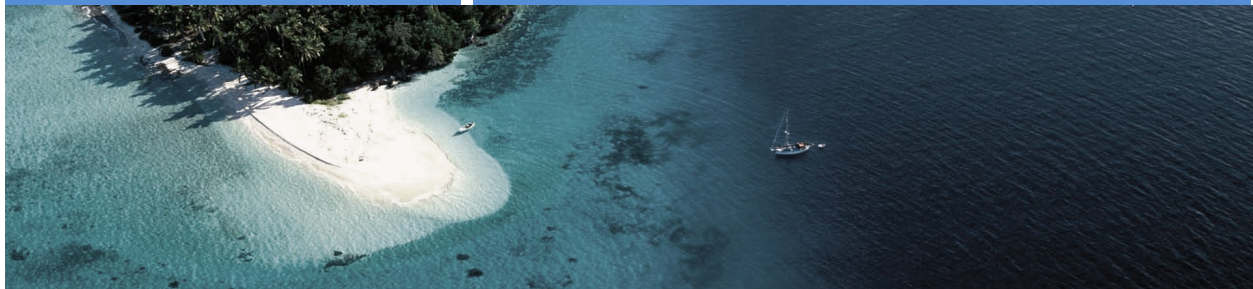


**Government
of Tonga
Energy
Efficiency
Master Plan**



August 2018



EXECUTIVE SUMMARY

At the request of the Tonga government, the Climate Technology Centre and Network has worked closely with the Tongan Energy Department to develop a Tonga Energy Efficiency Master Plan (TEEMP) for adjustment and adoption by the relevant Tongan entities. The plan is based on study of existing frameworks, plans, programs, and projects; extensive stakeholder consultations; and data development and analysis. The TEEMP encompasses electricity use and ground transportation. The TEEMP complements the approach of the 2009 Tonga Energy Road Map 2010–2020 (TERM). The TERM focuses on reducing Tonga’s fossil fuel dependence through increased energy efficiency and improved supply chains in an effort to mitigate the price volatility of imported products as well as reduce greenhouse gas (GHG) emissions and improve national energy security.

A baseline assessment of Tonga’s GHG emissions was built from Tonga’s nationally determined contribution (NDC), which identifies the key emitting sectors as transport (40%), electricity generation (23%), agriculture (21%), waste (11%), and other energy (5%). The TEEMP addressed 55% of these total GHGs: electricity generation (23%) and ground transportation (32%). A Sankey analysis determined energy source flows by fuel type for building electricity consumption and transportation. Roughly half of all diesel consumption goes towards transportation and the other half is consumed by electricity generation for building electrical use (primarily space cooling, lighting, and appliances in the residential and commercial sectors). The remainder of transportation fuel is petrol.

As of 2017, the total installed electricity generating capacity on Tonga’s largest island, Tongatapu, was 17.8 megawatts (MW), with 14 MW of conventional capacity from diesel generators, 2.3 MW from solar photovoltaics, 0.5 MW from wind, and a 1 MW battery storage system. This installed capacity is an increase from 2012, when Tongatapu had 12.6 MW of conventional capacity and 1.3 MW of renewables. The growth in capacity is attributable to government leadership to deploy more renewable energy (RE) generation, and increased electrical load, primarily driven by increased ownership of electrical appliances. Tonga Power Limited (TPL), the vertically integrated utility, owns and operates most of Tonga’s in-front-of-meter electricity generation, as well as its transmission and distribution assets. Electricity rates have important implications for incentivizing or disincentivizing energy efficiency investments. Despite differences in generation cost, the TPL tariff rates are standardized across the four main island; as of February 2018, the tariff was set at 0.8514 Tongan Pa’anga (aka TOP) per kilowatt-hour (kWh). There is also a subsidized “lifeline tariff” of 0.7 TOP for the first 100 kWh of monthly consumption, applicable to all customers. Given that most of Tonga’s electricity is generated from diesel, the price of electricity is sensitive to fluctuations in fuel costs.

Tonga’s estimated energy intensity is 216.8 gigajoules (GJ) of imported fuel per U.S. dollar of gross domestic product per capita, rising under the business-as-usual (BAU) scenario to 259.8 GJ by 2030. In 2017, the residential sector accounted for 44% of electricity consumption, with commercial, religious, government, and public service accounts making up the remaining 56%. The TERM indicates an expected growth in energy consumption of 28% by 2020 compared with 2010 levels. An estimated baseline for transportation is more than 16,000 vehicles in Tonga for residential, commercial, and government use in 2016. Most vehicles were either cars (6,031) or light trucks/vans/sport utility vehicles (7,103). Heavy duty vehicles, taxis and rentals, motorcycles, and buses accounted for the remaining 3,690 vehicles. Current average vehicle kilometers traveled per person was estimated to be 2,289 in 2016 and is projected to grow to 5,103 by 2050, tracking with anticipated gross domestic product increases. These vehicles used more than 25 million liters of gasoline and diesel in 2015, which was projected to grow to 38.5 million liters in 2030 resulting in the emission of 118,000 metric tons of carbon dioxide equivalent.

