give people convenient alternatives to driving. These include public transit, bike paths, transportation network companies, and rental bikes or scooters.

In addition to Auckland, some other relevant examples come from Suva and Lautoka, Fiji. Both of these cities have had paid parking since 1980 (The Laws of Fiji 2016a, 2016b). While these parking policies are simplistic due to the technology available at the time and therefore do not offer many lessons learned, these are proof that paid parking can be successful and beneficial to cities on relatively small Pacific Islands.

### 2.2.5 Hurdles to Implementation

It is often difficult to garner support for paid parking because the people that are currently subsidizing parking are not as aware of its costs, whereas the parking fees are clearly understood. Furthermore, many people who currently park for free might not foresee alternative commutes that could be available to reduce their parking fees in the future. Finally, the segment of the population that commutes in a single-occupancy vehicle is often wealthier and could be more politically active than those who would benefit from a paid parking policy.

### 2.2.6 Resilience Impact

A paid parking policy will increase the speed and number of people that are able to evacuate from Nukuʻalofa to designated safe zones (Figure 6) in the case of an emergency. This is because when parking is no longer free, the average number of people per vehicle increases and therefore every evacuating vehicle will likely carry more people on roads that have limited capacity.

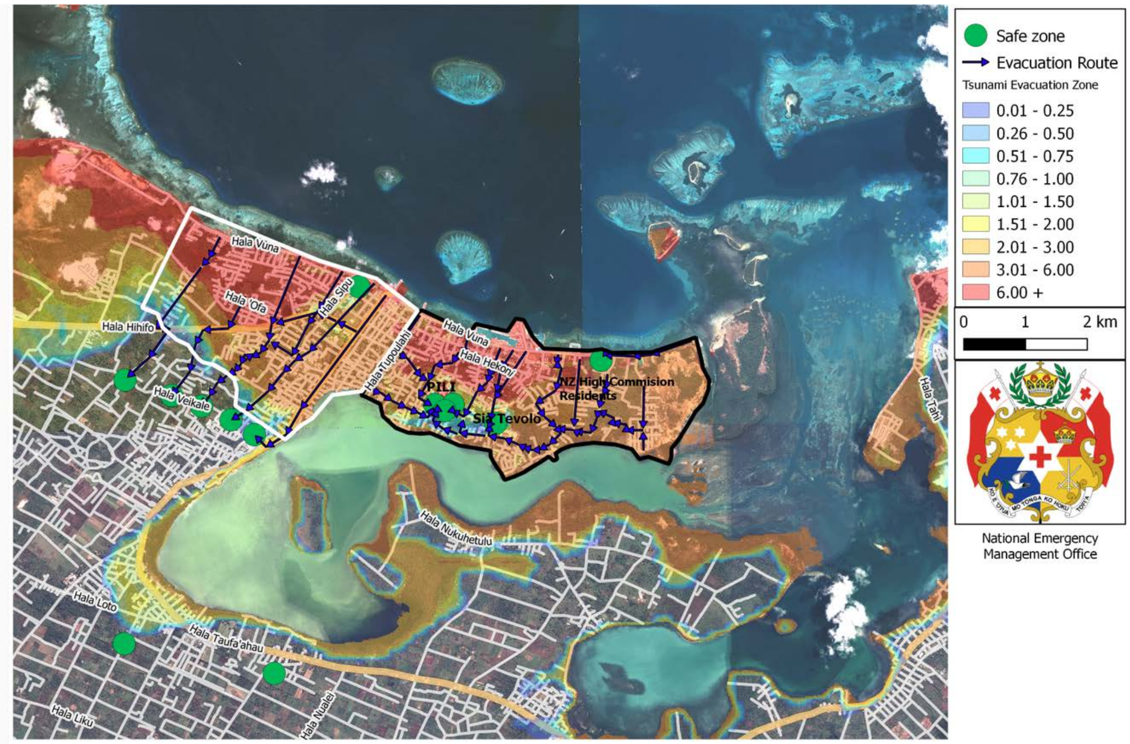



**Figure 6. Tsunami evacuation map for Nuku'alofa.**

Source: Tonga National Emergency Management Office.

### 2.2.7 Equity Impact

Free parking is a major subsidy paid for by non-vehicle owners (through sales and property taxes) to vehicle owners. Charging a market price for parking reduces this regressive subsidy. Revenues from paid parking can also be used on projects that benefit disadvantaged communities, effectively creating a more progressive subsidy. Parking payment stations need to accept cash because many people from lower-income communities do not have access to credit cards or smartphones.

### 2.2.8 Government Revenue Impact

This policy could generate substantial revenue for the government of Nuku'alofa, even after accounting for the cost of kiosks, administration, and enforcement. As with Auckland's paid parking program, it will require some adjustments in order to determine the market price and therefore the amount of revenue.

### 2.2.9 Implementation Recommendations

It is crucial to involve the community of Nuku'alofa when formulating the parking strategy, and to inform residents of both the downsides of free parking and the benefits of paid parking in terms of time savings and increased turnover for local businesses. It is best to pair a paid parking strategy with popular projects such as pedestrian or bicycle infrastructure (Section 3.1), bike- and scooter-share programs (Section 3.4), and on-demand shuttle service (Section 3.7). There will likely need to be collaboration between the Ministry of Police and the Ministry of Tourism to ensure that the parking policy is adequately enforced and implemented in a way that is amenable to tourists.

# 3 Policies for Mode Diversification

As mentioned in Section 1, Tonga has a relatively efficient transportation system (when measured in liters of fuel *per person*), yet that is projected to change (U.N. Climate Technology Centre & Network 2020). Such changes would be consistent with international development trends, driven primarily by an increase in per-capita VKT in personal vehicles (Ecola et al. 2014). These trends lead to increased traffic congestion, time wasted, injuries and deaths, fuel use, local air pollution, and GHG emissions (Ecola et al. 2014). These negative attributes can be reduced by diversifying transportation beyond personal vehicles to modes such as buses, bicycles, ride-share, and walking. Therefore, the policy options in this section are intended to allow Tonga to increase the accessibility of diverse mobility services to support development while minimizing the increase of per-capita VKT.

## 3.1 Bicycle and Pedestrian Infrastructure

Potential cyclists state that they are more likely to choose to cycle if there are off-street paths or physical barriers between them and car traffic (Winters and Teschke 2009). A person's likelihood of cycling also increases as their space from traffic increases and the speed of traffic decreases (Sandt et al. 2015). Scooters and skateboarders need quality cement sidewalks and paths in order to safely operate. More pedestrians will walk if there are good sidewalks, crosswalks, ramps, and dog fences.

### 3.1.1 Policy Details

A bicycle and pedestrian master plan should be developed, with frequent community input, using the following general steps:

1. Map the origins and destinations of likely bikers and pedestrians and highlight the routes between them.
2. Assign a qualitative estimated traffic flow to various routes and note the populations served (e.g., handicapped, children, elderly, tourists). Community input is required.
3. Develop a rating system of how amenable the current infrastructure on the route is for bikers and pedestrians. The ratings could range from 0 (not passable) to 10 (conveniently and safely passable). Community input is required.
4. Assess improvement projects for prioritized routes and obtain cost estimates from traffic engineering firms. Such projects could include (from most expensive to least) new sidewalks or paths, protective bollards, rumble strips, painted bike lanes, and sharrows.
5. Prioritize specific projects, given their costs and benefits. Community input is required.
6. Publish a bike and pedestrian map of the area so that people can choose the routes that best fit their ability and comfort level.

### 3.1.2 Intended Result

The intended result is to increase the number of pedestrians and cyclists, as well as trips taken on foot and bicycle. This will reduce fuel use and GHG emissions.

### 3.1.3 Relationship to Other Proposed Policies

Bicycle and pedestrian infrastructure need to be particularly strong in downtown Nukuʻalofa in order to enable people that arrived via alternative means of transportation, to avoid paid parking (Section 2.2), to still move around town easily. This policy will make the bike- and scooter-share system (Section 3.4) feasible and safe. Biking infrastructure from the proposed park-and-ride (P&R) lot in Pea to Nukuʻalofa will also increase the utility of this P&R lot (Section 3.5). Infrastructure will also be key to a successful Safe Routes to School (SRTS) program (Section 3.3) and will help make the on-demand shuttle service (Section 3.7) more efficient by providing quick access to cluster stops.

### 3.1.4 Application in Other Relevant Jurisdictions

Wausau, Wisconsin (population 39,600), was ranked as the most bikeable small city in the United States (Andersen 2018). Although different in many regards to Nukuʻalofa, the city does offer some relevant lessons. Wausau has an active bike culture centered around a couple of bicycle clubs. As Figure 7 shows, Wausau uses a map as the centerpiece of its infrastructure plan and as a user guide. The city prioritized schools and open spaces for bicycle paths, therefore increasing ridership of students, tourists, and recreationalists.

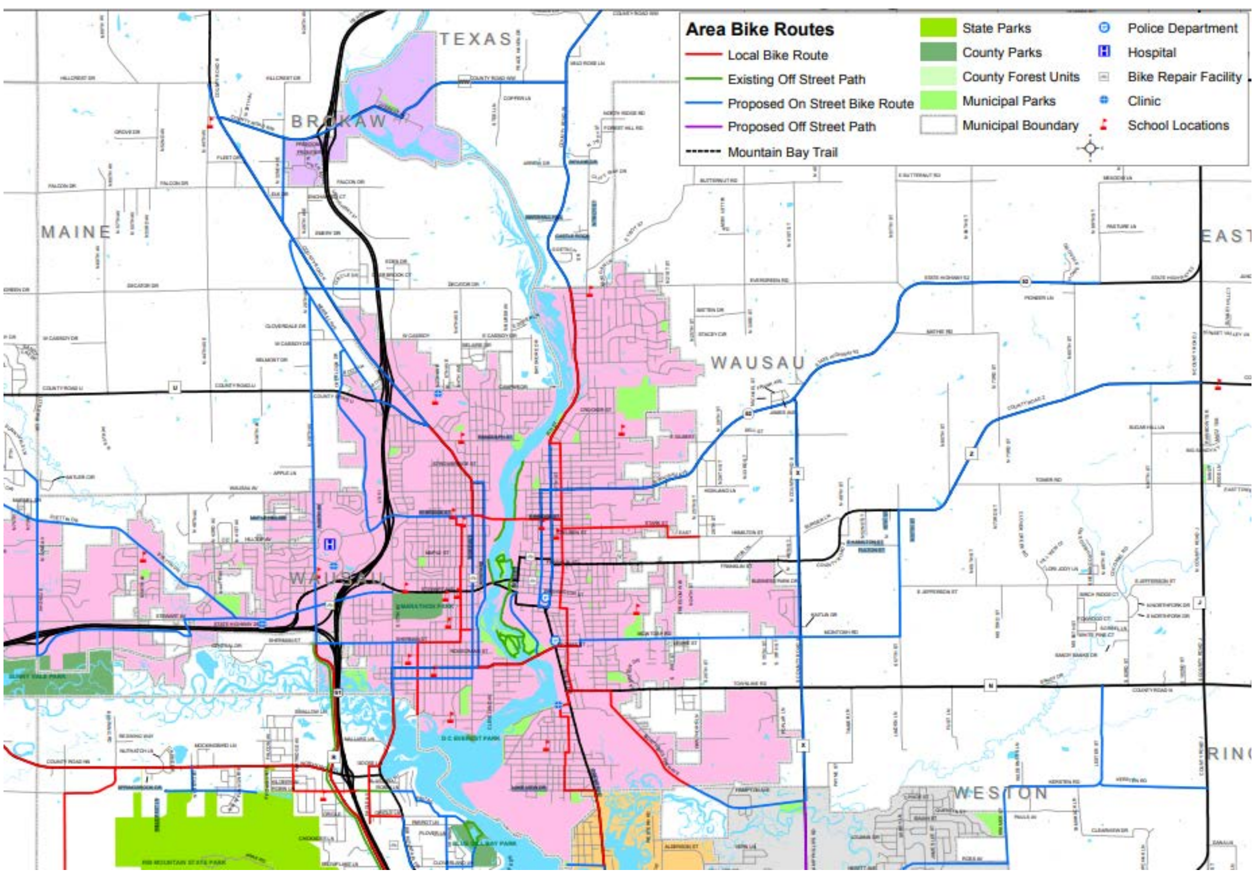



**Figure 7. Bike map of Wausau, Wisconsin.**

Source: Wausau Department of Engineering (2023). Note: Wausau has a population of 39,600 and was rated the best small biking town in the United States.

### 3.1.5 Hurdles to Implementation

Often, bike and pedestrian infrastructure takes space from cars or is viewed as an inconvenience to cars. In addition, the current biking culture in Tonga is under-developed. Community engagement is key to increasing the popularity and political feasibility of such projects.

### 3.1.6 Resilience Impact

Paths, lanes, and sidewalks that lead from low-elevation areas to high-elevation areas will increase the evacuation capacity and therefore resilience of an area.

### 3.1.7 Equity Impact

Walking and biking are two of the least expensive forms of transportation. Therefore, efforts to facilitate them are economically equitable. The planning process (Section 3.1.1) should take accessibility and safety into account. This is particularly helpful for handicapped, youth, and elderly communities. Furthermore, ensuring that infrastructure is safe and well-lit is equitable for female travelers whose commute times and locations tend to be more limited by physical safety issues.

### 3.1.8 Government Revenue Impact

A database of bicycle and pedestrian infrastructure improvement projects and their costs in the United States is available from Bushell et al. (2013). The Tongan or Nukuʻalofa governments would likely be responsible for funding these projects. However, these projects would be appropriate to fund with the Nukuʻalofa paid parking scheme, and funding bike and pedestrian infrastructure would likely increase the popularity of the paid parking policy.

### 3.1.9 Implementation Recommendations

Due to the different travel patterns on Sundays in Tonga, certain roads could be closed to cars on this day and be designated as pedestrian and cycling zones. This pilot project could support broader awareness and acceptance of cycling and walking as viable modes of transport, thus engendering support for cycling and pedestrian infrastructure.

## 3.2 Safe Passing Laws

Safe passing laws require motorists to not come within a certain distance (usually 1 meter) when passing bicyclists. This law is directly enforceable, and it also assigns guilt to the motorist in cases where bicyclists are hit (The League of American Bicyclists 2018).

### 3.2.1 Policy Details

Safe passing laws tend to focus on bicyclists, so they are often paired with vulnerable road user (VRU) protection laws. Vulnerable road users are any road users who are not protected by the shell of a vehicle. These include bicyclists, pedestrians, scooter riders, skateboarders, and more. Vulnerable road user laws include very strong punishments for drivers who seriously injure or kill VRUs. The League of American Bicyclists (2023) has made a model law available that can easily be adopted for different jurisdictions. There are also a number of education programs that complement safe passing and VRU laws. These programs can be adopted into driver education curriculums and driver's licensure tests. One example is the Dutch Reach Project (2023), which teaches drivers to open their door with their right hand and therefore rotate and look for cyclists that might hit their opening door (for Tonga, drivers would open their door with their left hand, because driving occurs on the left side of the road). Another example is the Colorado Bicycle-Friendly Motorist class, which helps motorists understand the nature of bicycle/motor vehicle crashes and how to prevent them (Colorado Department of Transportation 2023a).

### 3.2.2 Intended Result

The intended result of such laws and programs is to increase the safety of VRUs and therefore increase the number of people traveling via microtransit. This, in turn, reduces traffic congestion, fuel use, and emissions.

### 3.2.3 Relationship to Other Proposed Policies

These rules make microtransit safer, which will increase participation in SRTS programs (Section 3.3) and bike- and scooter-share programs (Section 3.4). It will also have synergies with bike and pedestrian infrastructure projects (Section 3.1) and paid parking strategies (Section 2.2).

### 3.2.4 Application in Other Relevant Jurisdictions

Safe passing laws are common throughout North America, Europe, and Australia (Brisbin 2022; Fruhen, Rossen, and Kanse 2021; Schusta 2023).

### 3.2.5 Hurdles to Implementation

Safe passing laws are challenging to enforce. When cyclists report violations, those violations can be difficult to prove. However, the laws at least create a legal framework to protect bicyclists who are hit by vehicles, create a less arbitrary standard, and raise awareness of the importance of safe passing.

### 3.2.6 Resilience Impact

Safe passing laws should increase the number of bike trips. Bicycles can be one of the fastest ways to evacuate short distances, especially when evacuation routes are congested.

### 3.2.7 Equity Impact

Walking and bicycling are two of the least expensive means of transportation. Protecting these modes greatly increases transportation equity.

### 3.2.8 Government Revenue Impact

This law will have minimal impact on government revenue. It can be enforced by traffic patrols that are already deployed. Educational components will be a small addition to currently existing classes and tests, so these will likely have a negligible impact on government revenue.

## 3.3 Safe Routes to School Program

### 3.3.1 Policy Details

SRTS programs empower local schools, parents, children, transportation planners, and community leaders to address barriers to walking or riding bicycles to school. These groups are empowered through financial resources, technical assistance, training, and peer-to-peer learning with other schools. The flexibility of such programs allows them to reduce various barriers such as unsafe traffic, road surface dangers, threats posed by dogs, inclement weather, bicycle theft, and more. Methods range from crossing guards to temporary road closures around the schools

(Pedestrian and Bicycle Information Center 2015). A national-level SRTS program would have a proposal process whereby local schools apply for resources, and the national entity would rank these applications by needs, strengths of proposals, and other factors deemed relevant.

### 3.3.2 Intended Result

The most immediate outcome of an SRTS program is to increase the walking and biking rates of the participant schools while reducing the health risks of such commutes. This can substantially reduce morning traffic, as in the United States around 12% of car trips during morning rush hour are school traffic (U.S. Department of Transportation 2015). Secondary outcomes include increased pedestrian and ridership rates beyond the student population as associated infrastructure expands to the local communities. Other outcomes include the health benefits associated with exercise. Finally, by enabling children to walk or bike to school, habits are engrained that transfer to more adults walking or biking to work in the future.

### 3.3.3 Relationship to Other Proposed Policies

This program should coordinate with the bike and pedestrian infrastructure development policy (Section 3.1). It should also benefit from the safe bicycle passing law and educational programs on driving with cyclists (Section 3.2).

### 3.3.4 Application in Other Relevant Jurisdictions

Odense, Denmark, started the first SRTS program in the late 1970s, and has seen an 82% reduction in the number of accidents in school slow-speed zones (Andersen 1997). From there, the program spread to a number of cities in Denmark, the UK, and the United States. A nongovernmental program in the UK has taken the program a step further and actually restricts cars' access to schools during peak pickup and drop-off hours (Sustrans 2019). The United States nationalized the program in 2005 and provided SRTS funding to state departments of transportation for them to distribute to schools. In 2012, the United States combined the program with a few other similar initiatives and created the Transportation Alternatives Program.

### 3.3.5 Hurdles to Implementation

SRTS programs have to coordinate a wide variety of stakeholders, including students, parents, and neighbors of schools. This can lead to many compromises and slower project implementation. The selection process to determine which schools get funding can be complicated, and steps must be taken to ensure impartiality of the selection board. Weather could be another hurdle to implementation. Some possible ways to overcome this hurdle could be to initially implement this program seasonally, avoiding the rainy season. Another way to address this hurdle would be to allow the children to use school locker rooms before class to change out of wet clothes in the case of rain. Finally, the uniforms of Tongan children (tupenus and skirts) could make it difficult for them to ride bikes to school. This could be countered by adding locker rooms to the schools that enable children to wear shorts or pants when riding, and then change into their uniforms when they arrive at school.

### 3.3.6 Resilience Impact

Children that are dropped off at school by their families cannot depend on them to return to school and evacuate them in a timely manner during an emergency. A school with many students on bicycles and well-established bike routes could be better equipped for a timely evacuation, as significant car traffic often impedes evacuation efforts. However, many schools will likely depend on school buses, with high clearance and high capacity, for evacuation. It is possible that a successful SRTS program would rely less on buses to get students to school and therefore have fewer available for evacuation.

### 3.3.7 Equity Impact

The equity impact of an SRTS program is large because its benefits are bestowed primarily on an underrepresented group: children. It will also be equitably distributed amongst various socioeconomic groups because Tongan schools tend to represent various socioeconomic groups proportionally.

### 3.3.8 Government Revenue Impact

An SRTS program will require government funding, possibly from the paid parking system. While statistics are difficult to find, one award cycle in the United States funded seven schools at nearly $230,000 each (Colorado Department of Transportation 2023b). It is recommended that the selection process prioritizes schools that match funding to a certain degree in order to demonstrate commitment. In-kind contributions from neighborhood associations, children's advocacy groups, bicycle associations, and other related groups can also reduce the cost of the program and signal community support, which often translates to project success.

### 3.3.9 Implementation Recommendations

Sundays in Tonga have atypical travel patterns, with many Tongans attending church. Thus, a safe routes program could be piloted with churches in addition to schools, essentially as a "safe routes to church" program.

## 3.4 Bike- and Scooter-Share Program in Nukuʻalofa

Many of the proposed policies in this section enable and incentivize people to travel to Nukuʻalofa without a car. However, people still need to travel within Nukuʻalofa in order to run errands, eat, and shop. Bike-share and e-scooter-share systems can fill this niche well. They are also appealing to tourists who arrive at the port or ferry terminal.

### 3.4.1 Policy Details

Bike-share systems can be low-tech or high-tech. The low-tech versions have locking docks where the rider swipes their credit card to pay for usage and place a deposit to ensure that they return the bike. High-tech versions utilize geotrackers and a phone application for locating, paying for, and unlocking the bikes. E-scooter-share systems typically use the high-tech version. Two companies that might provide high-tech bike and e-scooter services and support in the Pacific region are Beam (https://www.ridebeam.com/) and Flamingo (https://flamingoscooters.com/).

The government of Tonga or Nukuʻalofa could establish a bike-/scooter-share system themselves following the steps laid out by the Institute for Transportation and Development Policy (2018). A faster and less costly alternative would be to publish a call for proposals from micromobility companies, select a winner, and grant a license to operate in Nukuʻalofa. The license agreement should include restrictions on where bikes and scooters can be placed in order to ensure that sidewalks and roadways are not obstructed. The agreement could also include guidance on how, when, and where the e-bikes and e-scooters are charged. The government also needs to establish traffic rules for e-scooters that apply to rentals and privately owned scooters, as well as standards for e-bike and e-scooter chargers, as discussed in Section 4.3.

### 3.4.2 Intended Result

Shared bikes and e-scooters should enable people to move around Nukuʻalofa quickly and conveniently without a car. This, in turn, should enable people to take alternative modes of transportation into Nukuʻalofa such as the shuttle, bus, ferry, or carpool.

### 3.4.3 Relationship to Other Proposed Policies

The paid parking policy (Section 2.2) will create a financial incentive for people to take alternative modes of transportation, and this policy will increase the convenience of their car-free time in Nukuʻalofa. Therefore, the policy will support all proposals of alternative modes of transportation. The success of this program is dependent on having adequate and safe spaces to ride the bikes and scooters, which will be enhanced by policies to develop robust bicycle and pedestrian infrastructure (Section 3.1) and a safe passing law with education programs (Section 3.2).

### 3.4.4 Application in Other Relevant Jurisdictions

In 2021, there were 1,890 bike-share systems spread across six continents (PBSC Urban Solutions 2021). Global statistics are not readily available for e-scooter-share systems, but in North America there are 191 e-scooter systems—almost as many as the region's 204 bike-share systems (North American Bisheshare & Scootershare Association 2022). The systems in New Zealand and Hawaii might be the most applicable to Tonga. In Hawaii, an e-scooter company is operating in numerous locations despite the fact that policymakers have not addressed electric scooters and they are technically illegal to ride on streets or sidewalks (Rodriguez 2021). Of the nine New Zealand cities with bike- and scooter-share programs, Taupo is the most relevant because it has a similar population and geography as Nukuʻalofa. The city partnered with Beam and has highly regulated the use of scooters. The scooters can only be used on footpaths, between 7:30 a.m. and 10:30 p.m., and have speed limited to 12 km/h (Taupo District Council 2019).

### 3.4.5 Hurdles to Implementation

Safety is a concern with bike and scooter rentals. In order to improve safety, some programs enhance road or path quality, require helmets, limit vehicle speed, restrict where scooters can operate, restrict operation times to daylight hours, make riders aware of rules, and make the drivers of conventional vehicles (CVs) aware of scooter riders. One example of such a program and resource is the U.S. state of Georgia's Scoot Safe campaign (https://www.scootsafega.com/). Fires have occurred when charging low-quality scooter and bike batteries, so it is recommended that only UL-certified batteries and chargers be used (UL Solutions 2023). Many residents consider micromobility programs to be a nuisance due to clutter or pedestrian safety issues. Some ways around these hurdles are limitations on where scooters can be parked, speed governors, or requiring that scooters be ridden in bike lanes or streets rather than sidewalks.

### 3.4.6 Resilience Impact

Shared bikes and scooters can be used for a quick evacuation from Nukuʻalofa before a natural disaster, thereby increasing the resilience of Tonga's transportation system.

### 3.4.7 Equity Impact

Shared bikes and scooters are paid for by the trip or kilometer and require no upfront cost for vehicle purchase. This makes them a good form of transportation for low-income residents. However, bikes and scooters are one of the least handicap-accessible forms of transportation, which makes them unequitable to the disabled population.

### 3.4.8 Government Revenue Impact

Most government-run bike-share systems do not recover their operating costs through membership and user fees, and therefore require government subsidies (Institute for Transportation and Development Policy 2018). However, programs that are outsourced to private companies have nominal capital costs to the government. Nevertheless, in-kind costs such as overseeing the permit review process and enforcing permit requirements and traffic rules need to be accounted for. A breakdown of bike-share system costs and revenues can be found via the Institute for Transportation and Development Policy (2018).

## 3.5 Park and Ride

### 3.5.1 Policy Details

P&R lots are sites where drivers park their vehicle, transfer to another means of transportation, and continue their journey. The lots are typically located at bottlenecks going into cities or other congested destinations. An ideal P&R lot location for people traveling into Nukuʻalofa is at the intersection of Loto Road and Taufa'ahau Road in Pea (Figure 8); 17,000 vehicles pass through this intersection per day, funneling from the entire east side of Tongatapu into Nukuʻalofa. This P&R lot will enable people to park for free in order to complete their trip to Nukuʻalofa via carpool, shuttle, bus, bike, or microtransit. To make the best use of land, solar canopies should be placed over the parking spaces. Shade from the panels also keeps cars cooler, and one study showed a 75% reduction in energy consumption for the initial cooldown period of a vehicle—a savings that substantially increases the range of EVs (Jeffers, Charney, and Rugh 2015).

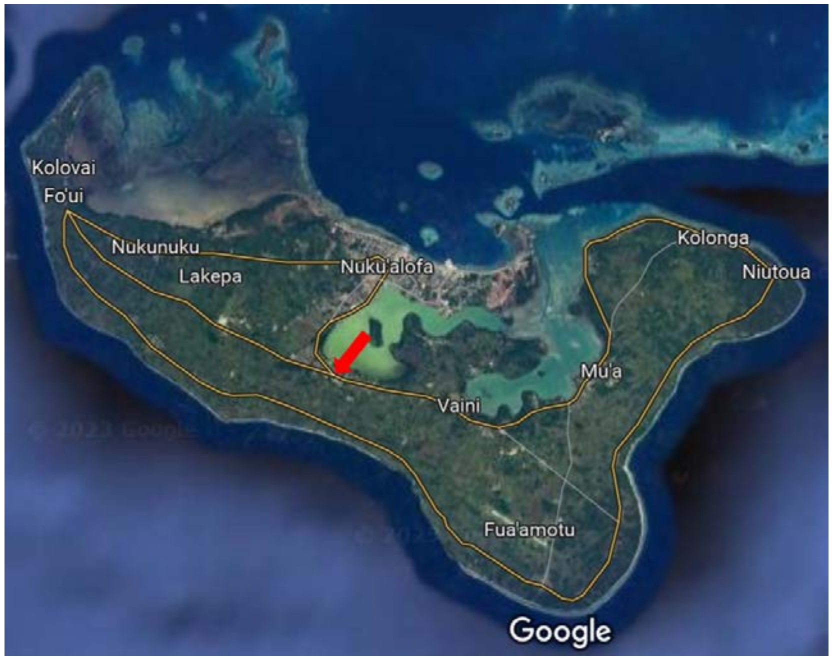



**Figure 8. Location of the proposed P&R lot.**

Source: Google Maps. Imagery © Airbus, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map Data © 2023

### 3.5.2 Intended Result

A P&R lot located in Pea (Figure 8) should reduce the number of vehicles that travel the 6.5 km from there to Nuku‘alofa. This will reduce the parking burden and traffic congestion caused by these vehicles. It will also reduce fuel consumption, GHG emissions, and other air pollutants.

### 3.5.3 Relationship to Other Proposed Policies

The Nuku‘alofa paid parking policy (Section 2.2) will be the primary motivator for people to use the P&R lot to save parking money, as well as the primary source of funds to purchase the land and build the lot. The lot can also be a special designated stop for the on-demand shuttle service (Section 3.7), possibly requiring shuttles to circulate between the lot and set stops in Nuku‘alofa during rush hours. If the lot is large enough, it could utilize the legacy fixed-route buses, thereby giving these bus owners a market share while ceding to the on-demand shuttle service in parts of Tonga with lower population density. This project could also connect with the biking infrastructure (Section 3.1). Furthermore, the people who leave their cars in the lot would be likely to use the shared bikes and scooters in Nuku‘alofa (Section 3.4).

### 3.5.4 Application in Other Relevant Jurisdictions

P&R lots started in the United States in the 1920s (Ortega, Tóth, and Péter 2021) and are now common throughout North America (Sinhasane 2020), Europe (Dijk and Montalvo 2011), Asia (Barter 2010), Australia (PARKnRIDE 2023), and New Zealand (Transfund New Zealand 1999). There is no minimum number of parking spots. Many of the locations offer amenities such as bike lockers, EV charging stations, and rental scooters or bikes.

### 3.5.5 Hurdles to Implementation

Convincing drivers to take the additional time to park, switch modes of transport, and continue their trip to Nukuʻalofa is a major hurdle to implementation. This hurdle can be reduced if transfer time to a ride-share vehicle, shuttle, or bicycle is minimized. Therefore, the shuttles used should be smaller vehicles that fill up more quickly and circulate more frequently. Another way to overcome this hurdle is to make it financially rewarding to use the P&R lot. The paid parking policy and free parking at the P&R lot accomplish this.

### 3.5.6 Resilience Impact

As shown in Figure 6, the intersection of Loto Road and Taufa'ahau Road is less likely to flood compared to downtown Nukuʻalofa. This would substantially reduce the damage from a natural disaster. However, the proposed location is close to a flood plain of the lagoon. The lot becomes safer from flooding as one moves further east on Loto Road. This information must be taken into consideration when procuring land and determining the exact location of the P&R lot. Parking passenger vehicles outside of Nukuʻalofa could clear the downtown roads for higher-occupancy vehicles that can evacuate more people quickly.

### 3.5.7 Equity Impact

The P&R lot will primarily benefit the population of car owners, and therefore have little benefit to disadvantaged communities that might be less likely to own a personal car. However, the reduced traffic and air pollution in between Pea and Nukuʻalofa could benefit disadvantaged communities.

### 3.5.8 Government Revenue Impact

The P&R lot should be free or very inexpensive for those using it. Therefore, it will require government funding. This would be an appropriate project to pay for with the funds from paid parking in Nukuʻalofa.

## 3.6 Ride-Share Coordination Website

### 3.6.1 Policy Details

Ride-share (carpool) involves two or more commuters riding in the same vehicle, and therefore saves each commuter money on fuel, maintenance, and parking. The practice generally utilizes vehicles already owned by commuters and thus requires no additional vehicle purchases. However, many riders have difficulty finding convenient, safe, and pleasant ride-share partners. Setting up a website where commuters can enter their origin, destination, schedule, and willingness to drive has reduced these barriers, and therefore increased ride-share rates, in numerous cities across the world. These websites also provide accountability by sharing people's names and photos, and include rating systems to penalize unsafe or unreliable drivers. Finally, many of these websites provide a payment platform so that the riders can pass on some of their savings to the drivers. Many cities have set up their own websites, while others have adopted global platforms and tailored them to their specific needs.

### 3.6.2 Intended Result

The intended result of a ride-share coordination website is to fill empty seats in vehicles and reduce the number of vehicles required to transport a given number of people. This will save participants money, reduce overall fuel consumption and GHG emissions, reduce traffic congestion, and increase available parking.

### 3.6.3 Relationship to Other Proposed Policies

The paid parking strategy (Section 2.2) greatly increases the financial incentive for commuters to utilize a ride-share coordination website. This website could interface with the smart parking kiosks so that ride-share vehicles get discounted or free parking. It could also compete with the on-demand shuttle service (Section 3.7). However, the two systems could integrate in the future so that the website will direct passengers to either the ride-share service or the on-demand shuttle, depending on which option is the most convenient and economical for the circumstances. From the on-demand shuttle's perspective, the website is a way to service more customers without investing in more vehicles.

### 3.6.4 Application in Other Relevant Jurisdictions

Ride-share coordination websites have been created and maintained by communities, states/provinces, employers, universities, nonprofits, and for-profit companies in all parts of the world since the late 1990s (Chan and Shaheen 2012). One example close to Tonga is the New Zealand website coseats.co.nz. This simple website allows people to post their origin, destination, timing, if they are driving or riding, how much they are willing to pay or a minimum payment required, and their user ratings. This website does not have high fidelity on location or timing but connects people in order for them to discuss the trip details.

### 3.6.5 Hurdles to Implementation

One hurdle to implementation is a rider's need for flexibility in their departure time due to unforeseen circumstances. This is why numerous ride-share programs include a guaranteed ride home to encourage participation (Colorado Department of Transportation 2002). Under such a program, ride-share participants receive travel vouchers that can be used for taxis or rental cars in case of emergency. In most situations, the funding comes from employers whose employees participate in ride-share programs. Another hurdle to implementation is that approximately 22% of working age Tongans (ages 20–64) lack personal internet access, including via a smart phone.[2]

### 3.6.6 Resilience Impact

If all riders are close to one another, this program could facilitate more effective evacuation because it would increase the number of people that are evacuated per vehicle and thus reduce traffic congestion during evacuation. However, if the riders are relatively spread out, this policy could increase evacuation time. It is also possible that the driver will not wait for all passengers before evacuating, decreasing the resilience benefit of the ride-share program.

[2] Per the Tonga Statistics Department (2021), 22% of working age Tongans (ages 20-64) report no smartphones and 24% report no home internet, so the number with neither is likely less than 22%.

### 3.6.7 Equity Impact

Ride-share programs reduce the upfront and operational costs of transportation, therefore increasing the equity of the transportation system. However, the need for internet access is a regressive aspect of the program.

### 3.6.8 Government Revenue Impact

Ride-share coordination websites can be relatively simple and inexpensive, yet effective. They are generally maintained by organizations that already employ web developers, so new hires might not be required. Often, funding comes from nongovernmental organizations such as companies whose employees benefit from the program. Thus, it might be possible for a group of employers in Nukuʻalofa to sponsor such a website.

## 3.7 On-Demand Shuttle Service

### 3.7.1 Policy Details

With a population density of just 146 people per square kilometer (The World Bank 2023b), Tonga might have difficulty supporting a fixed-route bus system that circulates on a frequent basis (Binkovitz 2018). In areas where frequent fixed-route bus service is not a viable option, on-demand shuttle services are becoming an increasingly attractive and economical option. These on-demand shuttles are enabled by new routing technologies developed by companies such as Via, Transloc, Pantonium, and Tripshot. These platforms include algorithms that coordinate the ride requests of multiple riders, each with their individual origins and destinations. Through a phone app, on-demand services can instruct nearby passengers to walk to the same pickup location. They route a vehicle to maximize the number of passengers in a vehicle and minimize wait time and walking distance. Shuttles can be a variety of sizes, including everything from sedans to 40-foot buses, depending on the typical passenger volume. The systems are designed primarily for smartphone users, and thus could be compatible with Tonga's population where 78% (and rising) of working age individuals (ages 20–64) have a smartphone that uses mobile data (Tonga Statistics Department 2021). Accommodations can be made for those without smartphones, including access through websites, text notifications, and by calling dispatch lines (City of Auburn 2023). In portions of Tongatapu that have a population density that can support fixed-route buses, the on-demand software can be used to track buses and coordinate first- and last-mile connections.

### 3.7.2 Intended Result

The intended result of an on-demand shuttle is to increase the convenience and availability, and therefore ridership, of public transit in Tonga. This, in turn, will reduce the per-capita VKT, fuel use, GHG emissions, and traffic.

### 3.7.3 Relationship to Other Proposed Policies

The paid parking policy (Section 2.2) will boost demand for commuters to take the shuttle into Nukuʻalofa. The on-demand shuttle could be one of the paired projects that increases the popularity of the parking policy. The software could be integrated with the ride-share coordination website (Section 3.6).

### 3.7.4 Application in Other Relevant Jurisdictions

Numerous transit agencies across the world are realizing that they can save money while increasing convenience by implementing on-demand shuttles (American Public Transportation Association 2023; ioki 2021; Intelligent Transport 2020). Perhaps one of the most relevant and deeply analyzed jurisdictions for this service is Fort Erie, Canada (Powell et al. 2023). In 2021, Fort Erie (population density of 198 people per square kilometer) replaced their four fixed-route buses (on approximately 1-hour loops) with six minivan shuttles. As shown in Figure 9, many of the pickups and drop-offs occurred far from the retired bus route, indicating increased convenience for existing passengers and an expansion to new passengers.

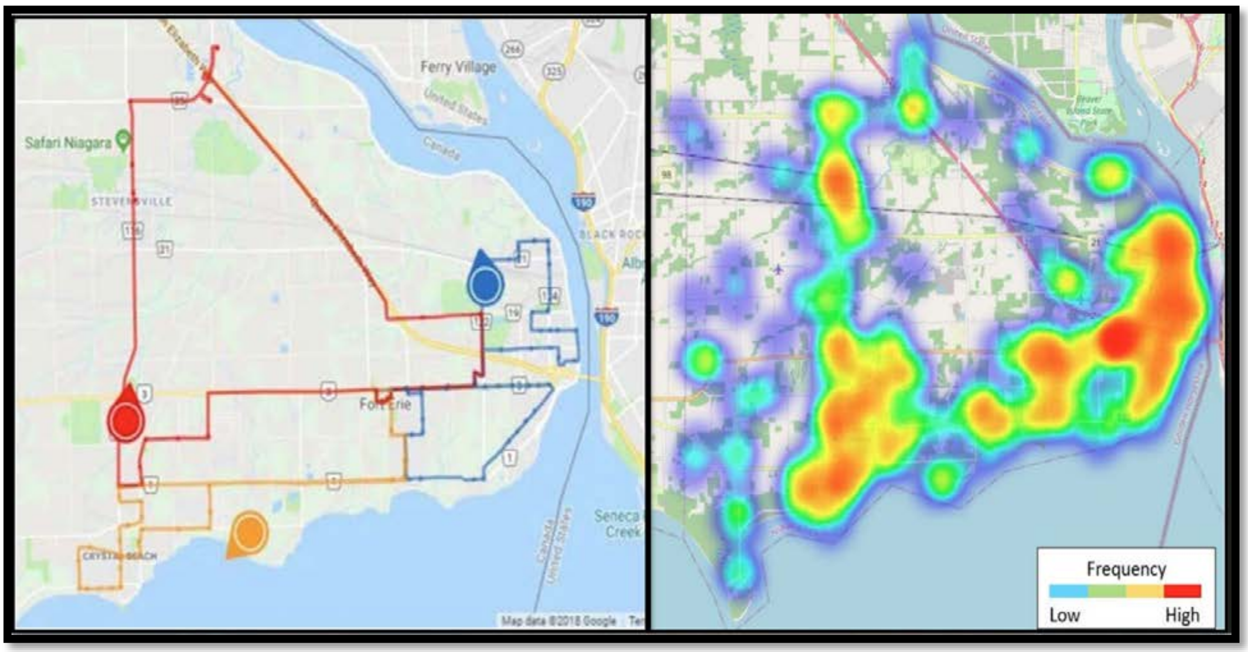



**Figure 9. Former fixed bus routes (left) contrasted by pickup locations of the on-demand shuttles (right) in Fort Erie, Canada.**

Source: Powell et al. (2023). Note: The map of on-demand pickups extends farther south and west than the map of former fixed bus routes. The map of pickup locations closely mirrors the map of drop-off locations.

Although early in its deployment, Fort Erie is already showing some very promising results. Ridership increased from pre-COVID-19 pandemic levels by nearly 90% and was continuing to increase at the time of the report's publication. $CO_2$ emissions per ride decreased by 63%. Per-ride costs to the transit agency reduced from $17.92 USD on the fixed-route system to $12.70, largely due to a reduction in fuel and maintenance costs. Customer feedback was positive, with overall trip satisfaction rated 4.5 out of 5.

### 3.7.5 Hurdles to Implementation

Implementation requires tech-savvy staff to program and maintain the system. It also requires a strong cellular signal of 4G or 5G strength and a large portion[3] of riders to have smartphones (which, as mentioned, is 78% of working age Tongans, although that number is rising quickly). Partnering with a transit company such as Via can reduce many of these hurdles. Another hurdle

[3] The system is most efficient when users book via smartphone instead of calling dispatch.

is that some private bus operators could view on-demand shuttles as competition for their customers. However, these buses and drivers could be incorporated into the on-demand system, which would boost their ridership. Thus, privately operated on-demand shuttles, leveraging the existing drivers, with government regulation could be a viable method for Tonga to implement this policy.

### 3.7.6 Resilience Impact

A system of on-demand shuttles could be helpful for strategically evacuating people before a natural disaster. If the system was programmed to prioritize wheelchair-bound people, it could evacuate more vulnerable populations. It does, however, depend on cellphone towers that are vulnerable to high winds. Tonga should ensure that their cellphone towers are reinforced and that emergency towers are ready to be erected quickly if the original ones are damaged.

### 3.7.7 Equity Impact

On-demand shuttles that are wheelchair accessible greatly improve the mobility of, and opportunities for, disabled citizens. The shuttles are preferable to fixed-route buses with wheelchair lifts because they pick the rider up at a location that is easier for them to get to. However, this system can be economically regressive because it is faster and more user-friendly for riders with smartphones. Therefore, efforts such as setting up and staffing a call line must be made to make the system usable by travelers without smartphones. Finally, on-demand shuttles can be more equitable than fixed routes from an environmental impact perspective because the vehicles tend to drive more, and hence emit more pollutants, in areas where the passengers live rather than routing through neighborhoods where non-passengers live and who are thus exposed to more vehicle emissions.

### 3.7.8 Government Revenue Impact

Investment in shuttles and on-demand hardware and software can be substantial. Furthermore, labor, maintenance, and fuel costs can result in high total operating costs. Generally, such systems charge riders a fee that only covers a fraction of the overall costs. However, it should be noted that the costs of an on-demand system in an area with low population density are lower than the costs of a fixed-route bus system—nearly 30% less per trip in the Fort Erie case study (Powell et al. 2023). This system is even more cost-effective when compared to a combined fixed-route and paratransit system.

# 4 Policies for Safe EVs and Charging

The policies in this section help ensure that EVs and charging infrastructure in Tonga are safe to humans, infrastructure, and the environment. For instance, robust EV charging standards are important to ensure safety, build societal confidence in electric mobility, and increase the effectiveness and reliability of the charging network. Furthermore, there are important health and safety considerations for end-of-life (EOL) EV batteries.

## 4.1 Standards for Mode 3 and Mode 4 Charging

### 4.1.1 Policy Details

PCREEE's draft report *Background on EV Charging Guidelines and Proposed Charging Guidelines for PICS* (Campbell 2022) provides valuable background information on the different charging modes (Modes 1–4). Mode 1 chargers connect to a regular outlet and do not have an in-cable charge controller, Mode 2 chargers connect to a regular outlet and have an in-cord control and protection device, Mode 3 chargers are permanently wired to the supply circuit and connect to the vehicle via tethered or untethered cables, and Mode 4 chargers are permanently wired to the supply circuit and connect to the vehicle via tethered cables. Modes 1–3 supply alternating-current (AC) electricity and Mode 4 supplies direct-current (DC) electricity.

The PCREEE document recommends that the AC Type 2 standard be used for Mode 3 charging and that both the DC CHAdeMO standard and DC Combined Charging System Type 2 standard (CCS2) be used for Mode 4 charging (Campbell 2022). Based on our assessment of Tonga's transportation system, we propose that Tonga consider adopting the AC Type 2 standard for Mode 3 charging and the DC CCS2 standard for Mode 4 charging. Given the large number of used vehicles coming from Japan, consideration can also be given to the CHAdeMO standard for Mode 4 charging in addition to, but not in replacement of, the CCS Type 2 standard. Furthermore, precautions are needed to ensure that EV charging stations of all modes do not introduce harmonic pollution into the grid, which reduces electricity quality and is a problem exacerbated by many cheap charging devices. Adhering to the Institute of Electrical and Electronics Engineers 519 standard can mitigate harmonic pollution.

### 4.1.2 Intended Result

This policy is intended to ensure safe charging and consistent standards throughout Tonga. Adopting uniform Mode 3 and Mode 4 standards will provide clarity for private developers of charging infrastructure and avoid fragmenting the market, which could occur if multiple standards are competing within Tonga. It could be an additional financial and regulatory burden to equip all Mode 4 stations with CHAdeMO charging capabilities in addition to CCS Type 2 connectors, particularly in the early stages of the EV charging market when there are fewer public chargers installed and range anxiety is particularly prevalent for Tongan EV owners. Therefore, the priority could be to first build out a robust network of AC Type 2 and DC CCS Type 2 public charging stations and then subsequently determine whether to equip the stations with additional connectors such as CHAdeMO depending on demand.

### 4.1.3 Relationship to Other Proposed Policies

This policy also relates to the Mode 1 and Mode 2 charging policy described in Section 4.2.

### 4.1.4 Application in Other Relevant Jurisdictions

Both the AC Type 2 and DC CCS Type 2 standards have been adopted in New Zealand and Australia. This is significant because Tonga imports many of its used vehicles from these countries, particularly New Zealand (Joshi et al. 2023). Other countries that have adopted this DC charging standard are shown in Figure 10. Most of the countries that have adopted these standards also have the same electric grid frequency as Tonga (50 Hz).

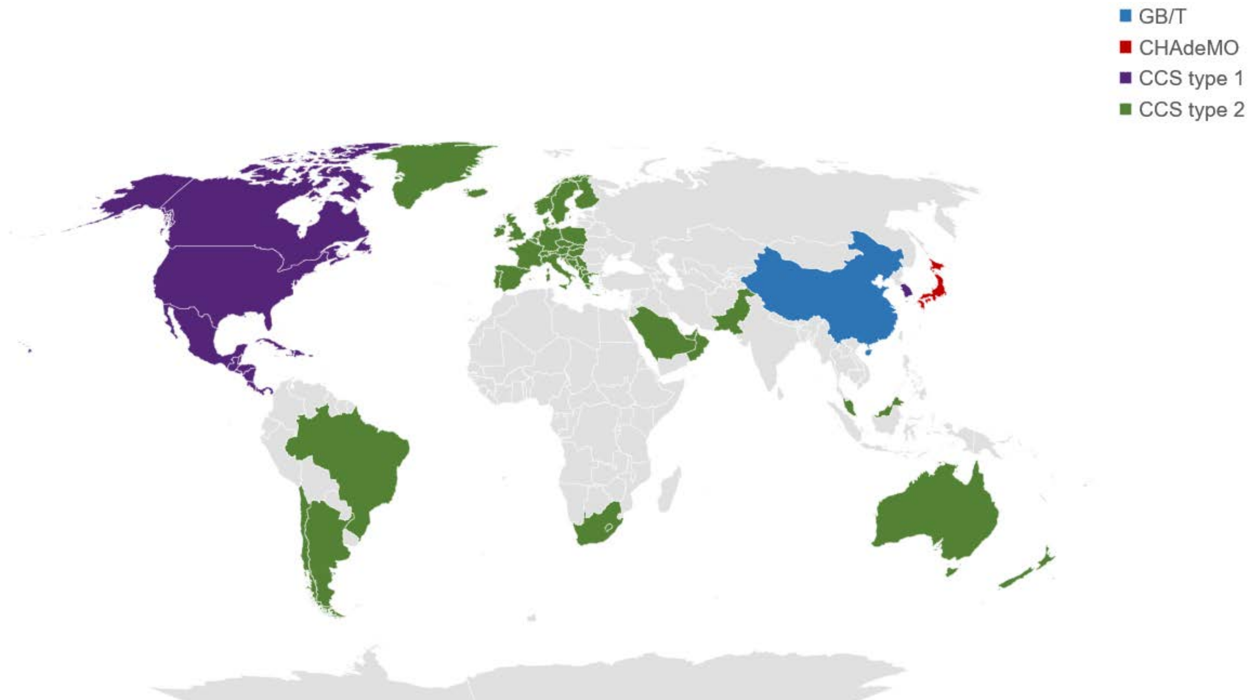



**Figure 10. Predominant DC fast charging connector standards by location.**

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

### 4.1.5 Hurdles to Implementation

EVs imported directly from Japan might only be compatible with the AC Type 1 standard for Mode 3 charging stations and the DC CHAdeMO standard for Mode 4 charging stations. However, used vehicles from Japanese automakers that are imported from New Zealand and Australia will likely comply with the AC Type 2 and DC CCS Type 2 standards. Therefore, it will be important for the government of Tonga to ensure that imports are compatible with the nationwide standard that is adopted.