Key policy options identified for transportation include vehicle import tariffs or registration fees aimed at improving fuel economy, restrictions in heavy-duty vehicle idle time, introduction of a 10% biodiesel blend, deployment of electric vehicles, and policies that reduce vehicle kilometers traveled by supporting pedestrians, bikers, carpoolers, and bus riders. These reductions in energy use in the transportation sector would result in an estimated 28% reduction in GHGs below BAU levels by 2030, which is an increase of 1% over the 2018 baseline.

In the building sector, Tonga’s electricity consumption is driven by building design, appliance use, and energy consumption behaviors. Given Tonga’s tropical climate, cooling commercial, government, and nongovernmental buildings with air conditioning is widespread and increasing. There may be opportunities to reinstitute design practices from historical buildings, such as passive ventilation and large overhangs to provide shading. Leading

energy use reduction options in the buildings sector center around increased deployment of RE, reductions for implementation of minimum energy performance standards, improvements to space cooling, increased appliance efficiency, and reductions in energy used for lighting (in building and streetlighting applications).

Taken together, reductions in energy use in both transport and buildings would offer a reduction of 106,000 metric tonnes of carbon dioxide equivalent per year by 2030, which is a 50.5% reduction from BAU emissions of 210,000 metric tonnes of carbon dioxide equivalent. As shown in Figure E1, transportation accounts for a 30.4% of the reduction, renewable electricity for 40% of the reduction, and energy efficiency in buildings and lighting for 29.6% of the reduction. If Tonga reaches 70% RE by 2030, it is assumed there will only be a slight increase in petroleum energy intensity by 2030. But if RE penetrations are greater than 50%, this energy intensity could be reduced, thereby also supporting Tonga’s energy independence and security.

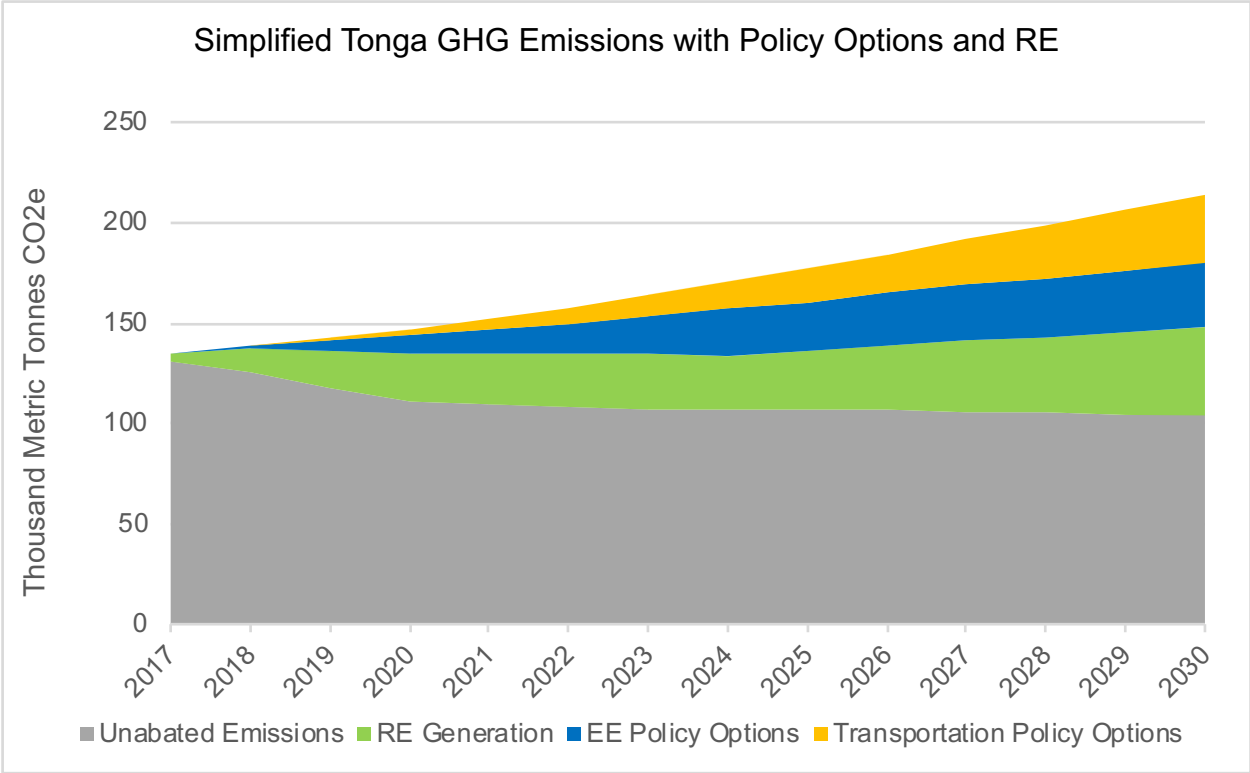


Figure E1. Wedge analysis of Tonga’s greenhouse gas emissions

Tables E1 and E2 provide further assessments of the top ten policy options for transport and electricity in buildings and streetlighting that could support the GHG reductions identified in the wedge analysis (additional policy options and measures are identified in this report). The options are ranked by the magnitude of GHG reductions, up-front cost, time to implement, ancillary benefits, and support available in terms of financing and political will. Green indicates positive attributes, yellow neutral, and red negative attributes.

Table E1. Top 10 Policies and Projects to Reduce Greenhouse Gas Emissions from Transportation

Wedge	Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Available
VKT Reduction	Use a platform such as NextBus to track and coordinate buses	High	Low	Low	High	High
VKT Reduction	Enact a safe bicycle passing law	High	Low	Low	Med	High
EV and HEV	Send a mechanic to HEV/EV maintenance training in Japan or New Zealand	High	Low	Low	Med	High
VKT Reduction	Provide pedestrians (particularly school children) and cyclists with safety reflectors and lights	Med	Low	Low	High	High
VKT Reduction	Install rumble strips and painted lines demarcating lane boundaries parallel to sidewalks to increase pedestrian safety	High	Low	Low	Med	Med
Idle Reduction	Limit idle time with the help of fleet partners and idle reduction technologies	Med	Low	Low	High	Med
Vehicle Efficiency	Adjust vehicle registration tax and import tariff according to vehicle weight, displacement, or fuel economy	High	Low	Low	Med	Low
Biodiesel	Blend diesel fuel with waste grease and coconut oil biodiesel at 10% blend	High	Low	Med	Low	High
VKT Reduction	Begin a water taxi in the lagoon (and some associated dredging)	High	Med	Med	High	Med
VKT Reduction	Build a strategic parking lot and bus stop at intersection of Taufu'ahau Rd. and Loto Rd. and accompaly with Nuku'alofa parking policy	High	High	Med	High	High

Table E2. Top Eleven Policies and Projects to Reduce Greenhouse Gas Emissions from Electricity

Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Available
Implement building standards for resilience and energy efficiency (e.g. passive ventilation and daylighting with appropriate external shading)	High	Low	Med	High	High
Perform energy audits of buildings to create baselines and implement energy conservation measures	High	Low	Med	High	Med
MEPs for equipment and appliances	High	Low	Med	Med	High
Set packaging and recycling standards to limit the amount of waste imported to Tonga	High	Low	Med	High	Med
Implement a public awareness campaign on energy efficiency and conservation	High	Low	Med	Med	Med
Establish a demand-side management revolving loan or rebate program to aid in financing more efficient equipment (residential, commercial and industrial)	High	Med	Med	High	Med
Prioritize on-site RE with islanding controls and energy storage within critical infrastructure	High	High	Med	High	High
Implement distributed energy generation projects that incorporate RE and fossil fuels to enhance resilience and reduce emissions associated with diesel generation, particularly when electrifying new areas or islands	High	High	Med	High	Med
Work with TPL to create an integrated resource plan to incorporate RE, EE, and more efficient reciprocating engines that can be dual fuel	High	Med	High	Med	High
Data collection exercise/database to manage energy data by sector	Med	Med	Low	High	Med

Given Tonga's vulnerability to climate change and tropical storms, it is important to consider how improvements in the electric and transport sectors can also support increased resilience in terms of enhancing the ability of energy and transportation infrastructure to withstand and recover more quickly from natural and manmade disasters. The primary ways in which Tonga can strengthen its resilience are by:

1. Incorporating resilience into building codes to enable buildings and structures to better withstand storms while also supporting energy-efficient, passive design
2. Continuing to harden transmission and distribution lines and power generation by burying strategic lines and installing minigrids and on-site RE, among other measures
3. Diversifying the fuel mix from diesel to biodiesel and exploring fuel procurement from sources other than Singapore
4. Improving vehicle efficiency, which enables more transport options if fuel supplies are diminished
5. Reducing dependence on roads, which may become damaged in a disaster, by enabling additional modes of transport such as water taxis, and shortcutting large sections of road with a bridge
6. Optimizing use of appropriate vehicles—such as buses with raised clearance—and using the bus system effectively to support evacuations.