### 4.1.6 Resilience Impact

Various standards, tests, and installation codes require that charging stations can withstand certain weather conditions, thereby increasing their resilience to cyclones and floods. The International Electrotechnical Commission has a set of tests (IEC 60068-2-XX) for water ingress, heat, cold, vibration, shock, salt mist, and other conditions that EV charging stations could encounter during extreme weather conditions (Experior Laboratories 2023). These tests are not specific to charging stations and can be applied to all modes of chargers. The U.S. National Fire Protection Association's National Electric Code 625.102, which requires charging stations to be installed 2 feet (0.61 meters) high, ensures a certain amount of flood resistance.

Furthermore, some standards improve resilience through cybersecurity. For example, the International Organization for Standardization 15118 standard includes encryption that improves resilience to cyberattacks.

#### 4.1.7 Equity Impact

This policy is assumed to have little to no impact on equity.

#### 4.1.8 Government Revenue Impact

This policy is assumed to have little to no impact on government revenue.

#### 4.1.9 Implementation Recommendations

We suggest that the government of Tonga consider formally adopting the AC Type 2 standard for public Mode 3 stations and DC CCS Type 2 standard for Mode 4 stations as soon as possible, given that this recommendation has also been validated by PCREEE's draft proposed charging guidelines. This will prevent a delay in charging station construction and provide clarity for developers, vehicle manufacturers, and consumers. The government can also consider having CHAdeMO connectors at the Mode 4 charging stations in addition to CCS Type 2 connectors.

### 4.2 Standards for Mode 1 and Mode 2 Charging

#### 4.2.1 Policy Details

In addition to the standards for Mode 3 and Mode 4 charging infrastructure that is installed in fixed locations described in Section 4.1, it is also important to have standards for Mode 1 and Mode 2 portable chargers. Portable chargers are typically included as part of the vehicle purchase and charge the EV at relatively slow rates using AC electricity from typical outlets in garages or other locations. These chargers do not require the costly installation of dedicated and permanently wired charging equipment needed for Mode 3 and Mode 4 chargers. It is important that Tonga only allow the import, sale, and use of portable chargers that are compatible with its electricity supply, which has a nominal frequency of 50 Hz and standard outlet voltage of 240 V. This is also a recommendation outlined in PCREEE's draft proposed charging guidelines (Campbell 2022). Overall, the quality of the imported charging equipment needs to be considered (i.e., "best value") as opposed to cost alone (i.e., "least cost").

#### 4.2.2 Intended Result

This policy is intended to ensure charging safety and prevent damage to electrical systems. If consumers use chargers that are incompatible with Tonga's grid specifications, this could create electrical hazards and subsequently reduce public support for EVs. It might also be unsafe to use an extension cord, plug adapter, or voltage converter for a portable charger that is not compatible with Tonga's electric outlets unless the equipment is specifically approved for this application (Campbell 2022). Therefore, it is preferable to only allow portable chargers that do not require such modifications.

#### 4.2.3 Relationship to Other Proposed Policies

This policy also relates to the Mode 3 and Mode 4 charging policy described in Section 4.1.

### 4.2.4 Application in Other Relevant Jurisdictions

It is important to ensure that any imports of portable chargers meet Tonga's requirements for frequency and voltage compatibility. This is similar to how appliances used in other countries might not be compatible for use in Tonga. Figure 11 is a map of the nominal frequencies and voltages in different countries for such portable appliances. The standard outlet voltage and nominal frequency in Tonga's electricity system is 240 V and 50 Hz, respectively. Thus, appliances used in countries shaded in blue in Figure 11 are generally compatible with Tonga's grid without the use of adaptors.

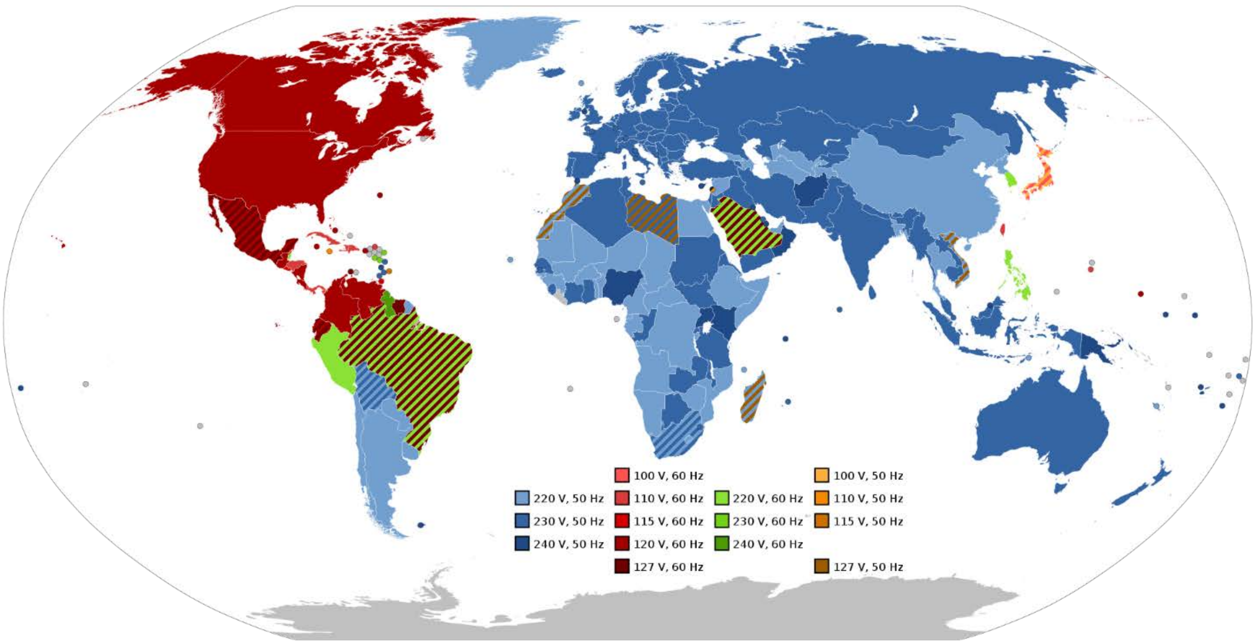



**Figure 11. Map of nominal frequencies and voltages in different countries.**

Source: Wikimedia Commons.

### 4.2.5 Hurdles to Implementation

This policy will require resources for the government of Tonga, such as the Ministry of Revenue and Customs, to inspect imports of portable chargers to ensure grid compatibility. This will also require training so that customs officials can accurately identify incompatible chargers. Because Tonga imports its vehicles, most of which are used, it will be difficult to quality check all imports for compatible chargers.

### 4.2.6 Resilience Impact

Incompatible or poor quality portable EV chargers can damage electric infrastructure and subsequently reduce electricity supply resilience. In addition, many of the same standards, tests, and installation codes mentioned in Section 4.1.6 apply to Mode 1 and Mode 2 equipment.

### 4.2.7 Equity Impact

This policy is assumed to have little to no impact on equity.

### 4.2.8 Government Revenue Impact

This policy is assumed to have little to no impact on government revenue.

### 4.2.9 Implementation Recommendations

Because it could be impractical or infeasible to inspect 100% of EV imports for compatible chargers, we suggest that Tonga subject a certain percentage of imports to more detailed inspections based on what resources the Ministry of Revenue and Customs has available. To supplement these periodic inspections, Tonga could roll out a public awareness campaign to ensure that EV owners are aware of the compatible charging standards and hazards of using possibly incompatible Mode 1 or Mode 2 chargers. In addition to Mode 1 and Mode 2 chargers, this policy could also apply to low-voltage DC chargers for electric bikes and push scooters. Other relevant guidelines for imports, related to chargers and different modes of electric mobility, can be found in the Pacific Region Infrastructure Facility draft report *Electric Vehicle Standards for the Pacific Region* (Campbell and Kim 2023).

## 4.3 Charging Mode Requirements

### 4.3.1 Policy Details

It is valuable for Tonga to specify basic requirements or restrictions for the different charging modes (Modes 1–4). These charging modes are described in greater detail in PCREEE's draft proposed charging guidelines (Campbell 2022) and Campbell and Kim's (2023) draft EV standards. For instance, Mode 1 and Mode 2 charging could only be allowed for private charging in homes or businesses, but the use of Mode 1 charging could be discouraged (see Section 4.3.4). Additionally, private charging could also include Mode 3 stations if the building owner chooses to incur the additional installation and electric panel upgrade costs. This policy suggests that Mode 3 public charging stations allow for untethered charging cables, which can connect to and disconnect from the station and the vehicle at both ends. Untethered charging cables are typically carried with the car, owned by the EV owner, and have plugs on both ends (i.e., one to connect with the charging station and one to connect with the vehicle). Thus, an EV owner in Tonga could have an untethered cable that can connect to the AC Type 2 socket at the Mode 3 public charging station at one end and connect to their vehicle at the other end, regardless of the specific charging standard used by the vehicle (Campbell 2022). Mode 4 public charging stations should only have tethered cables that have a fixed connection to the station, as is standard practice for higher-voltage DC charging. These guidelines are echoed by PCREEE, which also outlines additional suggested requirements for each charging mode in significantly greater detail (Campbell 2022). For microtransit such as electric scooters, we also suggest that the vehicle itself complies with standards such as UL's certification program (UL Solutions 2023). Additional guidelines for electric microtransit, which are charged via low-voltage DC chargers, can be found in the draft EV standards (Campbell and Kim 2023).

### 4.3.2 Intended Result

The restrictions on Mode 1 and Mode 2 charging are intended to ensure public safety. The requirement that Mode 3 charging stations allow for untethered cables is intended to ensure flexibility in vehicles that can be charged in Tonga. Section 4.1 discussed the importance of a consistent standard for Mode 3 charging, such as the AC Type 2 standard adopted by Australia and New Zealand. However, allowing for untethered cables to connect to Mode 3 charging stations can still allow EVs that are not compatible with this standard to charge in Tonga. This flexibility in Mode 3 charging could prove beneficial for a country like Tonga that relies heavily on used vehicle imports. Figure 12 is an image of a Mode 3 charging station with a tethered cable and Figure 13 is an image of a Mode 3 charging station with an untethered cable.

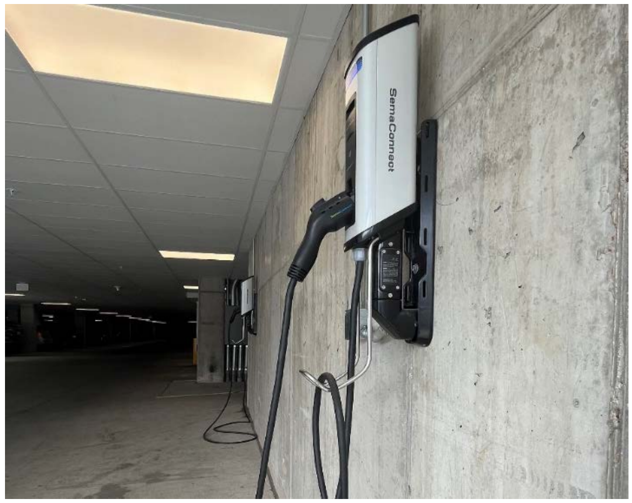



**Figure 12. Mode 3 charging station with a tethered cable.**

Photo by Prateek Joshi, NREL.

**Figure 13. Mode 3 charging station built into a streetlight post with an untethered cable.**

Photo by Prateek Joshi, NREL.

### 4.3.3 Relationship to Other Proposed Policies

This policy also relates to the Mode 3 and Mode 4 charging and Mode 1 and Mode 2 charging policies described in Sections 4.1 and 4.2, respectively. Those two policies describe technical standards that Modes 1–4 charging should comply with, while this policy describes other requirements on how these charging modes could exist and operate within Tonga.

### 4.3.4 Application in Other Relevant Jurisdictions

Mode 1 charging is prohibited in public areas in Italy and subject to restrictions in other European nations such as Switzerland, Denmark, Norway, France, and Germany due to safety concerns, as these chargers lack the "in cord – control and protection device" (IC-CPD) that is present in Mode 2 charging cables. Mode 2 charging is also prohibited in public areas in these jurisdictions due to a preference for permanently wired Mode 3 and Mode 4 stations, which are viewed as safer for public use due to their more robust control and protection functionality (Daze Technology 2021; Arar 2020). Untethered charging for Mode 3 stations, also known as "bring-your-own-cable" charging, are more prevalent in Europe and the United Kingdom but not the norm in the United States (Sanchez 2021).

### 4.3.5 Hurdles to Implementation

Mode 1 charging is banned for light-duty vehicles (LDVs) in certain countries such as the United States, Israel, and England due to safety concerns (Daze Technology 2021). However, if Mode 1 charging is allowed in Tonga, it could be difficult to enforce a requirement that limits its use to private settings. There could also be hurdles to implementing the untethered charging policy for Mode 3 stations, because EV operators would be responsible for carrying their own cable.

### 4.3.6 Resilience Impact

If Mode 3 charging stations operate with untethered cables, this can reduce the likelihood of cable damage at stations during both normal operations and extreme weather conditions.

### 4.3.7 Equity Impact

This policy is assumed to have little to no impact on equity.

### 4.3.8 Government Revenue Impact

This policy is assumed to have little to no impact on government revenue.

### 4.3.9 Implementation Recommendations

As Tonga implements its nationwide charging standards, the government can also specify the aforementioned restrictions on Mode 1 and Mode 2 charging for consumer awareness and requirements for Mode 3 charging for developer awareness. Consumer awareness can be achieved with a public information campaign to promote electromobility, and developer awareness can be achieved by setting construction requirements for EV charging stations. The public information campaign can also inform EV operators on how to charge their vehicles both at public stations and at home, as the procedures for charging with tethered and untethered cables slightly differ.

## 4.4 Battery End-of-Life Planning

When an EV reaches the end of its useful life, proper care must be taken to ensure that the vehicle battery does not end up causing environmental harm or pose a fire risk. If left unhandled or put into a landfill, EV batteries are likely to leach toxic chemicals that can impact soil and groundwater quality. Additionally, if EV batteries are not handled carefully, they can cause a fire that can quickly grow out of control and be very difficult to put out—especially if multiple EOL batteries are stored together improperly. Fortunately, EV batteries hold value for reuse in stationary energy storage applications and recyclers. It is therefore important to establish a policy specifying the proper handling of EOL EV batteries to avoid these consequences and ensure the value of these batteries is not lost.

### 4.4.1 Policy Details

A policy around the handling of EOL EV batteries in Tonga should be focused on ensuring batteries are handled properly and do not result in dangerous battery fires or unmitigated environmental harm through chemical leaching. Policies implemented should focus on three primary areas listed below in order of priority and timeline:

1. Near term: Ensure safe storage of EVs that are no longer in operation and/or EOL batteries that have been removed from the vehicle prior to their reuse or recycling/disposal.
2. Midterm: Identify opportunities for battery second life, such as integration of EOL vehicle batteries into stationary storage projects paired with variable renewable energy generation.
3. Long term: Identify international partners with recycling facilities for shipping agreements to facilitate the offshoring of EOL batteries. Alternatively, coordination across the Pacific Island countries could enable the required scale to sustain the development of centralized EV battery recycling facilities.

### 4.4.2 Relationship to Other Proposed Policies

This policy is directly related to shipping assurance policies (Section 5.1), as batteries will need to be shipped to international partners for EOL handling. It is critical for Tonga to develop shipping agreements and partnerships to handle EOL EV battery disposal and recycling in the near term to midterm to avoid the improper storage or disposal of hazardous battery waste.

### 4.4.3 Application in Other Relevant Jurisdictions

Drive Electric New Zealand has developed a product stewardship program to prioritize a circular economy for batteries including battery registration, tracking of ownership, and eventual reuse and disposal. This plan was developed through collaboration between government and industry stakeholders and is enabled by the development of a "battery passport" that would efficiently track batteries through their lifetime (Drive Electric New Zealand 2023). Direct collaboration with New Zealand on setting standards for battery EOL care can help inform future requirements for EV batteries in Tonga and other Pacific Island countries.

### 4.4.4 Hurdles to Implementation

Battery recycling facilities are expensive to build and operate and require specialized equipment and significant economies of scale for effective operation. Therefore, until these capabilities can be developed and coordinated across the Pacific Island countries, shipping EOL batteries to other countries in the region who are developing recycling facilities in the near term will be the best option (e.g., New Zealand, Australia, Japan, etc.). However, EOL batteries can be seen as a risk for shipping companies, and it may be difficult and expensive to develop an agreement.

### 4.4.5 Resilience Impact

Improper handling of EOL batteries can result in environmental damage and risk of catastrophic battery fires. Implementation of policies requiring safe and proper storage and shipment of batteries can reduce these risks, especially within the context of natural disasters.

### 4.4.6 Equity Impact

Chemical leaching into groundwater due to the improper handling of EOL batteries could lead to health consequences and environmental damage. These impacts would disproportionately impact communities living near battery storage sites.

### 4.4.7 Government Revenue Impact

Establishing guidance and policy around the proper disposal of EOL batteries in Tonga will be a cost to the government. However, in the long term, the proper handling of EOL batteries can reduce the risk of fire and environmental impacts that could require significant government funding for recovery or mitigation.

### 4.4.8 Implementation Recommendations

Policies regarding EOL batteries in Tonga can be developed in coordination with other Pacific Island countries to determine efficient and effective paths toward the proper treatment of EOL batteries for the region. This could involve standardization of a battery passport, development of centralized recycling facilities, and group contracting with international shipping partners.

# 5 Policies for Accessible EVs and Charging

There are currently very few EVs in Tonga, and the policies in this section can help ensure that EVs and charging infrastructure are accessible to more Tongans. Policies related to EVs could include a few different vehicle types (Figure 14).

Full battery-electric vehicles (BEVs) run only on electricity, have relatively large batteries, and can be charged using high-powered DC fast chargers. Plug-in hybrid EVs have smaller batteries that still offer some amount of electric-only driving range and can be plugged in to charge, but also have a small gasoline tank with which they can be driven similar to a hybrid electric vehicle. Hybrid EVs have a very small battery that is charged using regenerative braking, cannot be plugged in to charge, and are powered primarily by an internal combustion engine using liquid gasoline or diesel fuel. This analysis refers to BEVs and plug-in hybrid EVs together as EVs, a term that typically includes vehicles that can be plugged in for charging (and therefore excludes hybrid electric vehicles). These vehicle types are compared to gasoline- or diesel-fueled conventional vehicles (CVs), which do not include a battery connected to the powertrain. Electric two- and three-wheelers are only available as BEVs.

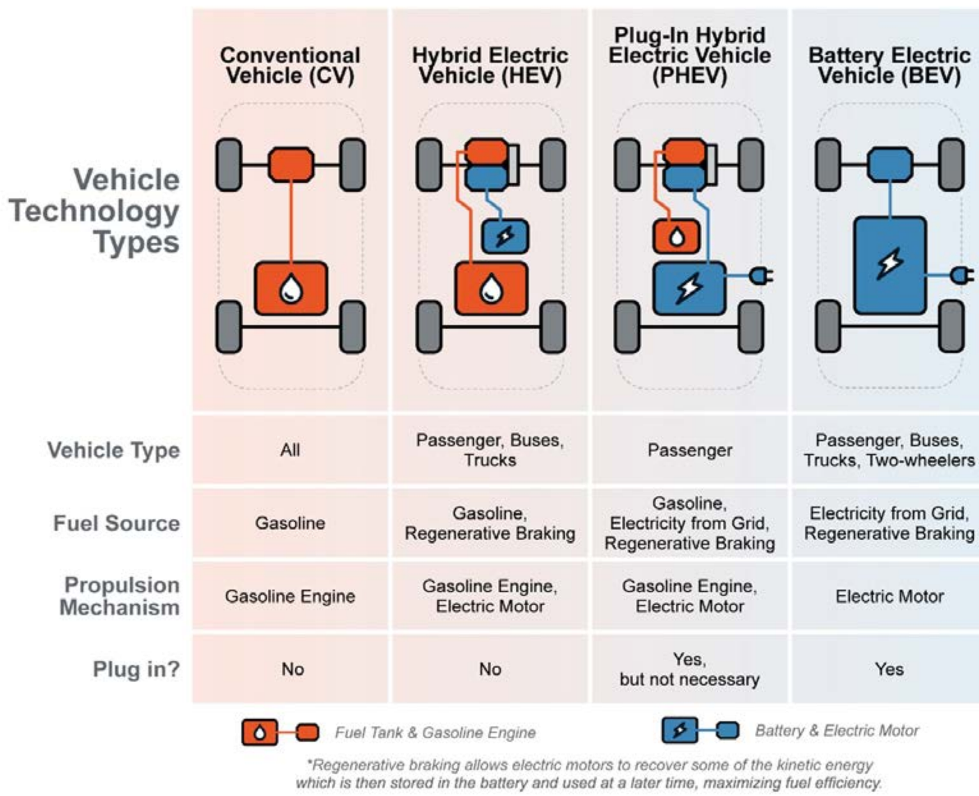



**Figure 14. Overview and comparison of EV technology powertrain types.**

Illustration by Christopher Schwing, NREL.

## 5.1 EV Shipping Assurances and Precautions

### 5.1.1 Policy Details

The current shipping companies that deliver vehicles to Tonga may be hesitant to ship EVs at scale due to risks associated with shipping EV batteries. While there are legitimate concerns related to shipping EVs, there are methods to reduce the risks, highlighted by AIG (2023) and the American Bureau of Shipping (2022). Additionally, as EV adoption grows worldwide, shipping companies will continue to develop best practices for shipping these vehicles safely and further reduce the associated risk.

A condensed version of the AIG and American Bureau of Shipping guides starts with ensuring that the EVs be certified safe for transport according to the United Nations *Manual of Tests and Criteria*. Secondly, the shipper must include documentation that the EVs, batteries, or cells have passed tests (done by an accredited laboratory) prescribed in Section 38.3 of its *Manual on Transport of Dangerous Goods* (United Nations 2023). Next, it is important to nominate a dangerous goods specialist who has completed the training to conduct pre-shipment surveys of the vehicles, among other things. This survey should confirm that the battery state of charge is less than 50% and that battery temperatures are not 5°C above ambient temperature. Greater caution must be taken with older EVs and EOL batteries. Training of personnel for the careful handling of EVs and EV batteries can also help reduce the risk of fire during loading and unloading of ships.

### 5.1.2 Relationship to Other Proposed Policies

Additional shipping agreements for EOL batteries would be valuable, and this topic is discussed further in Section 4.4.

### 5.1.3 Application in Other Relevant Jurisdictions

EVs are being shipped internationally in greater numbers as adoption of the technology steadily grows. Island nations with growing EV adoption such as New Zealand are successfully importing EVs at scale.

### 5.1.4 Hurdles to Implementation

It may be difficult to negotiate terms for EV shipments in the near future. However, these challenges may reduce over time as the number of EVs shipped around the world continues to grow.

### 5.1.5 Resilience Impact

Policies to enable shipping of EVs can help ensure EVs are available for purchase and delivered in a timely manner to enable diversification of vehicles and transportation fuels in Tonga.