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Acronyms

BAU	business as usual
CO _{2e}	carbon dioxide equivalent
CTCN	[United Nation’s] Climate Technology Centre and Network
EE	energy efficiency
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
HDV	heavy-duty vehicle
HEV	hybrid electric vehicle
IRP	integrated resource plan
JICA	Japanese International Cooperation Agency
kWh	kilowatt-hour
LED	light emitting diode
LDV	light-duty vehicle
MCCTIL	Ministry of Commerce, Consumer, Trade, Innovation, and Labour
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change, and Communications
MEPS	minimum energy performance standards
MET	Ministry of Education and Training
MOI	Ministry of Infrastructure
MWh	megawatt-hour
NDC	nationally determined contribution
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PRDR	Pacific Regional Data Repository
PV	solar photovoltaic
RE	renewable energy
TEEMP	Tonga Energy Efficiency Master Plan
T&D	transmission and distribution
TERM	Tonga Energy Road Map
TPL	Tonga Power Limited
UN ESCAP	United Nation’s Economic and Social Commission for Asia and the Pacific
VKT	vehicle kilometers traveled

I Context

Tonga is dependent on imported petroleum to meet its energy needs for electricity and transportation. Electricity generation consumes nearly 13 million liters of fuel per year, at a cost equivalent to about 10% of total gross domestic product (GDP) and transportation consumes 25 million liters at a cost close to 20% of GDP.¹ Dependence on imported fuels places Tonga in a vulnerable position due to volatile fuel prices, which have a downstream effect on electricity, transportation, and cost-of-living expenses. This study provides background information for setting an energy and emissions baseline and establishing a business-as-usual (BAU) projection. The data collection methods and sources highlighted in this report will also help Tonga track energy use and emissions in the future. The BAU scenario was then taken as a starting point to assess the options, magnitude, and feasibility of reducing Tongan greenhouse gas (GHG) emissions. The Tongan Energy Department requested technical assistance from the United Nation's Climate Technology Centre and Network (CTCN). Under the CTCN, support was provided for technical assistance and capacity building surrounding the development and implementation of a Tonga Master Energy Efficiency Action Plan (TEEMP). A training was held in Nuku'alofa in June 2018 with the dual purpose of capacity building and in-depth review of the TEEMP by Tongan officials. This document hereby represents the flagship deliverable of this effort and reflects extensive research conducted in 2017 and 2018 via in-person stakeholder consultations, policy and regulatory analysis, and modeling.

I.1 Background and Focus of Effort

In 2009 Tonga developed the *Tonga Energy Road Map 2010–2020: Ten Year Road Map to Reduce Tonga's Vulnerability to Oil Price Shocks and Achieve an Increase in Quality Access to Modern Energy Services in an Environmentally Sustainable Manner*, known as the TERM.² The goal of the TERM was to create an approach to reduce Tonga's dependence on fossil fuels through cost-effective and sustainable efforts. The process of developing the TERM was a joint effort among the Government of Tonga, the electricity generator and distributor Tonga Power Limited (TPL), and other development partners. The TERM focuses on electric energy efficiency (EE), improving supply chains to mitigate the effect of price fluctuations in imported products, reducing GHG emissions, and improving national energy security. The TERM establishes a goal of approving a policy to supply 50% of electricity generation through renewable resources by 2020. The TERM includes improvements in the petroleum supply chain to reduce the price and price fluctuation of imported petroleum products, increase the efficiency of converting petroleum to electricity (i.e., through increases in efficiency and reductions in losses at TPL), and improve the efficiency of converting electricity into consumer electrical services (demand-side management measures). It also includes replacing a portion of current or future grid-based generation with renewable energy (RE).³ Transportation is not a focus of the TERM.

Policies and initiatives that have been implemented since the creation of the TERM include:

- The National Strategic Planning Framework (2009)
- The Electricity Act (2007)⁴
 - Established an energy commission appointed by the monarch in council, which has broad regulatory authority. The Act sets standards for generation, supply, and distribution concession contracts submitted to the commission.
- The Renewable Energy Bill (2008)⁵
 - Established a renewable energy authority, consisting of members appointed by the monarch in council and tasked with developing renewable standards, conducting research, relaying international obligations to the monarch, and enforcing violations of RE policy against offenders.
- Joint National Action Plan on Climate Change Adaption and Disaster Risk Management (2010)⁶
 - Assesses geographic risk posed by natural disasters such as cyclones and tsunamis. Provides framework and financing structure to integrate disaster and risk planning into budgeting at all levels.
- Ozone Layer Protection Act (2010), amended (2014)⁷
 - Bans the importation of products (refrigerators, freezers, dehumidifiers, air conditioners, heat pump units, vehicle air conditioners, ice machines, water coolers, aerosol products, fire extinguishers, insulation boards, and pre-polymers) that contain hydrochlorofluorocarbons (which are ozone-depleting substances and also potent GHGs).
- Tonga Village Network Upgrade Project (2012)⁸
 - Reduced line losses from 18% to 12% in 20 villages, working to expand to more.

- Promoting Energy Efficiency in the Pacific (2014)⁹
 - Funded by Asian Development Bank, Australia, and Japan
 - Residential light replacements saving 383,999 kilowatt-hours (kWh)/year
 - Public Service Building light replacements saving 158,706 kWh/year
 - Streetlight upgrades saving 97,219 kWh/year.
- Tonga’s Intended Nationally Determined Contribution
 - Formalizes 50% renewable electricity goal by 2020, 70% by 2030
 - Reduce line losses to 9% by 2020
 - Formally deposited, rendering it a nationally determined contribution (NDC).
- Tonga Strategic Development Framework II (2015–2025)¹⁰
 - Revisits the original TERM goal of 50% renewable from 2012 to 2025; 2020 for rural communities (this contradicts the NDC released the same year)
 - Sets a goal of no more than 12% transmission and distribution (T&D) losses by 2020
 - Sets a short-term goal of converting 75% of the diesel-based water pumping systems in Tongatapu to solar photovoltaics (PV)
 - Establishes a goal of 80% of retail stores selling reliable compact fluorescent lightbulbs at the “same cost” as incandescents
 - Banning import of inefficient electrical appliances
 - Banning all inefficient electrical appliance at border control.
- Outer Island Renewable Energy Project (2017)¹¹
 - The first phase of the Tonga Renewable Energy Plan
 - Project to rebuild ‘Eua’s grid announced in 2012
 - Invitation for international bids announced in February 2017.
- Tonga Renewable Energy Plan (2017)¹²
 - A project supported by the Green Climate Fund to finance projects intended to contribute towards Tonga’s 50% renewable by 2020 plan. Total project cost is estimated at \$84.47 million, with \$64.37 million requested from the Green Climate Fund, \$9 million from the government of Tonga, and \$6.10 million from TPL.
 - Phase 3 of a broader plan, including the Outer Island Renewable Energy Project (Phase 1), and power purchase agreement procurement of solar and wind resources (Phase 2).
 - Includes the installation of a new biomass plant on Tongatapu along with battery storage, PV, and wind.

1.2 About Tonga

Tonga's geographic location, demographics, and governance structure have important implications for the energy sector. Tonga is in the Pacific Ocean, as shown in Source: **University of Texas**

Figure 1,¹³ and comprises 170 islands, 36 of which are populated.

Tonga is prone to both earthquakes and tropical cyclones. Notable instances include a 2009 magnitude 8.1 earthquake and subsequent tsunami, as well as 2014's Cyclone Ian, which struck Ha'apai directly, damaging or destroying 90% of T&D lines.¹⁴ In 2018, Cyclone Gita brought the strongest winds Tonga had seen in 60 years, damaging 40%–50% of Tongatapu's electric grid.¹⁵ In the average El Nino year, 1.88 cyclones affect Tonga, 1.63 in La Nina years, and 1.67 during neutral years.¹⁶ Tonga's government vocally attributes the increasing severity of tropical cyclones to climate change; in response, policy documents focus on planning for resiliency.

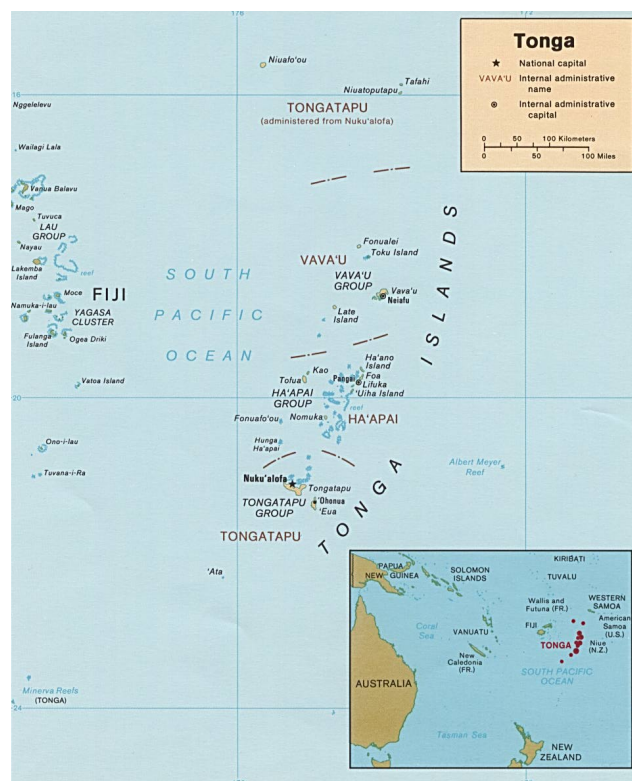
Due to its small economy and lack of a significant local manufacturing base, Tonga imports almost all its goods, including fuel for energy generation and transportation, vehicles, appliances, and electronics. The TERM recognizes the vulnerability that results from this dependence and outlines some goals to address the challenges created by relying on imported goods and fuels.