### 5.1.6 Equity Impact

This policy will have a minimal impact on equity.

### 5.1.7 Government Revenue Impact

If EV shipping is significantly more expensive, shipping agreements may represent a cost to the government to ensure reasonable pricing for EVs as compared to CVs.

### 5.1.8 Implementation Recommendations

Implementation of this policy will require direct contracting with shipping companies to facilitate the reliable shipment of EVs to Tonga. The details of policy implementation will be driven by negotiation of those contracts.

## 5.2 EV Education Programs

### 5.2.1 Policy Details

EVs are a relatively new technology for most consumers around the world. Awareness of this technology, how it operates, and its ability to replace the CVs that people have driven their entire lives is therefore critical to enabling widespread adoption. A review of studies examining consumer awareness programs for EVs found that they are a "key part of supporting the growth in the early EV market" and many of the findings showed a lack of understanding of the important benefits of EVs for many of the survey participants (Jin and Slowik 2017). Increased awareness of these benefits, and how to overcome adoption hurdles, can grow the base of potential buyers who would consider an EV for their next purchase.

Education events can take multiple forms, the most common and effective of which is a ride-and-drive event where the public can come and see EVs, take them for test drives, and ask questions of volunteer owners or officials with EV knowledge (Figure 15). These events give participants a chance to learn how EV ownership could fit their lifestyle, and studies show that regular ride-and-drive events result in more information passed by word of mouth and as many as 15% of attendees purchasing an EV within 6 months of the event (Jin and Slowik 2017). PCREEE Policy Action 10 highlights ride-and-drive events, public exposure for EVs, and the provision of educational materials on EV costs, promotional policies, charging, and EV ownership as key aspects of a successful introduction of the technology to Pacific Island nations.

**Figure 15. An EV ride-and-drive event in Colorado.**

Photo by Dennis Schroeder, NREL.

Other forms of education are also important, including training for workers in the auto industry. Auto dealers, maintenance workers, and emergency personnel should all have dedicated training programs to prepare them for local growth in EV adoption. TEEMP places a priority on sending Tongan maintenance workers to EV training programs in other countries such as Japan as an important step in developing Tongan domestic capabilities at the outset of the nation's focus on EV growth. These capabilities could also be developed through offering EV maintenance courses and a certification program at the Tonga National University, which already has a vehicle mechanics trade certificate program. PCREEE is also developing a renewable energy and energy efficiency course, which could integrate aspects of EV-specific knowledge.

#### 5.2.2 Intended Result

These policies are intended to spread awareness and knowledge of the benefits of EV adoption for Tonga—both at the level of individual ownership and societal spillover benefits. Educational programs are an extremely cost-efficient method of increasing EV adoption, especially in the early stages.

#### 5.2.3 Relationship to Other Proposed Policies

These educational programs are a key component contributing to the success of the other policies related to EVs and charging infrastructure because they ensure that the public is aware of the policies and their operation. Also, the presence of public charging infrastructure and clear signage can raise public awareness of EV deployment. Finally, increasing EV maintenance capabilities in Tonga can reduce insurance pricing, reduce risks associated with damaged EVs and batteries, and increase vehicle reliability.

#### 5.2.4 Application in Other Relevant Jurisdictions

Barbados has developed their own EV maintenance courses for training workers in-country (Viscidi et al. 2020). Additional details about types of programs set up in locations around the world are summarized in Figure 16.

| Region | Information and tools | | | | | Public events | | Exposure to EVs from fleets | | | | | Regional planning | | Consumer awareness campaigns | Youth education and professional development | Awards and recognitions | Auto dealer awareness activities | Consistent Signage and labeling |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | General information | Cost comparison | Public charger location | Incentives | Model availability | Ride and drive | EV showcase | Public fleet | Government fleet | Carsharing/Rental cars | Company cars | Tourism | Action plan/Initiative | Demonstration projects | | | | | |
| Germany | x | x | x | x | x | x | x | x | x | x | x | | x | x | | x | x | x | |
| Netherlands | x | x | x | x | | x | x | x | x | x | x | | x | x | | x | | | |
| Norway | x | x | x | x | x | | | x | x | x | x | | x | x | | | | | |
| United Kingdom | x | x | x | x | x | x | x | x | x | x | x | | x | x | x | x | | | |
| California | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | x | x | x | x |
| Oregon | x | x | x | x | x | | x | x | x | x | x | x | x | x | | x | x | x | x |
| Northeast U.S. States | x | x | x | x | x | x | x | x | x | x | | x | x | x | x | | x | x | |
| British Columbia | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Québec | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Beijing | | | | | | | x | x | x | x | | | x | | | | | | |
| Shanghai | | | | | | x | x | x | x | x | | | x | x | | | | | |

**Figure 16. Consumer awareness programs in locations around the world with high EV adoption.**

Source: Jin and Slowik (2017). Licensed under a Creative Commons CC BY-SA 4.0 License. No changes made.

### 5.2.5 Hurdles to Implementation

Ride-and-drive events require current EV owners to give people rides in their EVs. This requirement is a hurdle right now in Tonga, where very few EVs exist. Perhaps the first ride-and-drive events should be held by a vehicle dealership, Tongan government ministry, or another organization that has the incentive, mission, and technical expertise to be a first adopter of EVs. Subsequent ride-and-drive events should be able to garner EVs since most ride-and-drive events have found that EV drivers and enthusiasts readily participate in ride-and-drive events for free.

### 5.2.6 Resilience Impact

Expertise in EVs is critical for ensuring their continued reliability for island operations, especially bringing knowledge of EV maintenance to Tonga. This will better allow owners to protect their vehicles during natural disasters and mechanics to repair them after natural disasters.

### 5.2.7 Equity Impact

Disadvantaged or low-income communities are less likely to have exposure to EVs, as historically EV buyers have been overwhelmingly high-income and highly educated homeowners with access to home charging (Hardman et al. 2021). Therefore, education programs such as those described in this section are critical to disseminate knowledge about the benefits of EVs, the funding available to offset the costs, and other types of EV-related policies.

### 5.2.8 Government Revenue Impact

Assuming that early adopters will be willing volunteers at ride-and-drive events, there will be a minimal impact on government revenue from these programs.

### 5.2.9 Implementation Recommendations

Education events should start with a general awareness campaign and then could transition to ride-and-drive events once there are EVs available in government fleets or offered voluntarily by private owners. Also, as government vehicles become electrified (especially transit), the vehicles should be clearly labeled outside and contain additional information for reading on placards inside. These are particularly low-cost options to raise awareness of EV technology.

## 5.3 Charging Station Placement

### 5.3.1 Policy Details

For public Mode 3 and Mode 4 chargers, Tonga can prioritize installations on the island of Tongatapu, first at government buildings and then in public spaces (e.g., offices, gas stations, shopping centers, etc.). The proposed parking strategy described in Section 2.2 could create more vehicle charging demand in downtown Nukuʻalofa. Thus, public Mode 3 and Mode 4 chargers can be prioritized at popular parking destinations, leveraging the traffic count data developed for TEEMP. In Nukuʻalofa, battery swapping stations in high-traffic areas can also satisfy charging demand from low-voltage e-mobility (e.g., two-wheelers) and microtransit (e.g., electric scooters). After Tongatapu, which is the largest and most populous island in Tonga, the government can extend the network to the island groups of Vava'u and Ha'apai. For the outer islands, solar photovoltaics (PV) powering off-grid charging stations could be better-suited solutions if there is insufficient electric grid capacity or if there is a predominance of low-voltage mobility options such as two-wheelers or electric scooters. Finally, Tonga can require new buildings with parking facilities to be "EV-ready" by ensuring sufficient capacity at switchboards and easy routes for cabling.

### 5.3.2 Intended Result

This policy is intended to help Tonga fulfill some of its goals in the TERMPLUS document: EV chargers installed at government buildings by 2025, an EV charger network across Tongatapu, chargers in strategic locations for the Vava'u and Ha'apai islands by 2030, and EV chargers in other outer islands by 2035. Furthermore, TERMPLUS encourages support for battery swapping stations for low-voltage e-mobility in addition to Mode 3 and Mode 4 public charging stations.

### 5.3.3 Relationship to Other Proposed Policies

This policy relates to the Nukuʻalofa parking strategy described in Section 2.2 because that strategy could influence potential locations for charging infrastructure in the capital city. This policy also relates to the policy on charging incentives described in Section 6.4 because incentives could differ based on charging station type and location.

### 5.3.4 Application in Other Relevant Jurisdictions

Astypalaia is a Greek island that is initially piloting EVs and associated EV infrastructure in government fleets and buildings (Joshi et al. 2023). The Cook Islands government is doing the same and is also interested in solar-PV-powered off-grid charging stations for its more remote areas (Joshi et al. 2023). Taiwan has been a pioneer in battery swap technology for two-wheelers, with many Gogoro stations located throughout the island's densely populated cities (Figure 17). Many jurisdictions, including California and the United Kingdom, are including "EV-ready" requirements in their new construction codes (Salcido, Tillou, and Franconi 2021; Dent 2021).


**Figure 17. Gogoro battery swap station in Taichung City, Taiwan.**

Photo by Prateek Joshi, NREL.

### 5.3.5 Hurdles to Implementation

Having economically viable EV charging stations in a variety of locations will require enough charging demand from a sufficient number of EVs among both the public and private vehicle fleet. Furthermore, battery swap stations might not be an appropriate option for Tonga if there is not a sufficient market for two-wheelers. Building codes that contain "EV-ready" requirements could increase construction costs. Finally, once the EV market is more mature, the additional load on the grid might require infrastructure upgrades.

### 5.3.6 Resilience Impact

Solar-PV-powered off-grid charging stations in Tonga's outer islands and rural areas, especially if paired with stationary battery storage, can increase the resilience of electric mobility in those parts of the country because the infrastructure might not be impacted by damage to the main electric grid. Also, buildings with charging infrastructure could potentially benefit from the backup energy source provided by connected EV batteries (e.g., vehicle-to-building capabilities described in Section 7.4). Furthermore, locating charging stations along evacuation corridors can increase their accessibility during evacuation events and bolster the overall resilience of the country's transportation system (Johnson et al. 2022).

### 5.3.7 Equity Impact

Ensuring that EV chargers are built in the outer islands of Tonga and rural areas increases equity by extending access to charging for those communities. Furthermore, providing charging services for low-voltage mobility, micromobility, or two-wheelers in the form of battery swap stations, for example, increases access to lower-cost forms of electric transport for Tongans.

### 5.3.8 Government Revenue Impact

"EV-ready" requirements in building codes could increase construction costs, including at new government facilities. However, charging stations hosted by government facilities, if open to the public, could provide a minor source of increased revenue.

### 5.3.9 Implementation Recommendations

The Tongan government can codify this charging station location policy package in an official strategy document, which could serve as the basis for guiding decision-making on this topic. The government can also implement this strategy by providing incentives or subsidies for charging stations in certain locations, described further in Section 6.4. By starting with EV chargers at government buildings, Tonga's ministries can become more familiar with the infrastructure and take advantage of their investment by simultaneously electrifying their fleets (this would also enable EV education efforts such as ride-and-drive events, described further in Section 5.2). These government sites can serve as pilot projects and kick off investment in the charging network to enable greater private EV adoption. These pilot sites could also inform charging station development in other locations throughout the country. For Tonga, other relevant locations could include Fua'amotu International Airport, Vuna Wharf, the Western Bus Terminal, Vaiola Hospital, the Royal Tombs area, a potential future P&R lot (Section 3.5), and major churches. All these locations, particularly the airport, wharf, and hospital, could have sufficient existing electrical capacity or require fewer upgrades compared to other locations.

# 6 Policies for Affordable EVs and Charging

Once access to EVs and charging is established and safe, they need to be made more affordable in order to facilitate large-scale adoption. This is because one of the largest hurdles to EV adoption is the difference in purchase price, with four-wheeled EVs costing significantly more than equivalent gasoline-fueled models due to the relatively high price of the lithium-ion battery. With battery prices falling rapidly over the past decade, this price difference has also decreased. In some markets, EV two-wheelers cost less than conventional two-wheelers (International Energy Agency IEA 2021). The price difference for four-wheelers is projected to continue falling due to economies of scale, advances in battery chemistry, and improvements in battery manufacturing technology. While projections previously anticipated the price of EVs would fall to be equivalent to CV prices by 2025, the price of battery packs increased globally for the first time in 2022 due to rising material costs and other production issues partly driven by the COVID-19 pandemic (Figure 18). With added uncertainty in the battery supply chain, the future trend in battery prices could be similarly volatile. Increased EV adoption could therefore continue to benefit from policies that help lower their purchase price.

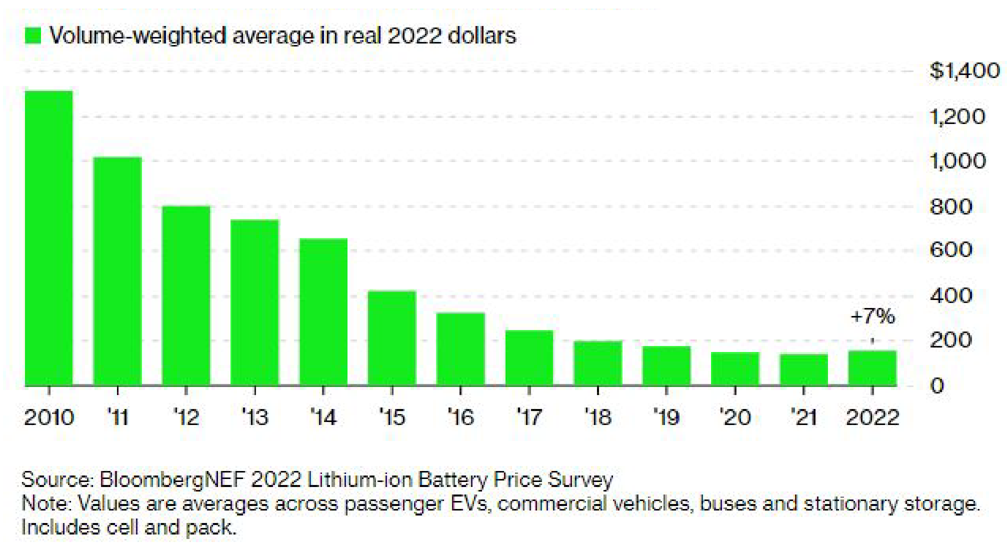



**Figure 18. Estimated average global lithium-ion battery prices for EVs over time.**

Source: BloombergNEF (2022).

Even though the total cost of ownership is already lower for EVs in most markets, the higher upfront cost is a significant impediment to EV market development. Furthermore, most nations with a robust EV market implement policies to further encourage EV sales.

With a target of 10% new light-duty vehicle sales to be EVs and a 30% improvement in fuel economy by 2030 (U.N. Climate Technology Centre & Network 2020), it will be important for Tonga to implement policies in the near term that incentivize the purchase of EVs and make charging more affordable. These policies for affordable EVs and charging, as well as the policies in Section 5 on accessibility, are directly linked to the electrification targets set in TEEMP for LDVs, medium- and heavy-duty trucks, public transit, and the government fleet. Setting those targets at a national scale can help all stakeholders plan for the pace of vehicle adoption and charging station deployment that the federal government is aiming for, and the implementation and scaling of policies around EV adoption should also be aligned to match those targets.

## 6.1 Waiving Vehicle Import or Registration Fees

### 6.1.1 Policy Details

As a separate fee on top of the vehicle purchase price, import or registration fees represent a useful mechanism for reducing the price of purchasing an EV. Implementing a policy that would waive or reduce these fees would result in a more immediate reduction in the price of EVs for the buyer without the complication of applying for a rebate or adding complexity to tax filing at the end of the year. The immediacy of the price reduction can be particularly important for making these vehicles available to low-income buyers, who may have less ability to pay a large lump sum at the time of purchase. However, the downside of this policy is its inflexibility, as the amount of the price reduction is limited by the maximum amount of the existing fees that can be waived. Precautions should be taken to ensure that qualifying EVs have enough remaining useful life. These could include, in order of increasing accuracy: vehicle age limitations, odometer limitations, remaining life estimates from a battery degradation tool, or streamlined battery testing (Carey and Lienert 2023). A screenshot of results from NREL's Battery Lifetime Analysis and Simulation Tool (NREL 2023) is shown in Figure 19. A graded structure to registration fees based on relative vehicle emissions could be implemented as described in the previous section and shown in Table 1.

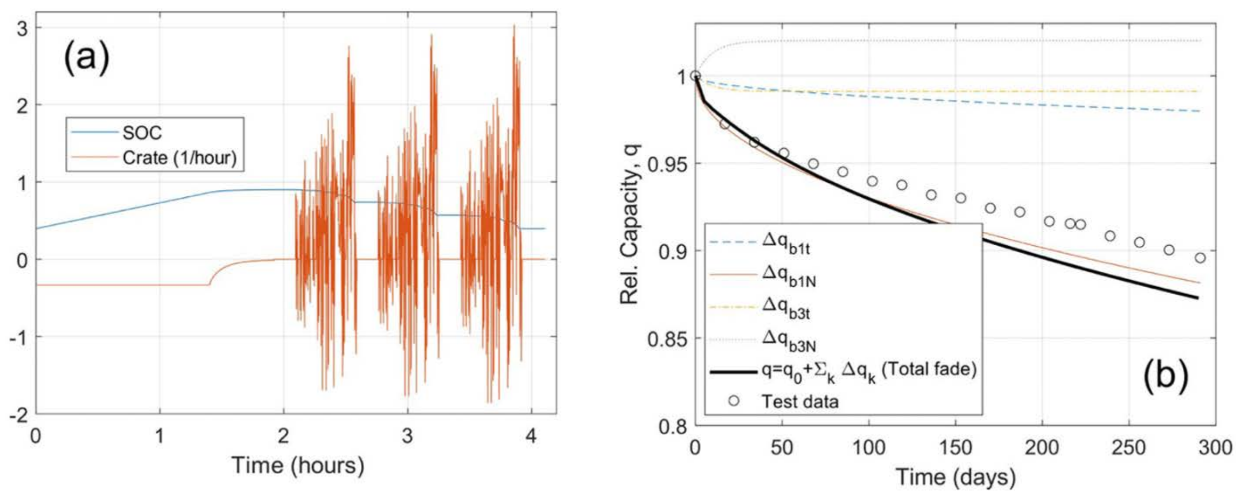



**Figure 19. Screenshot from NREL's Battery Lifetime Analysis and Simulation Tool.**

### 6.1.2 Intended Result

The outcome of this policy is to reduce the purchase price of EVs to incentivize EV adoption. This policy might be selected over policies based on tax credits or rebates to ensure the price reduction is more immediate and simplified for the customer.

### 6.1.3 Relationship to Other Proposed Policies

These policies can be used in tandem with other vehicle price reduction policies, such as those presented in Section 6.2, to further reduce the upfront cost of EV purchases.

### 6.1.4 Application in Other Relevant Jurisdictions

Vehicle registration fees for EVs are waived on Prince Edward Island, resulting in an annual savings of $74 USD (Maritime Electric 2022). Fiji has implemented a policy that lowers the vehicle import fee for EVs as long as the vehicle is less than 5 years old (Joshi et al. 2023). BEVs in the Philippines are exempt from excise taxes, and hybrid EVs are subject to a 50% reduction (IEA 2023).

### 6.1.5 Hurdles to Implementation

If this policy is not accompanied by a fee on high-emission vehicles (as part of a "feebate" policy), it could represent a significant reduction in net revenue to the government. There may also be unintended impacts related to lowering the barrier of bringing additional vehicles into the country. Applying a "remaining life" restriction for vehicles to qualify for this benefit could reduce the risk of too many vehicles being imported to Tonga that are close to EOL and need to be disposed of relatively quickly.

### 6.1.6 Resilience Impact

This policy has the same resilience impact as other EV incentives.

### 6.1.7 Equity Impact

A fee waiver is a potentially more equitable implementation of a price reduction policy than the tax credit or rebate policies from Section 6.2. The fee waiver reduces the upfront price at the time of purchase, making it more accessible for drivers with less disposable income available, whereas for the tax credits, the benefits are seen later and the full price of the EV is still required at the time of purchase.

This policy could also be implemented with an income qualification requirement where EV purchases by individuals above a given level of income would not qualify for fee waivers. However, this may need to be implemented at a later time as early EV adopters are likely to be relatively high income. The requirements that ensure EVs have a minimum remaining battery life will reduce the risk that low-income residents lose money by purchasing an EV that reaches EOL sooner than expected.

### 6.1.8 Government Revenue Impact

Similar to the other policies centered on EV purchase price reduction (Section 6.2), this could be implemented in tandem with a fee on high-emission vehicles to reduce the government cost burden and potentially make the policy revenue neutral. Furthermore, the requirement to prove the remaining life of the EV could potentially reduce cumulative disposal costs that might otherwise be borne by the government.

### 6.1.9 Implementation Recommendations

The waiver of vehicle registration or import fees is recommended as a targeted policy for specific groups that would benefit most from a vehicle price reduction, such as drivers with high annual VKT and low income. It also represents an additional mechanism for upfront EV cost of ownership reductions that can be used in tandem with other policies if needed and as appropriate based on the vehicles registered annually.

## 6.2 EV Tax Credit or Purchase Rebate (With Feebate)

### 6.2.1 Policy Details

#### *Subsidy: Income Tax Credit*

A tax credit for the purchase of an EV is a commonly used mechanism in countries around the world for reducing the cost of an EV purchase. The policy can be structured in tiers based on potential emissions reduction by vehicle type, with higher tax credits for the purchase of BEVs, a smaller credit for plug-in hybrid EV purchases, and the lowest credit for hybrid electric vehicles. Variable amounts can also be applied based on how old the vehicle is, with a higher credit allocated to new vehicle purchases compared to used purchases. The credit can be claimed by the buyer when they file their tax return for the year the vehicle is purchased and is implemented as a reduction on their tax bill for that year. This policy can also be designed so it is allocated to the auto dealer (who will benefit when they file their taxes for the year), and the buyer receives an upfront price reduction for the vehicle at the time of purchase. Receiving the tax credit upfront has proven to increase EV sales more than if the purchaser has to wait until they file taxes to receive it (Narrassimhan and Johnson 2018).

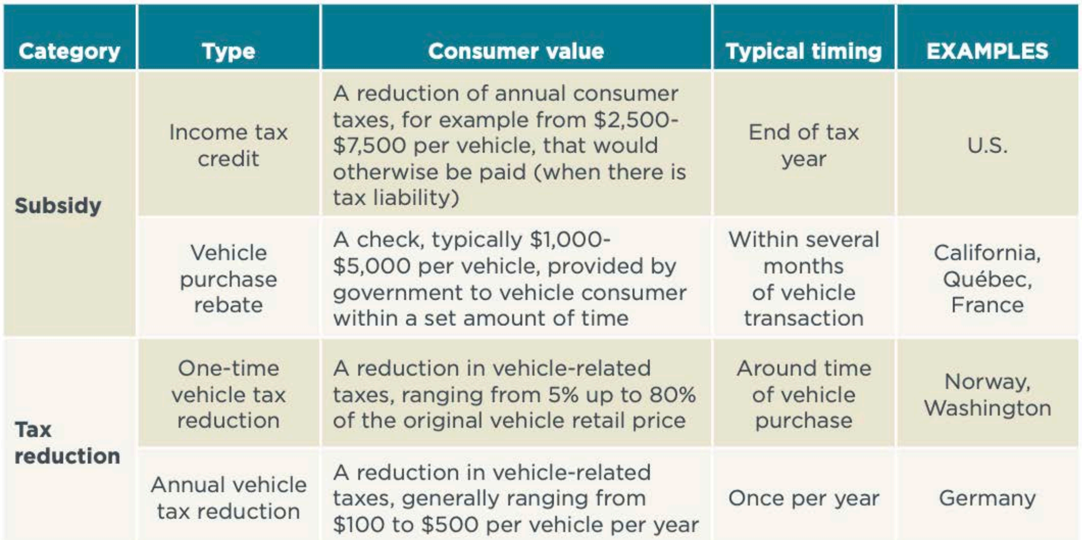
#### *Subsidy: Purchase Rebate*

An alternative method of reducing the purchase price of EVs is to provide a direct rebate to the buyer to reduce the upfront cost. The structure of this policy is similar to the income tax credit described previously, with different rebate amounts offered based on the EV type and the vehicle age (new or used). However, the consumer benefit is delivered much sooner, depending on how quickly the rebate is filed and can be fulfilled. Therefore, a rebate can be a more effective policy for reducing the upfront purchase price of an EV. The income tax credit and the purchase rebate make up the two options laid out in the subsidy section of Figure 20.