The monarch remains a significant power broker in Tonga—policy changes, related to energy or not, are subject to the consideration of both the king and the prime minister.¹⁷ Both the king and the prime minister are supportive of reducing Tonga's climate vulnerability and improving the nation's energy independence. In a move symbolic of "wider leadership," the monarch of Tonga joined the Solar Head of State program at the Conference of the Parties 23 in November 2017. The program will install a rooftop PV system on the king's residence, the first royal palace in the world to do so.¹⁸

The legislature established a National Statistics Department in 2015 tasked with conducting a census and compiling administrative records of government departments.¹⁹ Although the availability of information from government ministries has markedly improved since the passing of this act, a lack of consistency in statistics reported year-to-year and a difficulty in obtaining this information persists. These problems are also apparent for state-owned enterprises such as TPL. Data availability has important implications for analyzing and tracking changes and opportunities in the energy sector, and, thus, for the design of the TEEMP. Specific recommendations broached later on include engaging TPL in developing an integrated resource plan (IRP), collecting sectoral data, surveying energy usage habits in future censuses, and standardizing data collection of customs and annual ministerial reporting. Regional organizations such as the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE), the United Nation's Economic and Social Commission for Asia and the Pacific (UN ESCAP), and the Pacific Regional Data Repository (PRDR) already exist to aggregate applicable data sets, and working with such organizations would open opportunities for regional knowledge sharing and project financing. UN ESCAP regularly hosts expert consultations with statisticians to assist in capacity building for collecting and housing data.²⁰

2 Baseline

As reported in Tonga's NDC and based on Tonga's GHG emissions breakdown in the inventory conducted in 2006, Tonga's major emissions arise from transport (40%), electricity generation (23%), agriculture (21%), waste (11%) and other energy (5%). A baseline study was conducted as part of the TEEMP process to determine where savings

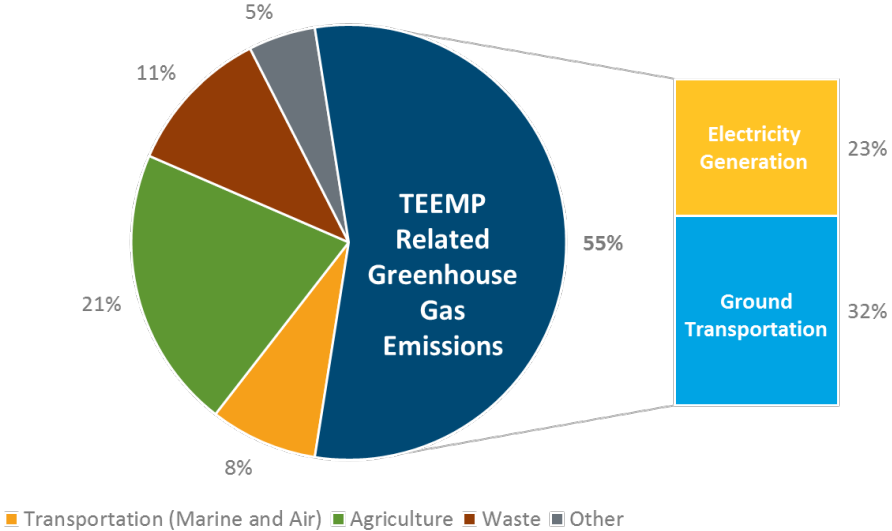


Source: University of Texas

Figure 1. Map of Tonga

could be achieved within each of the sectors to assist Tonga in achieving goals established in various legislation and policies. Using available data, the breakdown of Tonga’s emissions was estimated, as shown in Data Sources: **Tonga NDC and MCCTIL**

Figure 2. It is important to note that only 55% of the emissions in Tonga’s overall portfolio are being addressed through the TEEMP: electricity generation (23%) and ground transportation (32%). The remaining emissions from agriculture, waste, air and sea transport, and others are not covered by TEEMP.



Data Sources: Tonga NDC and MCCTIL

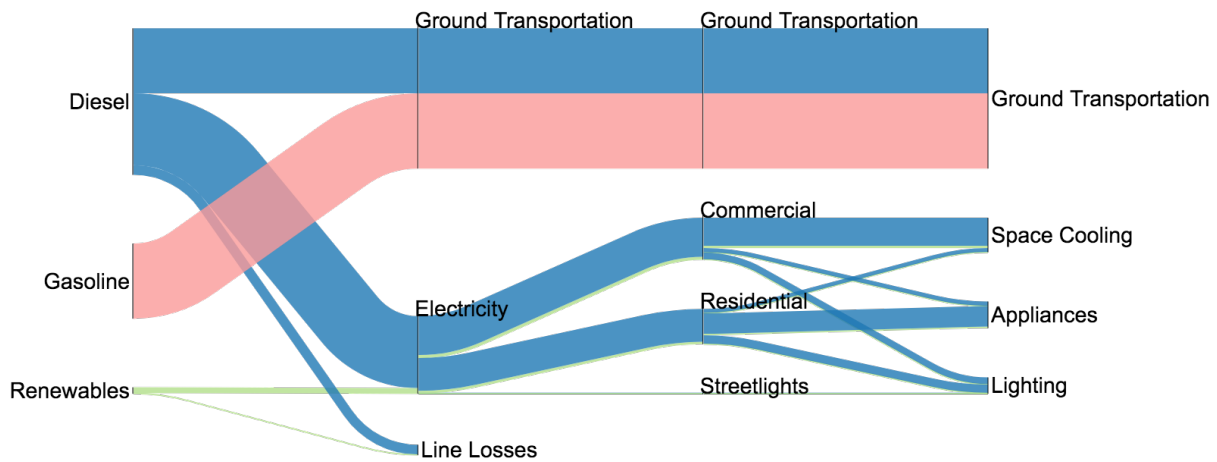
Figure 2. Tonga’s nationally determined contribution reported emissions and Tonga Energy Efficiency Master Plan-related greenhouse gas emissions

Tonga’s NDC states that transportation is responsible for 40% of emissions, and electricity generation is responsible for 23% of Tonga’s overall emissions; however, the NDC uses GHG data from a 2006 inventory. Since the time that the NDC was submitted, TPL’s billed customer consumption has risen by approximately 47%, most likely as a result of an increase in electrification efforts, so the proportion of Tonga’s emissions from electricity are assumed to be higher than stated in the NDC. It is assumed that emissions from non-TPL generators are negligible.

It is unlikely that emissions from the transportation sector have risen at a similar pace, so the proportion of Tonga’s emissions from electricity are assumed to be higher than stated in the NDC. The transportation segment of the NDC includes air and marine, but the TEEMP only addresses ground transportation, such as light- and heavy-duty vehicles. The TEEMP estimates that ground transportation accounts for 80% of Tonga’s total transportation-related emissions as calculated in the NDC.

Using the available data from MCCTIL, a Sankey diagram was created to demonstrate the energy flows, by fuel type, for electricity consumption and transportation fuel consumption for Tonga, as shown in Data Source: **MCCTIL**

Figure 3. These energy flows are influenced by the climate and infrastructure of the islands.



Data Source: MCCTIL

Figure 3. Tonga’s current energy flows by fuel type in the electricity and ground transportation sectors

2.1 Electricity Baseline

Census figures indicate the 2016 population in Tonga was 100,651.²¹ A 2010 survey indicated that 80% of the rural population and 100% of the urban population have access to electricity; in aggregate, the study reported that 92% of the population had access to electricity.²² The 2016 census indicates that 16,662 households get power from the public power supply, 767 from self-owned solar, and 44 from their own generators. TPL saw a 9% growth in new customer accounts between 2016 and 2017.²³ In total, the residential sector accounted for 44% of electricity consumption in 2017. TPL does not break down sectors further, but the remaining 55% of consumption is spread across commercial, religious, government, and public service accounts. There are two peak demands during weekdays—one in the morning and another in the late afternoon. Typically, this type of peak load profile indicates commercial customers are using energy (computers, lighting, air conditioning) when they arrive during the morning hours, and a second peak when energy needs shift to the residential sector as lighting and appliances are used in homes in the evening.

Based on TPL’s 2017 Annual Report, the TEEMP model assumes that the weighted average efficiency of TPL’s diesel generators is 4.15 kWh per liter of diesel fuel. The model allows for generator efficiency to be updated if overhauls or refurbishments are performed in the future. The interaction between RE technologies and diesel generators can also affect the efficiency of generators if they are required to cycle on and off frequently. The installation of battery storage systems as planned can help alleviate this. For both the electricity and transportation analysis, data from the greenhouse gases, regulated emissions, and energy use in transportation (aka GREET) model emissions database²⁴ were used to estimate emissions of diesel fuel at 3.29 kilograms of CO_{2e}/liter.²⁵ This number is a life cycle emissions calculation for the United States, so it includes emissions associated with the extraction and transportation of fuels within and to the United States; emissions associated with transportation of fuel to Tonga are most likely higher. The TEEMP model also accounts for reductions in line losses; Tonga’s NDC sets the target of 9% by 2020 (the Tongan Energy Department estimates they are around 10% as of 2018). In the model, line losses are applied evenly to all generation sources (diesel and renewables). In reality, renewable installations are likely to be located closer to loads and therefore will have lower line losses than diesel.

In 2009, Tonga’s energy intensity was reported as shown in Figure 4.²⁶ Through data collected for the TEEMP, Figure 5 shows the 2018 energy intensity per capita, indicating efficiency improvements. This analysis identified an energy intensity of 216.8 gigajoules (GJ) of imported fuel per U.S. dollar of GDP per capita, rising under the BAU scenario to 259.8 GJ by 2030.