#### *Tax Reduction*

The types of policies in the tax reduction section of Figure 20 are less commonly implemented but can provide some relief for EV buyers. Policies in a few regions, including Norway and Washington, focus on a reduction in the tax that would normally be applied directly to the vehicle purchase. These are reviewed within the context of reductions on import or registration fees in Tonga in the next section.

Finally, while most tax credit programs follow some variation of a one-time exchange of value based on a tax reduction or rebate, Germany has a program that reduces the annual taxes paid on the vehicle, and the vehicle owner sees these benefits over time. However, that structure does not help reduce the high upfront cost of the vehicle, which is still a significant hurdle to EV adoption.



| Category | Type | Consumer value | Typical timing | EXAMPLES |
|---|---|---|---|---|
| Subsidy | Income tax credit | A reduction of annual consumer taxes, for example from $2,500-$7,500 per vehicle, that would otherwise be paid (when there is tax liability) | End of tax year | U.S. |
| | Vehicle purchase rebate | A check, typically $1,000-$5,000 per vehicle, provided by government to vehicle consumer within a set amount of time | Within several months of vehicle transaction | California, Québec, France |
| Tax reduction | One-time vehicle tax reduction | A reduction in vehicle-related taxes, ranging from 5% up to 80% of the original vehicle retail price | Around time of vehicle purchase | Norway, Washington |
| | Annual vehicle tax reduction | A reduction in vehicle-related taxes, generally ranging from $100 to $500 per vehicle per year | Once per year | Germany |

**Figure 20. An overview of the different categories of vehicle price reduction policies that can be implemented with variations in the mechanism and timing.**

Source: Yang et al. (2016). Licensed under a Creative Commons CC BY-SA 4.0 License. No changes made.

### *Feebate*

The feebate, outlined in Section 2.1, can be designed to provide a powerful upfront incentive to purchase EVs. The incentive increases as the assumed emissions from an EV reduce. As outlined in Section 2.1, this could track Tonga's current electricity fuel mix, 2025 target of 70% renewables, or 2035 target of 100% renewables.

### *Fee Structuring*

The share of the baseline tax imposed on each vehicle can also be graded to the relative emissions intensity of the individual vehicle being imported. An example of how this policy might be structured is shown in Table 1, starting at a baseline assumption of a 20% tax on vehicle purchases. The exact discounts for each vehicle type will differ from this example and could also evolve over time as the types of vehicles being imported change to ensure that the government revenue derived from vehicle taxes does not decline significantly over time. Additional tax reductions can be driven by vehicle weight, which is a rough measure of vehicle efficiency beyond the emissions standard and powertrain category. Differentiating between these tax brackets must be a relatively easy task for customs to complete when the vehicle is imported. This structure could be implemented with any of the mechanisms described in this section (income tax credit, purchase rebate, tax reduction, or feebate).

**Table 1. Example Graded Structure for Vehicle Registration Fees**

| Vehicle Purchased | Baseline Tax | <1,500 kg Curb Weight |
|---|---|---|
| CV – no emission standard | 20% | 18% |
| CV – EURO IV emission standard | 15% | 13% |
| CV – EURO V emission standard | 12% | 10% |
| Hybrid electric vehicle | 10% | 8% |
| Plug-in hybrid electric vehicle | 5% | 3% |
| BEV | 0% | 0% |

### 6.2.2 Intended Result

These types of policies are intended to incentivize the uptake of vehicles that produce lower emissions by reducing their relatively high purchase price. If implemented as a feebate program (as described in Section 2.1), these policies will also disincentivize the purchase of vehicles with particularly high emissions through additional fees. The balance of these price reductions and fees should result in similar purchase prices for EVs as compared to similarly styled CVs. Using the feebate structure, the policy should also mostly pay for itself, with the fees providing the funding for the tax credit.

### 6.2.3 Relationship to Other Proposed Policies

This policy is built on the feebate proposed in Section 2.1. It also enables the more rapid uptake of EVs, which results in a more attractive business case for the installation of new public EV chargers. This relationship between EV adoption and charger installation is mutually beneficial, with EVs also becoming more attractive for vehicle owners as more public charging becomes available.

### 6.2.4 Application in Other Relevant Jurisdictions

See Section 2.1.4 for an overview of other regions that have implemented a feebate program. An income tax credit policy is active in the United States, while Japan, Singapore, New Zealand, and France (among others) have a cash rebate program for EV purchases (IEA 2023).

### 6.2.5 Hurdles to Implementation

As discussed in Section 2.1.5, individuals who purchase vehicles with high emissions might be displeased by the additional fees on top of the original vehicle price. Also, setting the tax credits such that the policy truly pays for itself can be difficult as the balance between EV and non-EV sales changes over time. Therefore, EV incentives need to be periodically reviewed and phased out as the cost of EVs reduces to parity with CVs.

### 6.2.6 Resilience Impact

Higher EV adoption will help increase investment in public charging stations, making the whole network more useful and resilient to localized issues. At higher shares of renewable energy production in the electricity grid, EVs can become a more resilient alternative to gasoline and diesel fuels. Import of these fuels can be disrupted by weather, and prices can fluctuate significantly based on international dynamics. Furthermore, EVs can be charged at vehicle owners' homes, giving greater flexibility than vehicles reliant on public fueling stations. EVs can be used to power critical electrical appliances during power outages, as described in Section 7.4. Finally, some EVs are waterproofed in ways that CVs are unable to be and therefore provide critical transportation services during flooding events (IEA 2023).

### 6.2.7 Equity Impact

Lowering the upfront cost of EVs for consumers can make them more affordable for any buyer considering EV ownership. With lower operating and maintenance costs than comparable CVs (Burnham et al. 2021), EVs can have a significantly lower cost of ownership over their lifetime, especially for an individual who drives more than average. However, large purchases are particularly difficult for low-income households with less flexibility to save up even with financing. Lowering that initial price burden can potentially make these vehicles affordable for those households who could benefit most from their reduced total cost of ownership (Bauer, Hsu, and Lutsey 2021).

This policy could also be implemented with an income qualification requirement where EV purchases by individuals above a given level of income would not qualify for tax credits or purchase rebates. This has been done in the United States (Internal Revenue Service 2023). However, this may need to be implemented at a later time as early EV adopters are likely to be relatively high income. Another way to make these credits more equitable is to ensure that they apply to used EVs.

### 6.2.8 Government Revenue Impact

Funding for this policy can be raised through a feebate, with fees collected on high-emission vehicles purchased while the policy is active, as described in Section 2.1.8. As more EVs and fewer high-emission vehicles are purchased, the amount of the credit or rebate can be reduced over time and eventually phased out, especially as the purchase prices of EVs fall. If carefully implemented such that the annual fee revenue from high-emission vehicle sales is approximately equivalent to the tax credit provided for EV sales, this policy should have a minimal impact on government revenue.

## 6.3 Charging Station Business Model Incubator

### 6.3.1 Policy Details

There are different business models for owners and operators of charging stations, including the government, Tonga Power Limited, and private companies. For instance, the utility could be the full owner and operator of the charger, it could contract with a private business to operate the charger while retaining ownership, or it could sell electricity to a separate entity that owns and operates the charger (Bopp, Zinaman, and Lee 2020). Private firms could also act as charging network companies, in which they own and/or operate a larger group of charging stations and associated digital infrastructure for communications and payment. These business models could generate revenue via different payment structures or a combination thereof, such as energy fees, peak demand fees, time-based fees, and membership fees (with associated benefits for members). Furthermore, facilities that host charging stations (e.g., hotels, shopping malls, grocery stores, restaurants, etc.) could also see indirect revenue from EV operators that visit while their vehicle is charging. Battery swap stations, also discussed in Sections 5.3 and 6.4, can be viable if there is a sufficient stock of low-voltage mobility or micromobility vehicles such as electric scooters or two-wheelers. Finally, encouraging or mandating that EV fleet operators open their chargers to the public when not in use could serve as an additional revenue stream for companies that manage vehicle fleets and increase public charger capacity. The government of Tonga can encourage this diversity of business models by setting up an incubator and supplying seed funding, competition prices, and/or consultation services.

### 6.3.2 Intended Result

This policy is intended to help Tonga fulfill some of its goals in TERMPLUS: EV chargers installed at government buildings by 2025, an EV charger network across Tongatapu and chargers in strategic locations for the Vava'u and Ha'apai islands by 2030, and EV chargers in other outer islands by 2035.

### 6.3.3 Relationship to Other Proposed Policies

This policy relates to the charging station placement policy package discussed in Section 5.3 and the charging station incentives policy package discussed in Section 6.4. Both the location of a charging station and the level of incentives provided can impact the success of different business models.

### 6.3.4 Application in Other Relevant Jurisdictions

The Alternative Fuels Data Center, hosted by the U.S. Department of Energy, contains data on charging stations throughout the United States and Canada, including charging mode, station ownership, and location type. Figure 21 is a map of stations that have ownership data available. The vast majority of stations with this attribute data are privately owned, though there are stations that are owned by the federal government, state/provincial governments, local/municipal governments, and utilities. The Hertz Corporation, a U.S.-based rental car company, is an example of a fleet owner that is engaging in public-private partnerships to build EV chargers that can simultaneously serve its fleet and the public in cities such as Denver (Taylor 2023).

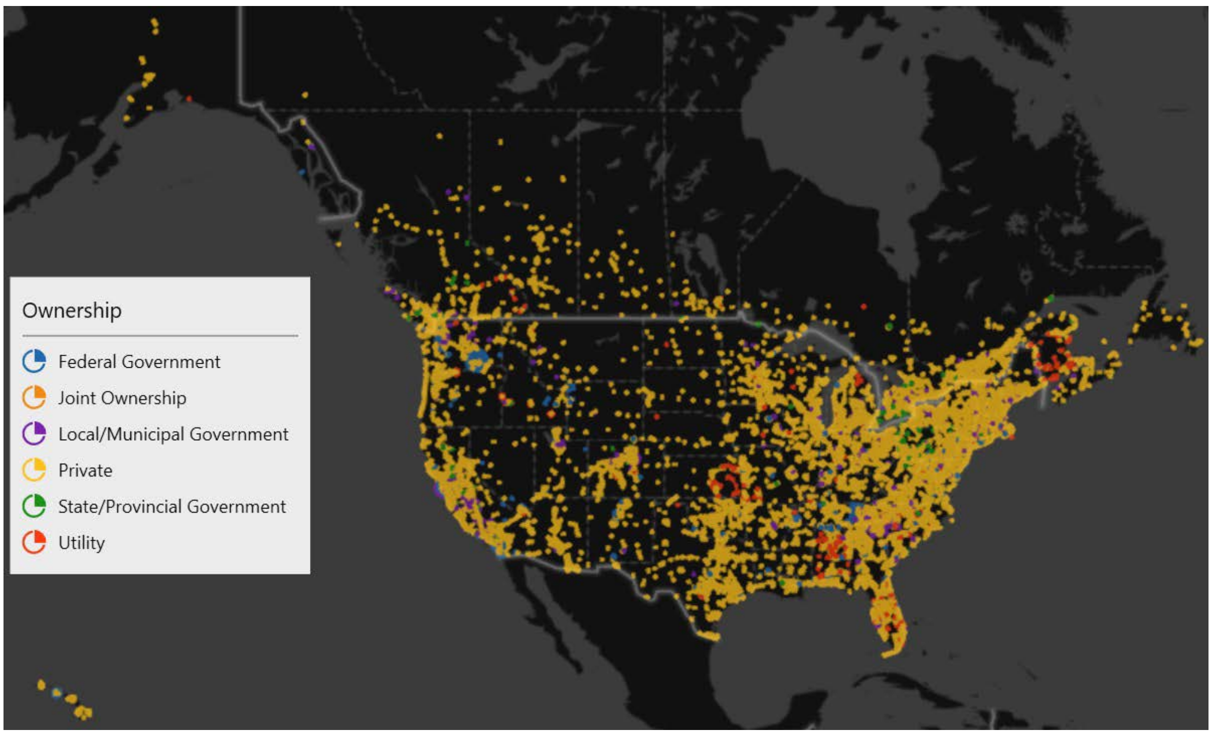



**Figure 21. EV charging stations by ownership in the United States and Canada.**

Data from the Alternative Fuels Data Center; only includes stations with ownership data available.

### 6.3.5 Hurdles to Implementation

For any of the proposed charging station business models to be successful in Tonga, the country needs a domestic EV market and sufficient EVs on the road to generate charging demand, which can be facilitated by this policy framework. For EV fleets that open their chargers to the public, there is a risk that fleets might not have adequate charging capabilities, and those stations might not be able to effectively serve the public if poorly planned.

### 6.3.6 Resilience Impact

This policy will increase the number of charging stations and the redundancy of charging infrastructure. The business incubator, if pursued, can also place a priority on resilient business plans in its judging factors.

### 6.3.7 Equity Impact

This policy is assumed to have little to no impact on equity.

### 6.3.8 Government Revenue Impact

If the charging stations are owned by the government or the state-owned utility, different business models may impact the revenue generated by the facility.

### 6.3.9 Implementation Recommendations

The government's role could be piloting different business models at their own facilities or increasing awareness of these opportunities within the private sector. Relevant ministries, including Tonga Power Limited, could also embark on public-private partnerships to build EV chargers, similar to Hertz Corporation's partnership with the city of Denver. Avis Car Rental is another large international rental car company, and because it operates in Tonga, it might be interested in a partnership with the government on investing in charging infrastructure. The utilization rate of a charging station is one of the most important components of its business model and should therefore be a main focus for owners and operators. Planners, developers, and other relevant stakeholders in Tonga could also use and adapt NREL's free and publicly available Electric Vehicle Infrastructure – Financial Analysis Scenario Tool (EVI-FAST; [nrel.gov/transportation/evi-fast.html](nrel.gov/transportation/evi-fast.html)) to model the financial viability of different business models. If the government of Tonga decides to pursue a business model incubator approach, it could model its program off one developed to support small- and medium-sized enterprises in Pakistan (PFAN 2023).

## 6.4 Charging Station Incentives

### 6.4.1 Policy Details

Hosting an EV charging station can be a profitable business plan in the long run, but many entrepreneurs are hesitant to invest. Charging station incentives, which vary widely, can reduce this hesitancy. To jump-start the EV market in Tonga, the government could subsidize the initial set of stations at government buildings and in outer islands where commercial interest might be lower, offer special tariffs for EV charging including at battery swap stations, and allow independent companies to build and operate charging stations.

### 6.4.2 Intended Result

This policy is intended to help Tonga fulfill some of its goals in TERMPLUS: EV chargers installed at government buildings by 2025, an EV charger network across Tongatapu and chargers in strategic locations for the Vava'u and Ha'apai islands by 2030, and EV chargers in other outer islands by 2035.

### 6.4.3 Relationship to Other Proposed Policies

The suggested charging station incentives help support the proposed charging station placement policies described in Section 5.3 and align with the policy to reduce the cost of public charging for consumers, described in Section 6.7.

### 6.4.4 Application in Other Relevant Jurisdictions

The Caribbean island nation of Barbados has successfully deployed many charging stations by allowing independent companies to own and operate these facilities, ensuring that the EV charging service is not in the exclusive domain of the national electric utility (Joshi et al. 2023). Hawaii has established a robust rebate program to partially cover the construction costs of charging stations (Joshi et al. 2023).

### 6.4.5 Hurdles to Implementation

Providing subsidies for EV charging station construction or offering reduced rates for EV charging could require significant financial resources, depending on the level of government support.

### 6.4.6 Resilience Impact

This policy will increase the number of EV charging stations and therefore add redundancy to the charging network, thereby improving resilience.

### 6.4.7 Equity Impact

Subsidizing charging stations in the outer islands of Tonga where commercial interest might be lower can help increase equity by increasing access to charging services.

### 6.4.8 Government Revenue Impact

Government support for EV charging stations would reduce government revenue.

### 6.4.9 Implementation Recommendations

Tonga could follow the model set by Barbados and classify EV charging activities as an "access service" as opposed to a strictly "electricity delivery service." An "electricity delivery service" interpretation for EV charging would likely mean that owning and operating EV chargers would fall in the exclusive domain of the national electric utility, Tonga Power Limited. This is the case in many of Barbados' Caribbean island neighbors. On the other hand, an "access service" interpretation would allow other companies to own and operate EV chargers, purchasing the electricity from Tonga Power Limited at wholesale levels and selling it to customers as a retailer. This is the standard practice in Barbados, which has led to a significant buildout of stations across the island (Joshi et al. 2023). If there are financial constraints on the level of rebates that the government can provide for charging station construction, it can prioritize these for government facilities and in areas with less commercial interest, in alignment with the strategy discussed in Section 5.3.

## 6.5 EV Insurance Pricing

### 6.5.1 Policy Details

Currently, EV purchase prices are higher than the price of comparable CVs. Additionally, as a new technology with less support in terms of maintenance knowledge and availability of parts, some vehicle repairs could be more costly. While the prices of EVs are expected to continue to fall, in the near term, insurance companies may respond by imposing higher rates for EVs. While insurance is uncommon for private vehicle owners in Tonga, vehicle fleets (such as Tonga Power) are more likely to purchase insurance. Consideration should therefore be given to pricing of EV insurance so that policy premiums are not pricing these fleets out of EV purchases. Some possible strategies to explore include:

1. Federal mandates for insurance companies to make sure they cover EVs at reasonable rates, similar to CVs. This could result in higher overall insurance rates if steps to reduce EV repair/replacement costs are not taken, and therefore all insurance policies would subsidize the increased EV costs.
2. Dealer assurances to keep repair/replacement costs below a certain level, even before the market is large enough to justify keeping spare parts nearby.
3. Mechanic training programs for EVs could alleviate insurance companies' concerns of high repair costs.

It is worth noting that with less regular maintenance required for a typical EV, it is possible that insurance for EVs will become cheaper than CV insurance in the long term.

### 6.5.2 Relationship to Other Proposed Policies

This policy is directly related to policies reducing the total purchase price of EVs for individual owners who are intending to purchase insurance for their vehicle (Sections 6.1 and 6.2), fleet owners purchasing vehicles in bulk who want their fleet insured (Section 6.6), and education around EVs, specifically for developing EV maintenance knowledge in Tonga to reduce uncertainty around repair costs (Section 5.2).

### 6.5.3 Application in Other Relevant Jurisdictions

Insurance pricing policies have not been enacted in other locations.

### 6.5.4 Hurdles to Implementation

It could be difficult to price insurance appropriately when EV adoption is low and estimates for EV maintenance costs are highly uncertain. This policy may also impact the price of insurance for all customers, resulting in some resistance for non-EV owners who see an increase in their insurance payments.

### 6.5.5 Resilience Impact

Insurance can help vehicles stay maintained and operate effectively for the duration of their expected lifetime. This is especially important for EVs as a mechanism to diversify vehicle fuel sources during natural disasters.

### 6.5.6 Equity Impact

This policy is assumed to have little to no impact on equity.

### 6.5.7 Government Revenue Impact

This policy will not impact government revenue significantly, aside from potential changes in the average price of vehicle insurance.

### 6.5.8 Implementation Recommendations

Implementation of an EV insurance policy should be prioritized based on the needs of fleets to accommodate the continued reliable operation of their vehicles. It should also be coordinated with education programs focused on developing maintenance capabilities for EVs in Tonga.

## 6.6 Bulk Vehicle Purchase Incentives

### 6.6.1 Policy Details

This policy would result in a discount on a per-vehicle basis for EVs purchased in bulk. For example, five or more vehicles purchased by a single entity could qualify for this discount. While this incentive would be primarily paid for by the government, auto dealers could benefit from the guarantee of multiple vehicle sales. Therefore, the Tongan government could collaborate with auto dealers to implement and pay for this policy. Likely candidates for this policy include government vehicles, Tonga Power, taxis/buses (if operated by a centralized owner), and rental fleets (e.g., Avis).

Vehicle fleets are a great candidate for early electrification for a few reasons. First, fleets can coordinate the purchase of both vehicles and charging infrastructure, therefore solving the issue of vehicles waiting for EV charging stations and vice versa. Second, fleet vehicles are typically driven farther on average (as much as 100% more VKT annually) than privately owned vehicles (Davis and Boundy 2022). To ensure these benefits are realized, electrifying vehicle fleets should therefore be prioritized to maximize local pollutant reductions, carbon emission reductions, and other external benefits such as noise reductions. While fleet owners typically have greater purchasing power than individuals, adding a bulk purchase incentive can help make a more rapid fleet transition possible and attractive for fleet operators.

Fleet electrification can also have spillover benefits that could incentivize electrification of non-fleet vehicles. Fleet vehicles are typically more visible to the population and used more frequently, helping to educate people on EVs as a viable powertrain for cars. Fleet electrification also requires the installation of new charging stations that will be highly utilized, setting the stage for further growth of the local charging network. Requirements should be attached to any fleet benefits that they will make their EV charging stations available to the public.

In contrast to the fleet incentive described above, a bulk purchase incentive policy could also apply to a group purchase of vehicles by individual consumers, a mechanism known as "cooperative purchasing." This would be facilitated by a local auto dealer who would then be responsible for coordinating the sale to multiple buyers. However, these types of policies have so far only been implemented in the United States (Javed 2022).

### 6.6.2 Intended Result

This policy would help incentivize a more rapid transition to electrified vehicle fleets. These are the highest-priority vehicles to electrify because of their high utilization and potential for centralized charging (requiring a less comprehensive network of chargers). If implemented in a manner that could facilitate a group purchase, this policy would also incentivize a more rapid adoption of EVs for individual Tongans. The amount of incentive provided for bulk purchases could vary based on the age of the vehicles purchased and the type of powertrain (BEV, plug-in hybrid electric vehicle, or hybrid electric vehicle), with the incentive provided for group purchases varying for each buyer depending on their specific vehicle.

### 6.6.3 Relationship to Other Proposed Policies

This is related to the on-demand shuttle service (Section 3.7) by having the potential to target these high-utilization fleet vehicles. This policy can also build on price reductions implemented through other policies.

### 6.6.4 Application in Other Relevant Jurisdictions

Fiji implemented a subsidy of $5,000 per vehicle for businesses purchasing five or more EVs, in addition to any other price reduction policies (Joshi et al. 2023).

### 6.6.5 Hurdles to Implementation

One of the largest hurdles to implementing this incentive is identifying stakeholders interested in bulk EV purchases in the early phases of EV adoption. Until EV technology is proven at scale within Tonga, there will likely be skepticism regarding their efficacy in replacing CVs. However, as EV adoption grows, that skepticism will decrease. Introducing more Tongans to EVs through educational programs or the electrification of highly visible vehicles such as public transit can help speed up the widespread acceptance of vehicle electrification.

### 6.6.6 Resilience Impact

Bulk purchases could be linked to island resilience through an increased familiarity with EV operation and maintenance. Businesses making bulk purchases of EVs, especially as early adopters, will gain expertise in their operation and maintenance, which could then be shared with other owners as EV adoption grows.

### 6.6.7 Equity Impact

This policy could incentivize the electrification of fleet vehicles that provide services to Tongan citizens. It could even be aimed to target fleets that disproportionately serve disadvantaged communities within Tonga. With lower operating costs, EVs could also enable lower costs for those services.

### 6.6.8 Government Revenue Impact

Similar to the policies centered on EV purchase price reduction, bulk purchase incentives could be implemented in tandem with a fee on high-emission vehicles to reduce the government cost burden. However, this policy would likely result in a somewhat significant cost to the government depending on how many bulk purchases are made.

### 6.6.9 Implementation Recommendations

This policy could be most effectively implemented as an incentive to private businesses who could be providing electrified transportation services or operating fleets in Tonga, such as taxi drivers or rental car companies. Therefore, this policy should be implemented with those businesses in mind as the primary target, especially when considering mobility programs such as the on-demand shuttle service described in Section 3.7. Government fleets, such as police departments or other agencies, could also benefit from such bulk purchase incentives. Additionally, the amount of this incentive could reduce based on the cumulative number of vehicles purchased using the benefit. This would incentivize early adoption by fleets.

## 6.7 Reduced Price of Public Charging

### 6.7.1 Policy Details

One significant benefit of EV ownership is their lower operating cost compared to CVs. When the EV owner has a home charger available for most of their charging needs, the cost to drive is particularly low. However, for those with little or no home charging access or who drive enough that they need regular public charging, EV operating costs can be significantly higher (albeit likely still lower than CV operating costs). The IEA (2021) reports that multiple nations who lead in EV sales have therefore implemented policies related to reducing the cost of public charging as a method to increase adoption.

Some research has shown that incentives based on vehicle use (such as free public charging) can be one of the most cost-effective methods to increase EV adoption (Langbroek, Franklin, and Susilo 2016). Providing free or low-cost public charging can be a helpful incentive that "could possibly increase" EV sales in a given region at an "efficient cost-benefit rate" (Maness and Lin 2019). Free public charging can be especially effective, as the "value of free" has consistently been shown to have a particularly strong influence within other market contexts. Free public charging was also a successful strategy for increasing early sales of Tesla. Clear signage displaying the price of public charging is critical to ensure the incentive is effective and known to EV owners (Figure 22). The cost of using these free chargers could be covered by Tonga Power Limited, as an increase in EV adoption would also result in more demand for their services.

This policy can also be accompanied by a free parking incentive for high-value destinations in Nukuʻalofa. Some of this parking could be made free for EVs (and paid parking for other vehicles), while other popular parking spaces could be equipped with EV charging (and thus should only be occupied by EVs). Implementation of different payments for parking would follow the paid parking policy deployment as described in Section 2.2.


**Figure 22. An EV charger sign in the United States advertising free charging.**

Photo by Stephen Russell, NREL.

### 6.7.2 Intended Result

Reduced pricing for EV charging should increase EV sales by making potential EV owners more comfortable with the cost of ownership. Many people have an intuition for the cost of operating CVs, including typical prices for gasoline on a per-liter basis because of the large pricing signs displayed at most gas stations. However, it may be much less clear how much it should cost to charge an EV at home versus at a public charging station. That uncertainty, combined with new EV owners' anxiety about vehicle range and driving capability, could discourage potential vehicle purchases. Reducing or eliminating the cost of public charging can therefore make early EV adopters more comfortable with their purchase and reassure them that if they do run low on charge, it will not be significantly more expensive to plug in at a public charger than at home (at least in some locations for a limited time).

### 6.7.3 Relationship to Other Proposed Policies

This policy is directly related to the policies focused on charging station placement (Section 5.3) and incentives (Section 6.4). Nuku'alofa's paid parking policy (Section 2.2) could also create a strong incentive to purchase an EV if EVs were allowed to park for free at charging stations.

### 6.7.4 Application in Other Relevant Jurisdictions

Drive Electric New Zealand reports that most public AC charging is free across the nation, and more details can be found on the NZ Transport Agency EV charging station tracker (NZ Transit Agency 2023b).

### 6.7.5 Hurdles to Implementation

Requirements to sell electricity for free or at a discount to EVs could make the business model for private EV charging station ownership difficult. This could therefore limit private owners/operators of EV charging stations and slow the rate at which charging infrastructure is built out. The specifics of any policy proposed under this category should be designed in consultation with Tonga Power Limited. This policy might also be particularly difficult to fund with the current high electricity tariffs.

#### 6.7.6 Resilience Impact

This policy is assumed to have little to no impact on resilience.

#### 6.7.7 Equity Impact

If early adopters of EVs are disproportionately wealthy, this program could have a regressive impact. However, these programs could have a component of income qualification where reductions in charging prices are only available for EV owners from certain income brackets. This would likely require EV owners to use a purchase card at the charging station and then get a rebate if they qualify.

#### 6.7.8 Government Revenue Impact

Offering lower electricity tariffs for EV charging would also reduce the total revenue that Tonga Power Limited could theoretically receive, though overall revenue could increase from baseline levels due to the increased electricity demand that will result from electric mobility.

#### 6.7.9 Implementation Recommendations

Reduced or free EV charging can be prioritized for the initial batch of public charging stations, including battery swap stations if applicable, in order to spur early EV adoption and investment in public charging stations that might have low utilization. Once the upfront cost of an EV purchase declines, the government could consider phasing out the reduced EV charging tariffs. Further details on EV charging tariff design that is beneficial to both the grid and customers, as opposed to just a lower rate applied uniformly, are discussed in Section 7.1.

# 7 Policies for EV Charging as a Grid Asset

As the population of EVs in Tonga increases, the new electric load can either be a liability to the grid (e.g., adding excessive peak demand) or an asset (e.g., supporting grid reliability and resilience). The policies in this section help ensure that EVs and their associated infrastructure can be leveraged more as a grid asset and less as a grid liability. This is increasingly important as Tonga increases its share of renewable energy up from its 2022 portion of 46%, as the load from EVs can be scaled up when renewables are in high production or scaled down when renewables are in low production.

## 7.1 Electricity Time-of-Use Pricing

### 7.1.1 Policy Details

Tonga Power Limited can implement time-of-use (TOU) electricity pricing through the deployment of smart meters. TOU pricing, in which electricity is more expensive during peak demand periods and less expensive during off-peak periods, is a method increasingly employed by utilities to incentivize customers to use electricity during off-peak hours (Jones et al. 2022). "Smart meters" measure electricity consumption in real time, enabling utilities to implement TOU rates (Jaffe 2021). Therefore, for Tonga Power Limited to implement TOU pricing, it will need to install smart meters for all its customers. This recommendation is also supported by PCREEE (Campbell et al. 2020c).

### 7.1.2 Intended Result

The intent of TOU pricing is to shift some portion of electricity consumption from peak periods to off-peak periods, reducing strain on the grid and making it easier for the utility to cost-effectively balance supply and demand. Widespread EV charging is anticipated to significantly increase electricity demand, particularly for residential customers (Jones et al. 2022). Thus, TOU pricing is designed to encourage EV charging at times of the day that are more beneficial to Tonga Power Limited's operations, thus facilitating the integration of EV charging demand into Tonga's grid. TOU pricing can also help facilitate the integration of renewable electricity generation by reducing curtailment and fully utilizing excess solar generation in the middle of the day. Therefore, this policy also helps support Tonga's power sector goals of 70% and 100% renewable energy for electricity by 2025 and 2035, respectively (Joshi et al. 2023). Furthermore, TOU pricing can help customers save money by shifting their usage of electricity to different times of the day, which can be financially beneficial regardless of whether a specific customer owns an EV.

### 7.1.3 Relationship to Other Proposed Policies

TOU pricing relates to the other charge management policies of demand response (Section 7.3) and vehicle-to-grid (V2G)/vehicle-to-home (V2H) (Section 7.4), as those recommendations also intend to reduce the strain of EVs on the electric grid. It also relates to the reduced price of public charging (Section 6.7).

### 7.1.4 Application in Other Relevant Jurisdictions

As of 2019, about half of investor-owned utilities in the United States have optional TOU rates for residential customers (Trabish 2019). Several utilities in the United States also offer EV-specific TOU tariffs (Figure 23), though generally the TOU rate does not need to be EV-specific for it to be effective at mitigating the grid impacts of EVs. These rates include additional categories beyond off-peak and peak, such as “mid-peak” and “super-off-peak.”

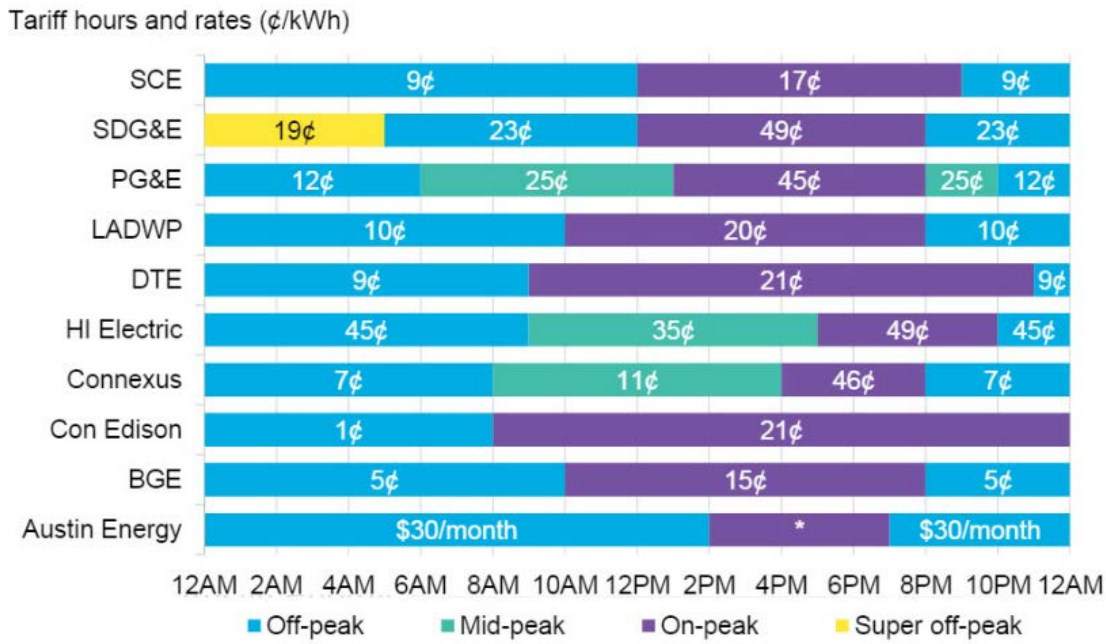



**Figure 23. TOU charging tariffs for select U.S. utilities.**

Source: BloombergNEF (2017).

### 7.1.5 Hurdles to Implementation

Deploying smart meters throughout the entire country, and subsequently implementing a TOU tariff regime, will require financial and human resources. Furthermore, if the TOU tariff is not adequately communicated to the public, it could be much less effective and there could be public resistance to the policy due to a perceived rate increase. People are also generally unreliable at manually starting the chargers at the right time over the long term, so efforts need to be made to ensure that EV drivers have vehicles or chargers that can be programmed to automatically charge at the appropriate time.

### 7.1.6 Resilience Impact

Because TOU pricing can shift EV charging to time periods that are more beneficial to the electric grid, this policy has the potential to increase grid resilience.

### 7.1.7 Equity Impact

If customers do not shift electricity consumption from peak to off-peak hours under a TOU system, their electricity bills could increase, and this would most significantly impact low-income customers. Alternatively, shifting electricity consumption has the potential to result in significant cost savings for all customers and the utility itself (Trabish 2019). Therefore, a sufficient outreach campaign could help ensure a positive impact on equity.

### 7.1.8 Government Revenue Impact

This policy is assumed to have little to no impact on revenue, as TOU tariffs can be designed to be "revenue-neutral" for the utility (Jaffe 2021). This means that under an appropriate tariff design, Tonga Power Limited would see its revenue neither increase nor decrease appreciably. However, Tonga Power Limited's costs might decrease, resulting in overall savings, because less generation capacity would be required to meet peak demand if TOU pricing significantly shifts load.

### 7.1.9 Implementation Recommendations

Tonga Power Limited already has a Smart Meter Project underway to provide all customers with this technology (Tonga Power Limited 2021). As of June 2023, 70% of the main island, Tongatapu, is covered by smart meters according to Tonga Power Limited. Therefore, a TOU tariff can be developed alongside this program and piloted for a subset of customers following a public outreach campaign to educate consumers on the benefits of this new tariff structure. After the initial pilot, Tonga Power Limited could extend the pilot phase to the entire customer base with the assurance that for the first year, customers will not have to pay any extra money above what they would have paid under the old tariff structure. This approach, called "bill protection," has been taken by utilities such as Pacific Gas and Electric and allows customers to try the plan risk-free for the first year (PG&E 2023). Finally, the initial TOU rates that are piloted could also be reduced for EVs, in accordance with the recommendations on a reduced price for public charging described in Section 6.7. Tonga Power Limited is currently engaged with the Global Green Growth Institute to assess different tariff structures for EVs, which will greatly assist this effort. To plan for both TOU pricing (Section 7.1) and demand response managed charging (Section 7.3), Tonga could utilize the EV Charging and Grid Integration Tool developed by the IEA (iea.org/data-and-statistics/data-tools/ev-charging-and-grid-integration-tool), which allows users to assess the grid impacts of EVs along with various strategies to mitigate this impact.

## 7.2 Net Metering

### 7.2.1 Policy Details

Net metering is a policy that compensates utility customers who generate their own electricity and sell excess back to the grid (Solar Energy Industries Association 2023). This policy has become a popular way to incentivize the deployment of distributed solar PV systems throughout the world. Under a net metering policy or similar compensation mechanism, EV owners could also be compensated for electricity that their vehicle sends back to the grid if V2G capabilities exist (Section 7.4). Paired with TOU rates in addition to V2G technologies, EVs could even engage in price arbitrage (i.e., buying electricity when it is less expensive and selling it back to the grid when it is more expensive).

### 7.2.2 Intended Result

By implementing a net metering policy, Tonga could simultaneously encourage the adoption of distributed solar PV (which could help it reach its renewable energy targets) and facilitate the integration of EVs (by increasing the financial case for V2G technology, and because distributed solar PV could help satisfy some EV load and reduce the load on the main grid).

### 7.2.3 Relationship to Other Proposed Policies

The net metering policy relates to the V2G policy (Section 7.4) because net metering would compensate EV owners for any excess electricity sold back to the grid, making V2G more financially appealing.

### 7.2.4 Application in Other Relevant Jurisdictions

Net metering, as a general policy and not necessarily for electric vehicles exclusively, has been implemented in many jurisdictions throughout the world, including the island nations of the Cook Islands (U.N. Economic and Social Commission for Asia and the Pacific 2013), Cape Verde (Roux and Shanker 2018), Sri Lanka, the Maldives, and the Philippines (Rehman et al. 2020). These jurisdictions have different compensation rates and allow various qualifying technologies of different sizes, so Tonga will need to determine what is most suitable for its context.

### 7.2.5 Hurdles to Implementation

From an operational standpoint, net metering will require policy changes within Tonga Power Limited. Utilities have generally had unfavorable views of net metering policies that allow customers to be paid the retail rate of electricity for any excess energy sent back to the grid, because the customer could avoid paying for certain grid maintenance and fixed costs (Smith 2018). From a technical standpoint, distribution systems and distributed energy resources typically need to meet certain interconnection requirements (U.S. Environmental Protection Agency 2015).

### 7.2.6 Resilience Impact

Because net metering financially incentivizes customers to install behind-the-meter solar PV and adopt V2G or V2H technologies, the policy can increase the resilience of both the electric grid and individual buildings.

### 7.2.7 Equity Impact

Net metering policies that pay customers the retail rate of electricity have also been viewed as inequitable, shifting the cost of grid maintenance to customers without rooftop solar (Trabish 2021).

### 7.2.8 Government Revenue Impact

Depending on the compensation rate in the net metering policy, there is a possibility that revenues to Tonga Power Limited could decrease because of reduced electricity sales. This could be partially offset by avoided investments in utility-scale generation and transmission infrastructure (Satchwell, Mills, and Barbose 2015).

### 7.2.9 Implementation Recommendations

Tonga Power Limited could consider a net metering policy that does not pay customers at the full retail rate of electricity or sets a cap on payments, as this could help mitigate some of the equity concerns about cost-shifting to customers without distributed energy resources such as solar PV and electric vehicles.

## 7.3 Electricity Demand Response

### 7.3.1 Policy Details

As Tonga builds its network of charging stations, we suggest that the country implement demand response policies. Demand response can involve direct reduction of loads by the utility in exchange for financial payments as a form of emergency action or system balancing during periods of high grid stress (Elsworth, Joshi, and Shah 2022). The demand response policies could require customers to opt in instead of being automatically enrolled. Demand response works best at charging stations with long dwell times, especially residential and workplace locations, because it has a minimal impact on charging convenience in these applications. This policy does not necessarily require smart meters because demand response can be used with less sophisticated technologies such as pagers and power-line communication.

### 7.3.2 Intended Result

The intended result of this policy is similar to that of TOU rates, which is to reduce and shift the electrical load and thereby enable the utility to balance supply with demand more effectively. For this demand response policy, however, the intent is for a direct reduction of loads as an emergency measure when there is a risk of rolling outages. Because of their high electricity demand, Mode 3 and Mode 4 EV chargers are prime candidates for this initiative. This policy will also support the recommendation from PCREEE that 50% of EVs are charged through devices that can manage charging by 2030 and 90% by 2050 (Campbell et al. 2020a). Finally, this policy can help Tonga reach its power sector goals of 70% and 100% renewable energy for electricity by 2025 and 2035, respectively (Joshi et al. 2023).

### 7.3.3 Relationship to Other Proposed Policies

Demand response relates to the other charge management policies of TOU pricing (Section 7.1) and V2G/V2H (Section 7.4), as those recommendations also intend to reduce the strain of EVs on the electric grid.

### 7.3.4 Application in Other Relevant Jurisdictions

Some workplaces, such as NREL's campus, have on-site EV chargers that have managed charging capabilities (Figure 24). Some transmission system operators in Europe are also piloting this technology (ENTSO-E 2023), in addition to islands such as Maui in Hawaii and Martinique in the Caribbean (Virta 2021).

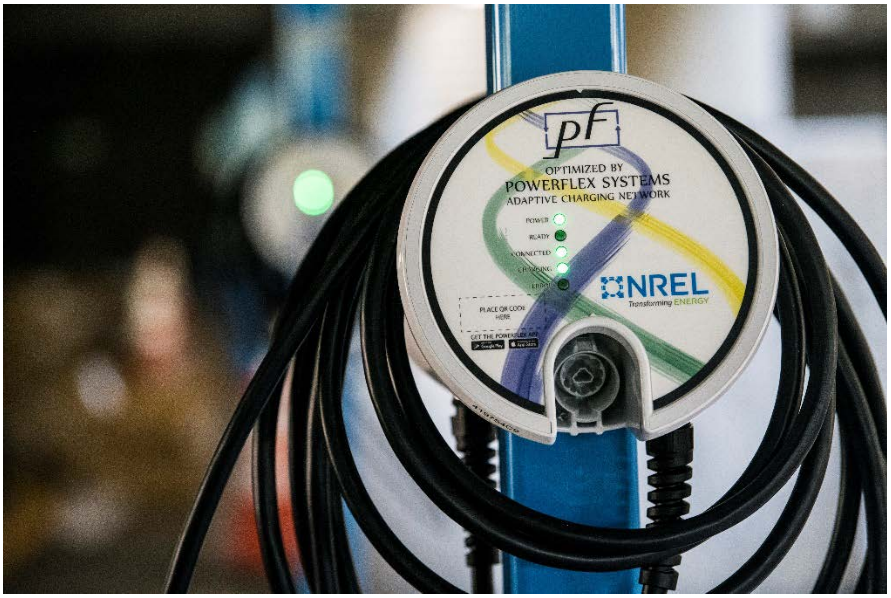



**Figure 24. EV chargers on NREL's campus capable of managed charging.**

Photo by Dennis Schroeder, NREL.

#### 7.3.5 Hurdles to Implementation

Charging stations will need to be designed to accommodate managed charging capabilities, and the utility will need the capacity to operate such systems, both of which could come at additional costs. Furthermore, public buy-in is also required for this policy, as some EV owners may be reluctant to allow the utility to temporarily curtail their vehicle charging.

#### 7.3.6 Resilience Impact

Because demand response and other forms of managed EV charging can reduce demand during time periods when the electric grid is stressed, such as a heat wave that increases the load of air conditioners, this policy can increase grid resilience.

#### 7.3.7 Equity Impact

This policy is assumed to have little to no impact on equity, as any customers that have their EV charging load temporarily curtailed or paused would be financially compensated by the utility.

#### 7.3.8 Government Revenue Impact

This policy is assumed to have little to no impact on revenue, as any financial payments made by Tonga Power Limited during demand response events would be balanced by financial savings due to avoided use of expensive peaking power plants or rolling blackouts.

#### 7.3.9 Implementation Recommendations

Tonga has the opportunity to incorporate managed charging and demand response capabilities from the start when planning its charging network. This might require a program similar to Tonga Power Limited's Smart Meter Project, and utility resources can partner with charging station installers to ensure that a certain percentage of public chargers have demand response capabilities as an initial pilot. Demand response managed charging can be done using relatively inexpensive technologies such as power-line communications or pagers, and Tonga can start by incorporating this capability into chargers that are installed at government facilities. To plan for both TOU pricing (Section 7.1) and demand response managed charging (Section 7.3), Tonga could utilize the EV Charging and Grid Integration Tool developed by the IEA, which allows users to assess the grid impacts of EVs along with various strategies to mitigate this impact.

## 7.4 Bidirectional Charging for Vehicle-to-Grid and Vehicle-to-Home

### 7.4.1 Policy Details

V2G technology enables sending electricity from the vehicle's battery to the grid in addition to the traditional flow from the grid to the battery. Tonga could implement policies that support V2G readiness for Mode 3 public charging stations. V2H technologies, which are more mature than V2G technologies and offered in some common EV models such as the Nissan Leaf and Ford F150 Lightning, are similar but simpler arrangements that allow electricity stored in a vehicle's battery to be exported to an isolated or local electrical circuit such as a home (Campbell et al. 2020c). Tonga could also plan for V2H capabilities for its Mode 3 private charging stations.

### 7.4.2 Intended Result

The intended result of this policy is to transform EVs from a potential grid stressor (though this stress can also be mitigated with TOU pricing and demand response as discussed) to a grid asset. For instance, V2G can provide Tonga's power network with another source of supply during periods of peak demand, provide ancillary services such as frequency regulation, and thus also support the further integration of renewable energy (Lopez et al. 2022). Therefore, V2G technology can help Tonga reach its power sector goals of 70% and 100% renewable energy for electricity by 2025 and 2035, respectively (Joshi et al. 2023). V2H technology can serve as an additional backup power supply for homes and other buildings because the vehicle batteries can act in place of or as a supplement to a stand-alone battery or generator.

### 7.4.3 Relationship to Other Proposed Policies

V2G and V2H technologies depend upon a smart meter. They can be more lucrative when paired with TOU pricing (Section 7.1) because an EV owner can charge their vehicle when electricity is cheap and sell it to the grid when electricity is expensive. These technologies can also make demand response (Section 7.3) programs more attractive to the utility, as residents could still power their homes with their EV even when the utility has curtailed their electricity supply. All of these policies reduce the electrical load of EVs on the grid.

### 7.4.4 Application in Other Relevant Jurisdictions

The Australian state of South Australia has recently approved V2G and V2H connections at homes and businesses, allowing EVs to supply power to buildings and send any excess energy to the local distribution network (Carroll 2023). V2G pilot projects have also occurred in smaller island power systems such as Hawaii and the Azores (Lopez et al. 2022). Vehicle manufacturers such as Hyundai and Kia offer V2H capabilities in EVs sold in Australia, the Nissan Leaf and Ford F-150 Lightning are both capable of bidirectional charging with appropriate charging equipment, and General Motors is planning to incorporate bidirectional charging into its EV portfolio (Akhtar 2023; Shahan 2022; Lambert 2022; Pickerel 2022).

### 7.4.5 Hurdles to Implementation

V2G equipment, and V2H equipment to a lesser extent, are features that increase the costs of EVSE and are not broadly commercialized. The technologies are in a demonstration phase, and thus Tonga Power Limited and building owners might not have the risk tolerance to invest in such systems. According to PCREEE, V2G might not be as cost-effective as stationary battery energy storage for Pacific Island nations, and V2H might be too costly for individual EV owners in the near term (Campbell et al. 2020c). Furthermore, not all EVs are equipped with V2G or V2H capabilities in their internal hardware and software, and Tonga generally relies on imported used vehicles that have older systems. These technologies can also impact the EV battery, reducing its lifetime depending on how often and how deeply the battery is charged and discharged. Thus, some vehicle manufacturers such as Tesla might void the warranty on a battery if it is used for bidirectional charging (Lambert 2021).

### 7.4.6 Resilience Impact

V2G equipment can increase grid resilience by transforming EVs from a potential grid stressor to a potential grid asset, providing valuable services such as frequency regulation or power supply during peak demand periods. V2H equipment can also increase Tonga's resilience by providing homes and businesses with another form of backup power in the event of grid outages.

### 7.4.7 Equity Impact

Due to the upfront price of V2G and V2H equipment, individuals who can afford this expense are more likely to reap its benefits such as lower electricity costs, payment for electricity supply and ancillary services, and increased resilience.

### 7.4.8 Government Revenue Impact

This policy is assumed to have little to no impact on revenue.

### 7.4.9 Implementation Recommendations

Because V2H technology is less expensive and more commercially available than V2G technology, we suggest Tonga prioritize V2H capabilities in some Mode 3 private charging stations in the near term. This could involve simple regulatory approval from Tonga Power Limited, as was done by South Australia Power Networks, or more extensive financial support. V2H can increase resilience for homes and businesses but does not require the more extensive grid operational changes and compensation structures associated with V2G. In the longer term, Tonga can develop a V2G strategy for its public Mode 3 charging stations, particularly as it approaches its goal of 100% renewable energy for electricity by 2035, because the value of V2G will increase as the percentage of renewables increases. This strategy could involve developing a method to compensate vehicle owners for electricity supplied from EV batteries that is used for grid power and ancillary services, accounting for potential battery degradation. Mode 4 charging stations might be less relevant for V2G because the vehicles themselves are not connected to the station for long periods of time.

# 8 Comparison to TEEMP, TERMPLUS, and PCREEE Plans

This analysis builds upon many of the policies proposed by the TEEMP, TERMPLUS, and PCREEE transportation electrification guidelines. It assesses them, further develops them, explores intended and unintended consequences, charts pathways to adoption, and adds new policies as needed. In many cases, this analysis incorporates policy proposals from prior documents into related policies. However, a number of policies proposed in these prior plans were either incorporated into other policies, replaced, or dropped altogether within this framework. Table 2 tracks these policies and explains the logic for incorporating or dropping them.

**Table 2. Policy Recommendations From TEEMP, TERMPLUS, and PCREEE That Were Incorporated, Replaced, Deleted, or Postponed in Current Policy Recommendations**

| Policy Recommendation | Source | Destination |
|---|---|---|
| Fuel economy labeling requirements | TEEMP | Incorporated into feebate policy (Section 2.1), and knowledge of EV benefits would be shared via EV education efforts (Section 5.2) |
| Track and coordinate buses with platform such as NextBus | TEEMP | Replaced by the on-demand shuttle service (Section 3.7) |
| Incentivize tuk tuks to queue at major bus stops | TEEMP | Replaced by the on-demand shuttle service (Section 3.7) |
| Coordinate taxis | TEEMP | Replaced by the on-demand shuttle service (Section 3.7) |
| Shared mobility in taxis | TERMPLUS | Replaced by the on-demand shuttle service (Section 3.7) |
| Euro V emissions standards | TERMPLUS | Deleted because reducing $NO_x$ to meet Euro V often reduces the efficiency of diesel vehicles (Omnagen 2023), and Tonga has no air quality problem |
| Adjust vehicle registration tax and import tariff according to vehicle weight, displacement, or fuel economy | TEEMP | Replaced by feebate (Section 2.1), fee waiver (Section 6.1), and tax credit or rebate (Section 6.2) policy options |
| Safety reflectors and lights for pedestrians and cyclists | TEEMP | Replaced with SRTS program (Section 3.3) |
| Motorcycle/scooter safety program | TEEMP | Postponed, but motorcycles helped by feebate (Section 2.1), parking strategy (Section 2.2), and VRU law (Section 3.2) |
| Water taxi in the laguna | TEEMP | Postponed until paid parking strategy (Section 2.2) is assessed |
| Toll bridge across the top of the laguna | TEEMP | Postponed until P&R lot (Section 3.5) is assessed |

| Policy Recommendation | Source | Destination |
|---|---|---|
| Vehicle electrification targets | TERMPLUS | Viewed as guiding targets and not operational or prescriptive policies |
| Portable charging guidelines | PCREEE proposed charging guidelines | Incorporated into Mode 1 and Mode 2 charging standards and guidelines (Section 4.2) |
| Untethered charging cables for Mode 3 charging | PCREEE proposed charging guidelines | Incorporated into charging mode requirements (Section 4.3) |
| Restrictions on Mode 1 and Mode 2 charging | PCREEE proposed charging guidelines | Incorporated into charging mode requirements (Section 4.3) |
| TOU pricing | PCREEE technical report | Incorporated into Section 7.1 |
| Managed charging | PCREEE technical report | Incorporated into demand response policy (Section 7.3) |
| V2G and V2H | PCREEE technical report | Incorporated into Section 7.4 |

Some of the TEEMP or TERMPLUS policies changed due to technological advancements, such as the on-demand shuttle technology and adoption of smartphones. Others were leapfrogged due to new data sources. Specifically, New Zealand's Fuelsaver database (New Zealand Energy Efficiency & Conservation Authority 2023) enables a feebate rather than a less precise registration fee based on vehicle size.

# 9 Policy Framework

This section ties together all the policies discussed into a cohesive and actionable framework, with information about sequencing of policies and their impacts on GHG emissions, fuel consumption, resilience, and cost/time savings.

## 9.1 Implementation Roadmap

Figure 25 summarizes the policy implementation roadmap for Tonga, and the key takeaways are also applicable to other jurisdictions. The policies are grouped based on the intended outcomes that they enable: Mode Diversification (Section 3), Safe EVs and Charging (Section 4), Accessible EVs and Charging (Section 5), Affordable EVs and Charging (Section 6), and EV Charging as a Grid Asset (Section 7). The feebate and parking strategy policies both result in funding and induced demand for alternative modes of transportation, including EVs, and thus these are considered foundational policies that strengthen the implementation of many of the other policies and contribute directly to all five intended outcomes (Section 2).


**Figure 25. Policy options supporting key intended outcomes and goals.**

Source: Fred Zietz, NREL.

The policies are interrelated, as discussed throughout the framework, and grouped into distinct phases (e.g., Phase 1) to indicate a rough sequencing. Within a specific intended outcome (e.g., Mode Diversification), policies in Phase 1 (e.g., bicycle and pedestrian infrastructure) are beneficial for the successful rollout of policies in Phase 2 (e.g., SRTS program). This phased approach can help the government of Tonga identify near-term, high-impact actions that it can take (i.e., Phase 1 policies) through its implementation working groups. The five main intended outcomes support Tonga's overall transportation system goals: cost and time savings, increased resilience, and petroleum and GHG reductions. The timing of phasing for policies under one intended outcome does not need to be closely synchronized with the phasing of policies under the other intended outcomes, although they are interconnected.

## 9.2 Resilience Impacts

The impact that a policy has on Tonga's resilience to cyclones, tsunamis, and other natural disasters is directly related to its intended outcomes, as shown at the top of each column in Figure 25.

More efficient vehicles, as shown in Figure 26, are the result of the feebate and increase resilience because a more efficient fleet can travel farther using less fuel when fuel availability is constrained. It should be noted that "more efficient vehicles" is the only intended outcome not listed in Figure 25.

Mode diversification will make the transportation system more resilient by decongesting evacuation routes and sometimes utilizing transportation that can be more ready for evacuation under variable conditions, such as a bicycle parked at the doorstop of one's office in Nuku'alofa instead of a car parked several blocks away. Some modes, such as buses and bicycles, can also traverse standing water more effectively than gasoline vehicles. However, one must also consider that the new modes (such as electric scooters) could be worse in standing water and that some modes could take longer for evacuation departure than a personal vehicle.

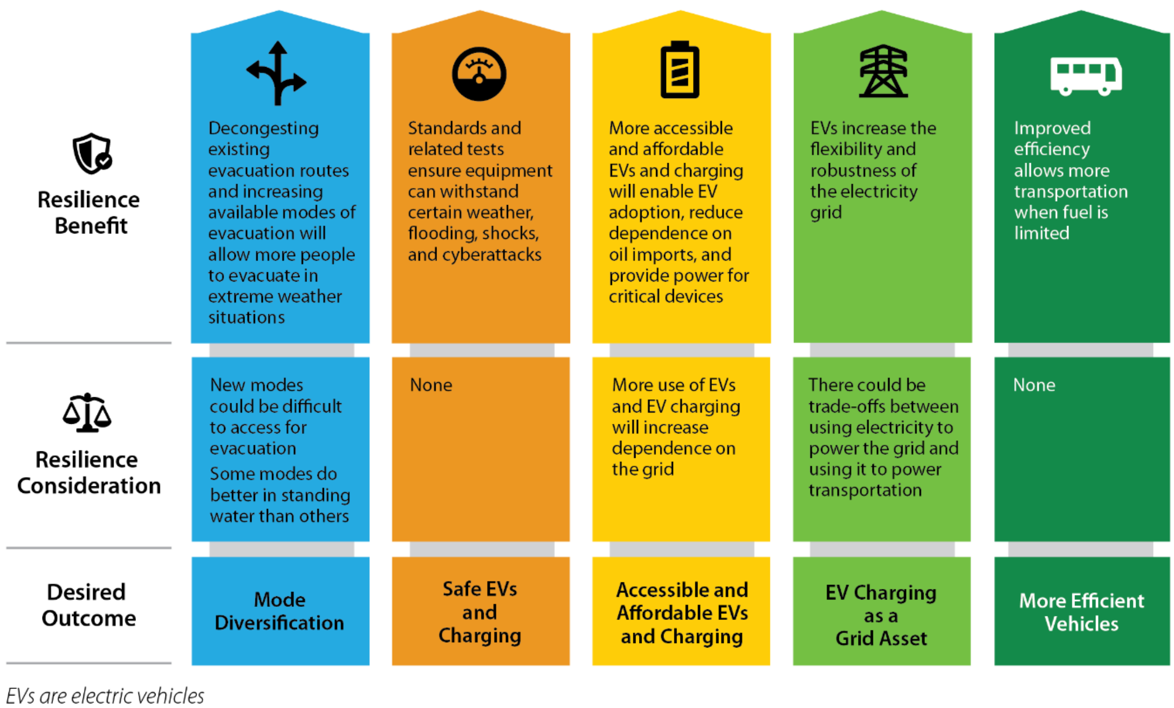



**Figure 26. Relationship between the intended outcome of policies and their impact on resilience.**

Source: Fred Zietz, NREL.

Standards that are implemented to ensure safe EVs and charging would also ensure more resilient equipment because a subset of these standards (IEC60068) tests equipment's ability to withstand water, corrosion, collisions, vibrations, and other stresses encountered during natural disasters. Policies that increase the use of EVs increase resilience by reducing dependence on petroleum imports that are often disrupted during disasters. Strategic EV charging station placement (Section 5.3) can be done in a way that makes charging infrastructure less vulnerable to flooding. Policies that improve EVs as a grid asset improve resilience by making Tonga's grid more robust to handle natural disasters. Furthermore, EVs can also be used to power critical electrical loads with their batteries, with the potential of expanding to power entire buildings or portions of the grid. However, one must consider that while introducing EVs would reduce reliance on fuel imports (as described in the next section), they increase the overall dependence on the electric grid, which can be vulnerable to disruption.

## 9.3 GHG and Fuel Use Impacts

To project the impact that these policies have on Tonga's 2030 and 2050 fuel use and GHG reductions, we tie them to the subgoals declared in TEEMP and TERMPLUS. It should be noted that Tonga's second nationally determined contribution contains no mitigation goals for the transport sector (Kingdom of Tonga 2020). These goals were selected to be the foundation of the wedge analysis because the proposed policies rely on one another to reach those common goals. Furthermore, most of the policies can be scaled up or down. It is therefore assumed that, through an iterative process, the aggregated and properly scaled policies can meet the subgoals listed below:

- VKT reduction: 20% reduction in LDV kilometers traveled by 2030.
- LDV electrification: 10% of LDV sales are fully electric by 2030 and 35% by 2035.
- Taxi electrification: 70% of commercial taxi sales are fully electric by 2035.
- Heavy-duty electrification: 5% of medium- and heavy-duty vehicle sales are fully electric by 2035.
- Bus electrification: 30% of buses are fully electric by 2035.

These subgoals are applied to the BAU case shown in Figure 1, and they encapsulate the intended outcomes of the listed policy options shown in Figure 25. The VKT reduction subgoal aligns with the policies that fall under the "Mode Diversification" intended outcome (Section 3). Mode diversification policies such as bicycle and pedestrian infrastructure, safe passing laws, SRTS programs, bike- and scooter-share programs, P&R lots, a ride-share coordinate website, and an on-demand shuttle service can guide people away from driving by themselves in a private vehicle and shift travel to other, more efficient modes.

The LDV electrification subgoal aligns with the "Affordable EVs and Charging" (Section 6) and "Accessible EVs and Charging" (Section 5) intended outcomes because those policies ultimately overcome the two largest barriers to EV adoption: their higher upfront cost and the ability to conveniently operate and charge an EV. The policies do this by providing incentives and public awareness of EVs. The taxi electrification goal also aligns most with the "Affordable EVs and Charging" (Section 6) intended outcome, including the bulk vehicle purchase incentives, which incentivize a transition to electric fleets. Taxi electrification also aligns well with the charging station placement policy because the vehicles will need to charge at accessible locations during the day to accommodate longer daily driving distances than other vehicle owners.

Heavy-duty vehicle and bus electrification is related to the intended outcome of "EV Charging as a Grid Asset" (Section 7), primarily because these vehicles will require high-power charging and thus the grid needs to be prepared for this significant load. While EVs can be an asset for providing electricity to the grid by discharging their batteries, high-power charging represents a new grid challenge. In addition, heavy-duty vehicles will most likely need to charge on set routes, which also ties into charging station placement and TOU pricing.

This section follows the process of using those 2030 and 2035 subgoals to project the GHG reductions through 2050. The first goal listed, a 20% reduction in LDV VKT by 2030, focused only on the island of Tongatapu because the system efficiency policies proposed would primarily be implemented there. Policies that feed into the VKT reduction include the bicycle and pedestrian infrastructure, safe passing laws, SRTS programs, bike- and scooter-share programs, P&R lots, a ride-share coordinate website, and an on-demand shuttle service. This analysis assumes that Tonga will implement these policies effectively and that the impacts of these policies will scale in a way that meets the VKT reduction goal for Tongatapu.

According to the imported vehicle data (2018–2023) received by the Tongan Ministry of Trade and Economic Development, about 3% of new vehicle registrations in Tonga are new vehicles. This suggests that the Tongan vehicle market is primarily made up of used vehicles that are imported from neighboring markets. From 2018–2022, Japan was the source of 60% of the vehicle imports to Tonga, while New Zealand accounted for 33% and Australia for 3%. Vehicle imports and new vehicle registration data were used to model the impacts of Tonga's goals for LDV electrification. In 2021, there were 2,674 imported vehicles and 2,511 new vehicle registrations. These data give some insight into the number of vehicle sales, which is used to model the percent of EV adoption in Tonga. It is important to note that the EV adoption rate is solely based on Tonga's electrification targets because the EV market is currently too small to make projections from. In addition, 10% of vehicle sales being fully electric by 2030 and 35% by 2035 amounts to an additional 5% of vehicles sales per year, resulting in Tonga's market being 100% EV sales by 2049. This is deemed realistic based on other applications of similar policies, assuming the relevant policies are successfully implemented.

Taking the data from the imported vehicles and new vehicle registrations (which includes new registrations of both new and used vehicles) results in an average of 2,999 vehicles purchased per year with a range of 1,787–4,423 vehicles/year. Because the vehicle import and registration numbers differ by a maximum of 200, only the new vehicle registrations were considered for this analysis, largely because more data are available from 2011–2021 and are organized by vehicle type. Figure 27 shows the new vehicle registrations from 2011–2021 by vehicle type with registrations increasing from 2011–2017, and then decreasing from 2017–2021. This could be because Tonga's vehicle stock was catching up with demand from 2011–2017, and because the population did not rapidly increase (as is the case with other island nations), once demand reached its peaked in 2017, the new vehicle registrations decreased through 2021.

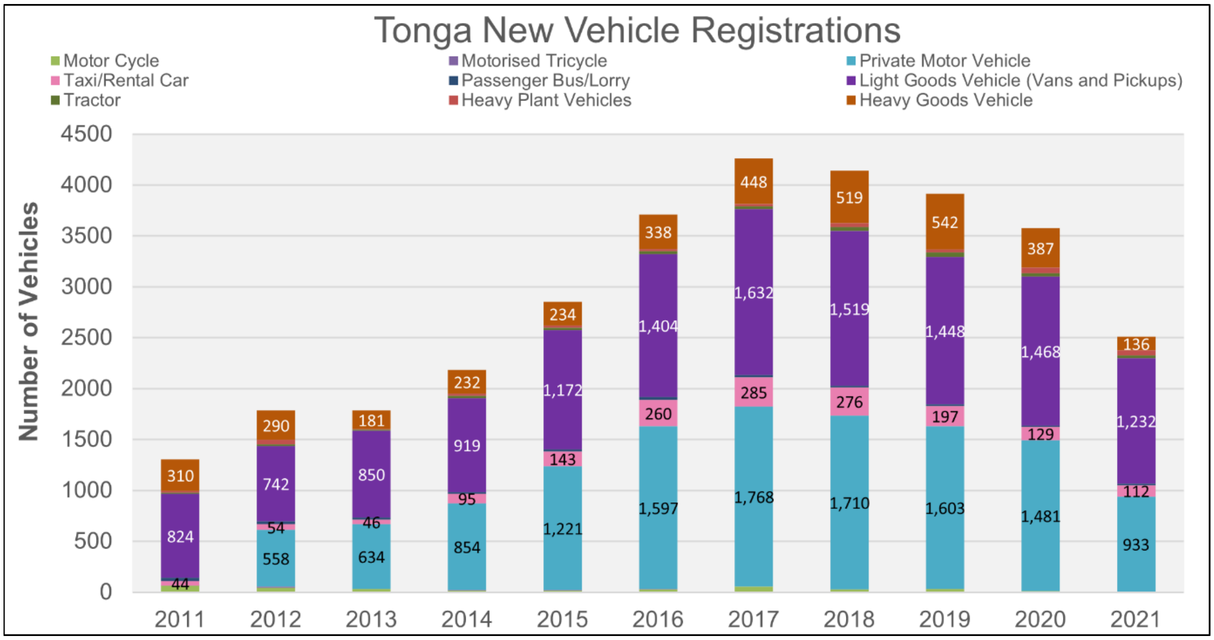



**Figure 27. Tonga new vehicle registrations (used and new vehicles).**

These new vehicle registrations are split into LDVs and medium- and heavy-duty vehicles to coincide with gasoline and diesel fuel use. The number of EV sales was calculated by using the electrification goals and multiplying the EV share by the average number of new vehicles registrations per year since 2011 for the given vehicle type. With an island population that does not drastically change, it was assumed that the average number of vehicle sales remained constant through 2050. It was also assumed that VKT reduction policies reduced per-vehicle VKT rather than reducing vehicle sales. However, a reduction in vehicle sales could also result in lower VKT and transportation-related emissions.

GHG emissions reductions resulting from EV sales in Tonga are based on EV emissions for the most popular EVs operating in New Zealand because a large portion of EV imports will likely be from New Zealand. The calculations for EV emissions also consider the changing share of renewables comprising the island's electricity generation mix. Tonga's goal to achieve 70% renewables by 2025 and 100% renewables by 2035 was used to model the emissions of EVs.

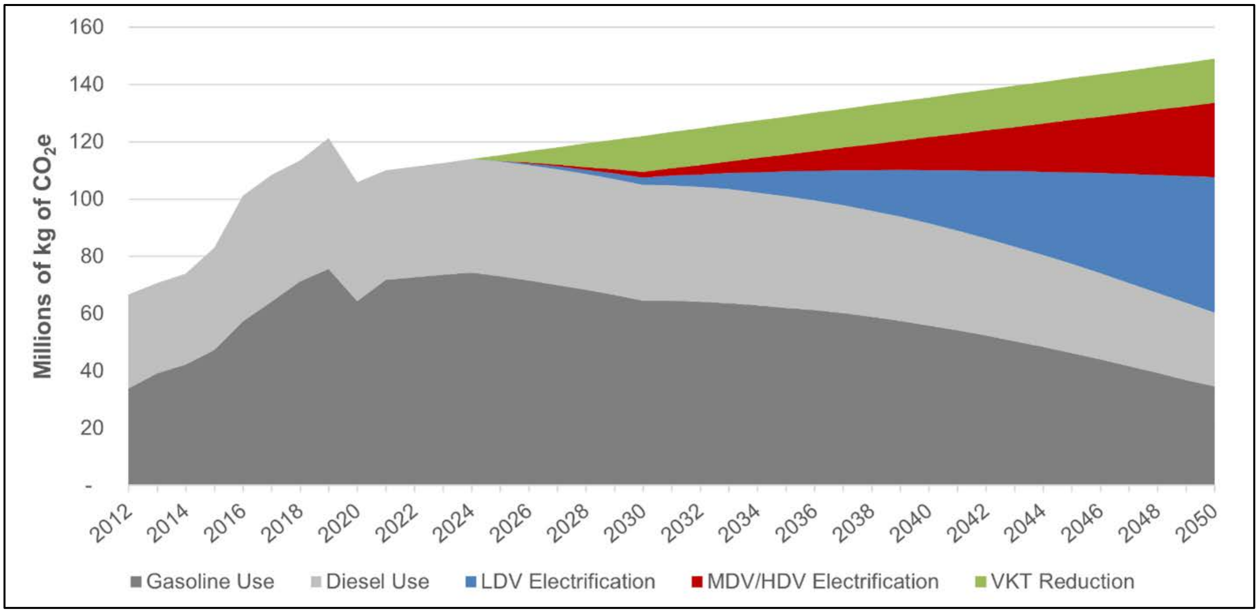



**Figure 28. Projected impact of proposed transportation policies on Tonga's land transportation GHG emissions.**

As seen in Figure 28, the largest GHG reductions from the BAU scenario come from LDV electrification. The goals contributing to GHG reductions from gasoline include reaching 70% EVs for taxi sales and 30% EVs for LDV sales by 2035. It was then assumed that Tonga followed the same trajectory as their current goals through 2050, resulting in 100% electric taxi sales by 2042 and 100% electric LDV sales by 2049. With 100% of vehicle sales being electric, there will still be a significant number of internal combustion engine vehicles on the road, resulting in 34 million kilograms of $CO_2e$ emissions by LDVs in 2050. As the largest contributors to Tonga's transport-related GHG emissions, electrifying LDVs is an important component to reducing those emissions. Following these trends, in 2050 the total gasoline emissions in Tonga will be reduced by 64% compared to the BAU scenario, while the diesel emissions will be reduced by 50% compared to BAU. Summed, this results in an overall reduction of 60% for Tonga's transportation sector in 2050, from 148 million to 60 million kilograms of $CO_2$.

# 10 Conclusion

The GHG emissions from Tonga's land transportation sector are projected to increase 35% by 2050 in a BAU scenario, as increasing GDP leads to more private car travel. Past efforts have been made to chart future emissions reductions, resulting in goals proposed in TEEMP and TERMPLUS. This policy framework translates those goals into specific policies that have been effective in relevant jurisdictions and that were developed through stakeholder working group meetings in Tonga in June 2023. These policies aim to reduce GHG emissions by improving vehicle fuel economy, diversifying transportation modes, and developing an EV market. The EV market is promoted through policies that ensure that EVs and charging are safe, accessible, affordable, and have minimal or positive impacts on the electricity grid. The policies are scalable and can be set to achieve the specific subgoals in TEEMP and TERMPLUS. The policies generally build upon each other and are therefore laid out in chronological phases. Once implemented, the policies can make Tonga's land transportation system safer, less congested, more equitable, more resilient, and reduce GHGs in the sector by 60% compared to the BAU scenario. Furthermore, this policy framework could be applicable to other Pacific Island nations and tailored to their specific transportation systems. Collaboration with organizations such as PCREEE, the Local2030 Islands Network, NREL, or others could further support application of this policy analysis framework and policy implementation with other island partners.

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# Appendix A: Data and Assumptions Supporting Tonga's Business-as-Usual Fuel Use Projections

To accurately project Tonga's BAU fuel use, Tonga's historical land transportation fuel consumption is taken into consideration, shown in Figure A-1. The historical gasoline consumption data are from the U.S. Energy Information Administration (2012–2014) and the Tonga Department of Energy (2015–2021). The historical diesel consumption data are from the Tonga Ministry of Tourism (2012–2014) and the Tonga Department of Energy (2015–2021). In 2015, road transportation accounted for 51% of all Tongan fuel imports and increased to 64% by 2021. Between 2012 and 2021, road transportation accounted for a total of 57% of all fuel imports. Diesel consumption has increased at a much lower rate than that of gasoline. Road transportation accounts for 42% of the total diesel consumption, while electricity accounts for 50% of the total diesel consumption.

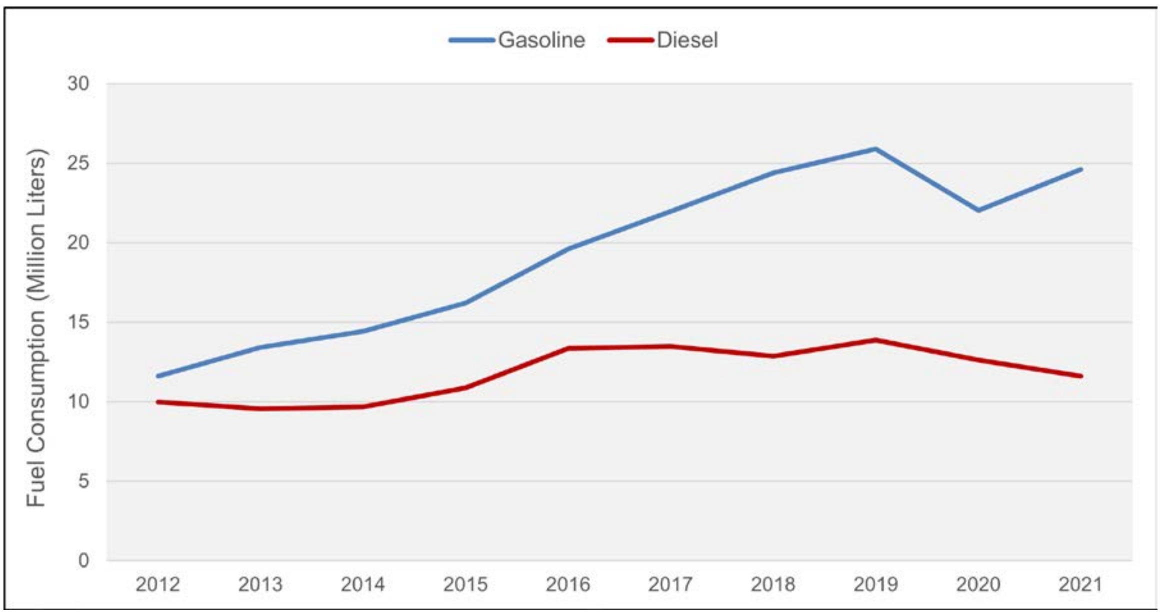


**Figure A-1. Historical gasoline and diesel fuel consumption for land transportation in Tonga (2012–2021).**

The next step in deriving fuel projections is estimating Tonga's VKT. The higher the VKT, the more a population is dependent on vehicles for travel, thus resulting in higher GHG emissions. Tonga's VKT was derived from the traffic count map of Tongatapu created by the Ministry of Infrastructure in 2015. This is the same process used in TEEMP. With the assumption that most of the traffic comes and goes from Nukuʻalofa, vehicles were counted twice per day and have the same distance on both trips. This simulates the morning and evening commutes. The vehicle counts are shown in Table A-1.

Table A-1 includes the counter location and the primary destination (Destination A) of the vehicles, which was a populated town, region, or the next counter. Destination B was a secondary destination beyond that of Destination A, which is only included for a few counters with longer and more populated roads. The number of vehicles was then multiplied by the kilometers to the destination, resulting in the daily VKT going to each destination. These numbers are listed under the "Daily VKT" column and are summed to get the total daily VKT.

**Table A-1. Traffic Counts, Destinations, and Vehicle Kilometers Traveled in Tongatapu**

| Road | Counter Location | Vehicles per Day | Destination A | Kilometers to A | Vehicles to A | Daily VKT | Destination B | Kilometers to B | Vehicles to B | Daily VKT |
|---|---|---|---|---|---|---|---|---|---|---|
| Taufa'ahau Road | Fanga | 21,528 | Tofoa | 1.2 | 15,837 | 19,111 | Havelu and Vaoloa | 0.5 | 5,691 | 3,022 |
| Bypass Road | Ministry of Infrastructure | 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 |
| Vaini-Longoteme Road | Vaini | 1,252 | Accounted for in Pea line | - | - | - | - | - | - | - |
| Taufa'ahau Road | Vaini Police Station | 9,298 | Accounted for in Pea line | - | - | - | - | - | - | - |
| Vaini-Longoteme Road | Sei'uhila | 554 | Accounted for in Pea line | - | - | - | - | - | - | - |

| Road | Counter Location | Vehicles per Day | Destination A | Kilometers to A | Vehicles to A | Daily VKT | Destination B | Kilometers to B | Vehicles to B | Daily VKT |
|---|---|---|---|---|---|---|---|---|---|---|
| Folaha Road | Nualei | 1,012 | Accounted for in Pea line | - | - | - | - | - | - | - |
| Taufa'ahau Road | Pea | 12,400 | Viani | 7.2 | 10,550 | 76,387 | Folaha [a] | 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 [b] | | | 4.8 | 5,000 | 24,135 | - | - | - | - |
| Intra-Hahake trips | No counters [b] | | | 4.0 | 5,000 | 20,113 | - | - | - | - |
| **Total daily VKT in Tongatapu:** | | **545,531** | | | | | | | | |

[a] 284 of these cars are assumed to continue 3.2 km past Faloha on to Vietongo and the coast.

[b] Source: Ministry of Infrastructure.

As shown in Table A-1, the total daily VKT recorded in Tongatapu was 545,531 VKT. Assuming that this flow is consistent 6 days per week (excluding Sunday for the religious holiday), this results in nearly 171 million VKT per year. To extend this calculation from Tongatapu to all of Tonga, a linkage was made between VKT and fuel use. Because 15% of land transportation fuel is used on islands other than Tongatapu, it was assumed that 15% of VKT also occurs on other islands. This assumption results in the estimate of 2,152 VKT per capita in 2015, when Tonga consumed 27,078,759 liters of fuel. With the assumption that the fuel economy is consistent, this equates to 2,311 VKT per capita in 2021. With a VKT per capita of 2,311 and fuel usage of 36,206,856 liters in 2021, this equates to a fuel economy of 12.5 L/100 km.

The connection between VKT and GDP per capita is used (shown in Figure A-2) as the next step in projecting Tonga's fuel consumption. According to RAND, a nation's per-capita VKT tracks its GDP per capita when it is between $5,000 and $10,000 (Ecola et al. 2014). This has been true since Tonga entered that range in 2015. The United Nations' population projections were used to project Tonga's GDP per capita (United Nations 2022). To project Tonga's VKT as its GDP per capita increases, the moving average equation of 25 countries was used as shown in Figure A-2. With $R^2 = 0.9808$, this is the most accurate projection method because it considers multiple sets of countries.

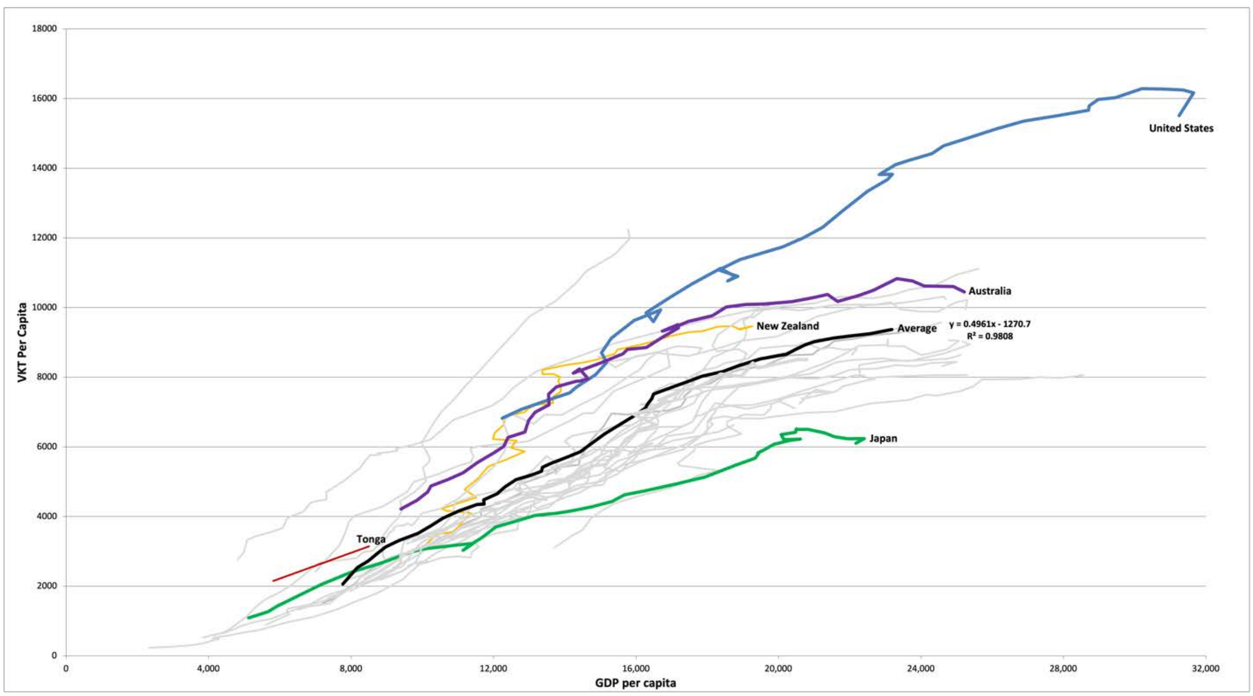


**Figure A-2. International VKT vs. GDP per capita (in international dollars).**

Derived from Ecola et al. 2014

Finally, because VKT is most closely related to fuel usage, the same best fit line was used in projecting Tonga's fuel consumption through 2050. As a result, Tonga is projected to consume 33,312,507 liters of gasoline and 15,723,645 liters of diesel in 2050. Figure A-3 and Figure A-4 show the plotted results for the BAU scenario; however, Figure A-4 also includes an upper and lower limit for the fuel projections. This gives a more accurate range of fuel consumption using a forecast and confidence function within Microsoft Excel. Finally, Figure A-5 shows the projected GHG emissions in this BAU scenario based on the diesel and gasoline consumption projections.

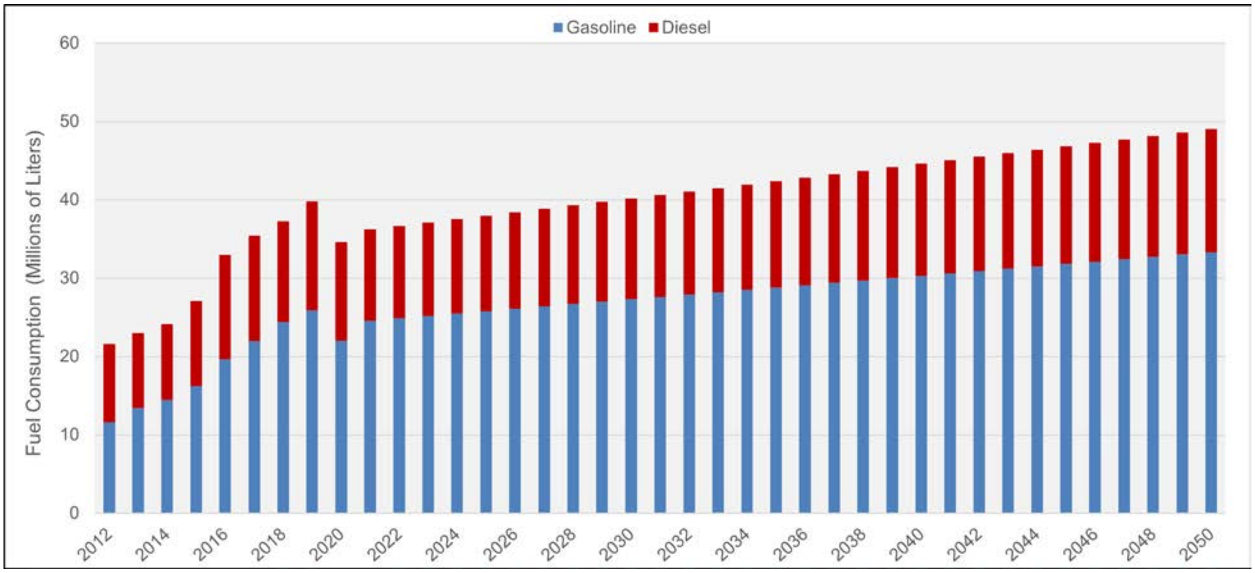


**Figure A-3. Historical and BAU projected gasoline and diesel fuel consumption for land transportation in Tonga (2012–2050).**

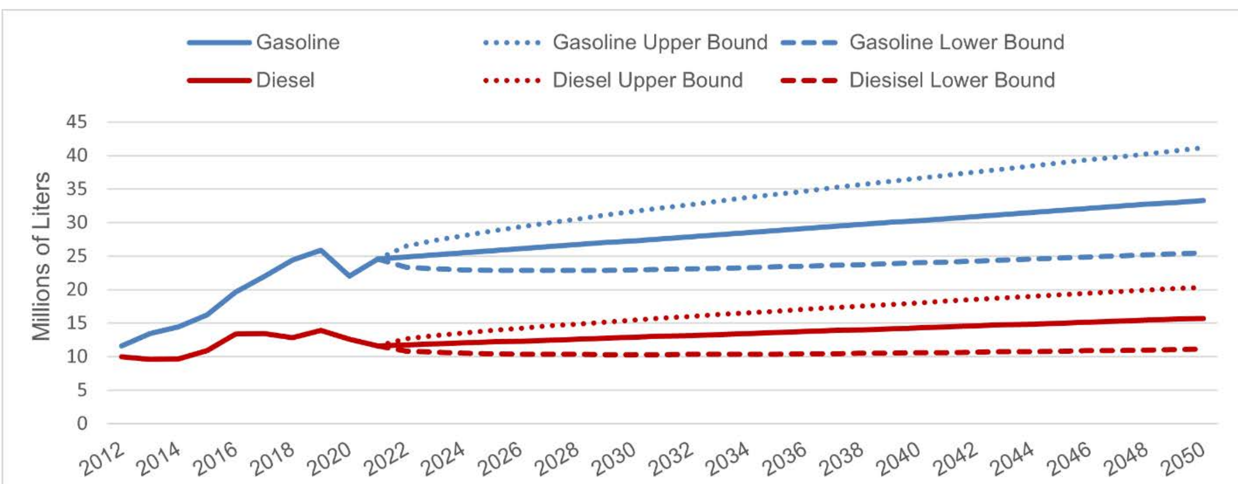


**Figure A-4. Historical and BAU range for projected gasoline and diesel fuel consumption for land transportation in Tonga (2012–2050).**

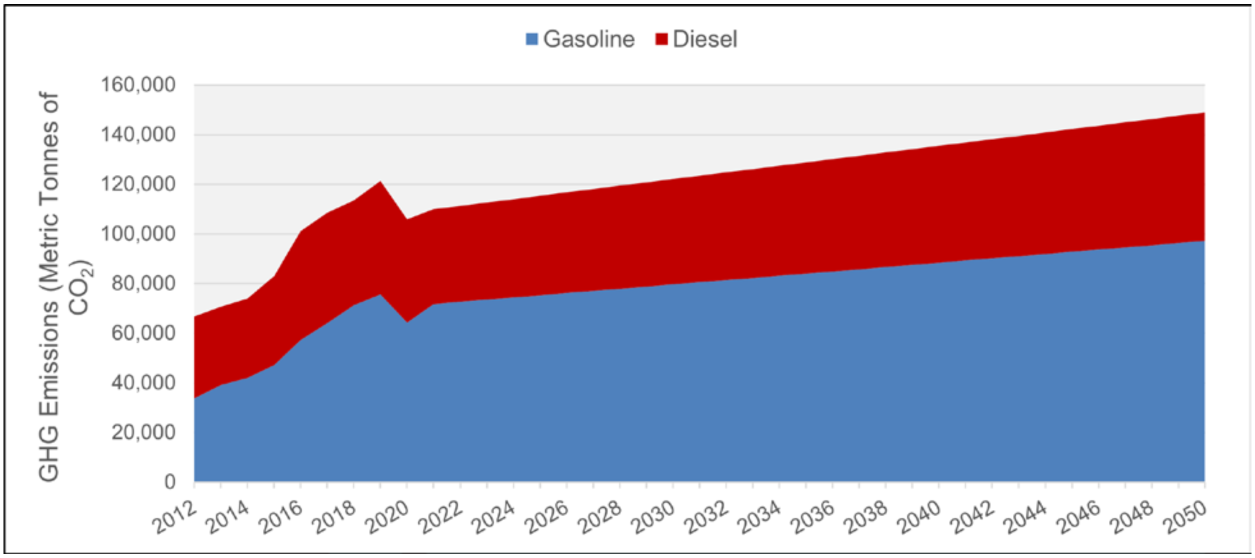


**Figure A-5. Historical and BAU projected GHG emissions from gasoline and diesel fuel consumption for land transportation in Tonga (2012–2050).**

Note: This assumes emissions factors of approximately 2.9 kg $CO_2$/liter and 3.3 kg $CO_2$/liter for gasoline and diesel, respectively. These are the same assumptions used in TEEMP.

# Appendix B: Battery End-of-Life Best Practices

## General Practices for Battery Storage and Transportation

- Individually package (bag) cells in nonconductive material.
- Arrange cells to prevent any cell-cell terminal contact.
- Use a nonflammable substance such as vermiculite as a packaging medium between cells.
- Store the cells in a nonflammable, rigid-walled container (to protect from mechanical damage).
- Regulate the environment to prevent temperature, pressure, and humidity variation.
- Maintain a cold, dry environment.
- Discharge cells as much as possible before storage or transportation.

## Resources for Further Reference


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# Appendix C: Summary of Policy Options and Interactions in Matrix Form

**Table C-1. Summary of Policy Options and Interactions in Matrix Form**

| Section | Policy | Phase | Intended Outcome | Relationship With Other Proposed Policies | Resilience Impact |
|---|---|---|---|---|---|
| 2.1 | Feebate | 1 | Improve fuel economy and provide funding | Revenues can fund most other policies | Improved efficiency gets more transportation done when fuel is limited |
| 2.2 | Nukuʻalofa comprehensive parking strategy | 1 | Induce demand for alternative transportation and provide funding | Revenues can fund other system efficiency policies focused on Nukuʻalofa | Decongested evacuation routes |
| 3.1 | Bicycle and pedestrian infrastructure | 1 | Mode Diversification | Enhances the bike-/scooter-share, P&R lot, SRTS, and on-demand shuttle policies. Paid parking funds and induces demand for this policy. | Decongested evacuation routes. Increased modes of evacuation. |
| 3.2 | Safe passing laws | 2 | Mode Diversification | Enhances the SRTS, bike-/scooter-share, bike/pedestrian infrastructure, and paid parking policies. | Decongested evacuation routes. Increased modes of evacuation. |
| 3.3 | SRTS program | 2 | Mode Diversification | Needs bike infrastructure and bicycle passing law to be effective. | Decongested evacuation routes. Reduced buses available for evacuation. |
| 3.4 | Bike- and scooter-share program in Nukuʻalofa | 3 | Mode Diversification | Enhanced by bike/pedestrian infrastructure and safe passing law. Paid parking funds and induces demand for this policy. | Decongested evacuation routes. Increased modes of evacuation. |
| 3.5 | P&R | 3 | Mode Diversification | Coordinates with on-demand shuttle, biking infrastructure, and bike-/scooter-share policies. Paid parking funds and induces demand for this policy. | Decongested evacuation routes. Could leave people stranded. |
| 3.6 | Ride-share coordination website | 3 | Mode Diversification | Integrates with on-demand shuttle policy. Paid parking funds and induces demand for this policy. | Decongested evacuation routes. Could leave people stranded. |

| Section | Policy | Phase | Intended Outcome | Relationship With Other Proposed Policies | Resilience Impact |
| --- | --- | --- | --- | --- | --- |
| 3.7 | On-demand shuttle service | 3 | Mode Diversification | Integrates with ride-share coordination website. Paid parking funds and induces demand for this policy. | Decongested evacuation routes. Could help evacuate handicapped people. Dependent on vulnerable cell towers. |
| 4.1 | Standards for Mode 3 and Mode 4 charging | 1 | Safe EVs and Charging | Coordinates with standards for Mode 1 and Mode 2 charging. | Standards and related tests ensure equipment can withstand certain weather, flooding, shocks, and cyberattacks. |
| 4.2 | Standards for Mode 1 and Mode 2 charging | 1 | Safe EVs and Charging | Coordinates with standards for Mode 3 and Mode 4 charging. | Standards and related tests ensure equipment can withstand certain weather, flooding, shocks, and cyberattacks. |
| 4.3 | Charging mode requirements | 1 | Safe EVs and Charging | Coordinates with standards for Modes 1–4 charging. | Reduces potential damage to the EV charging station. |
| 4.4 | Battery EOL planning | 2 | Safe EVs and Charging | Relates to the EV shipping assurance policy. | Reduces risk of fire during flooding. |
| 5.1 | EV shipping assurances and precautions | 1 | Accessible EVs and Charging | Important for battery EOL planning. | Enables EV adoption and diversification of transport powertrains/fuels. Also increases dependence on grid. |
| 5.2 | EV education programs | 1 | Accessible EVs and Charging | Public awareness enhances the effectiveness of all other policies. Maintenance knowledge linked to EV insurance and EOL battery planning policies. | Enables EV adoption and diversification of transport powertrains/fuels. Also increases dependence on grid. |
| 5.3 | Charging station placement | 2 | Accessible EVs and Charging | Impacted by parking strategy. Related to charging station incentives. | Minimizes flood risk to charging stations. Better EV evacuation is enabled. |
| 6.1 | Waiving import or registration fees | 1 | Affordable EVs and Charging | Related to the feebate policy. EV adoption is linked to charger deployment. | Enables EV adoption and diversification of transport powertrains/fuels. Also increases dependence on grid. |
| 6.2 | EV tax credit or purchase rebate | 1 | Affordable EVs and Charging | Related to the feebate policy. EV adoption is linked to charger deployment. | Enables EV adoption and diversification of transport |

| Section | Policy | Phase | Intended Outcome | Relationship With Other Proposed Policies | Resilience Impact |
| --- | --- | --- | --- | --- | --- |
| | | | | | powertrains/fuels. Also increases dependence on grid. |
| 6.3 | Charging station business model incubator | 2 | Affordable EVs and Charging | Directly relates to charging station placement, charging station incentives, and reduced price of charging. | Increases EV charging station numbers, redundancy, and resilience. Can promote resilient business models. |
| 6.4 | Charging station incentives | 2 | Affordable EVs and Charging | Directly relates to charging station placement, charging station business model incubator, and reduced price of charging. | Increases EV charging station numbers, redundancy, and resilience. |
| 6.5 | EV insurance pricing | 2 | Affordable EVs and Charging | Linked to EV affordability policies especially for fleets (bulk purchase incentives). | Increased insurance and vehicle repairs. |
| 6.6 | Bulk vehicle purchase incentives | 2 | Affordable EVs and Charging | Enables on-demand shuttle fleet purchases. | Enables EV adoption and diversification of transport powertrains/fuels. Also increases dependence on grid. |
| 6.7 | Reduced price of public charging | 3 | Affordable EVs and Charging | Integrates with paid parking and charging station deployment policies. | Enables EV adoption and diversification of transport powertrains/fuels. Also increases dependence on grid. |
| 7.1 | Electricity TOU pricing | 1 | EV Charging as a Grid Asset | Relates to the other "charging as a grid asset" policies and to reduced cost of public charging. | Increases flexibility and resilience of electricity grid. |
| 7.2 | Net metering | 1 | EV Charging as a Grid Asset | Makes V2G lucrative. | Increases flexibility and resilience of electricity grid. |
| 7.3 | Electricity demand response | 2 | EV Charging as a Grid Asset | Relates to the other "charging as a grid asset" policies. Generally not used with TOU pricing. | Increases flexibility and resilience of electricity grid. |
| 7.4 | Bidirectional charging for V2G and V2H | 3 | EV Charging as a Grid Asset | Requires net metering. Pairs with TOU pricing or demand response. | Increases flexibility and resilience of electricity grid. |