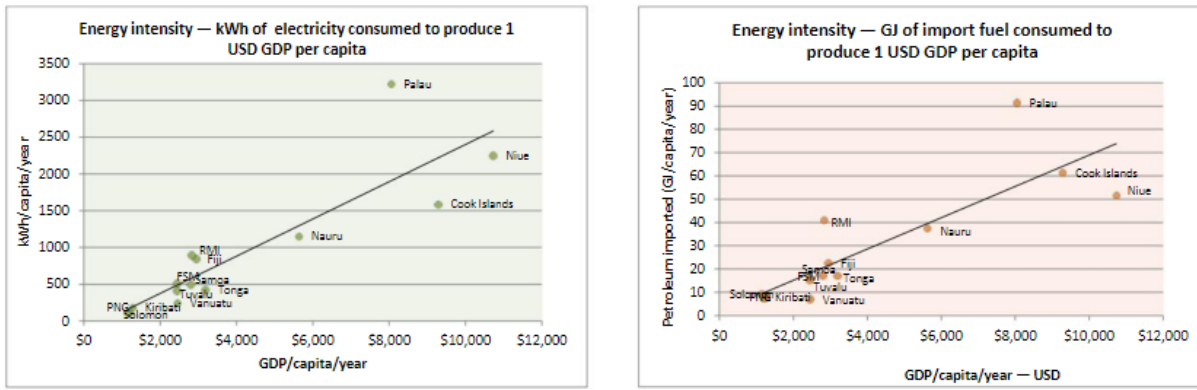


Figure 4. Tonga’s energy intensity per capita, 2009

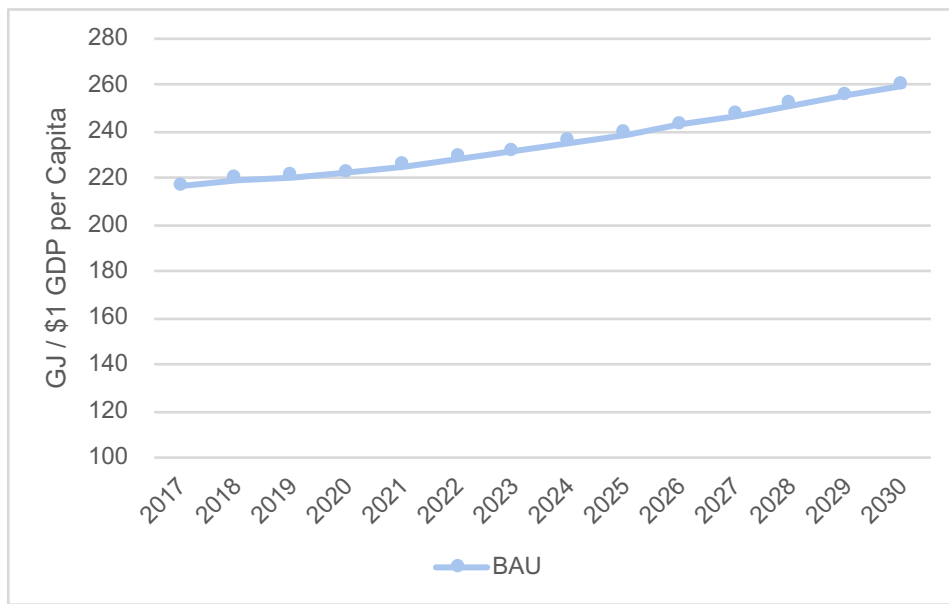


Figure 5 Tonga’s energy intensity per capita, 2017-2030 (business as usual)

2.1.1 Generation, Transmission, and Distribution

TPL is a vertically integrated utility responsible for generation, transmission, and distribution of electricity, and operates four grid systems in Tonga. The largest grid is on the island of Tongatapu, followed in size by the islands of Vava’u, Ha’apai, and ‘Eua. The following sections detail how energy is generated, transmitted, and distributed, as well as areas of consumption, where such data are available. Conservation and management of energy is important for meeting specific targets and goals. Demand-side management, energy conservation, EE, and supply-side management are common practices.

Supply-side management refers to the practice of electric utilities building generating plants to serve whatever demand customers require. This practice was common until the 1970s and now includes incorporation of more efficient generation sources. These are either higher efficiency generators or diversified generation portfolios that include lower-emission fuels (such as natural gas), or RE (such as solar or wind power). Demand-side management is typically undertaken by a utility to change the level or timing of energy use on the customer side of the electricity meter, generally with the intention of optimizing existing and planned generation and transmission assets on the utility side of the meter. It encompasses utility-initiated actions to improve EE, increase energy conservation, and reduce peak electricity demand. Demand-side management activities include rebates, incentives,

and utility investments that improve the EE of building systems (e.g., envelopes, heating and cooling equipment, and lighting systems) as well as rate structures that shift demand from times of peak energy use to off-peak hours.

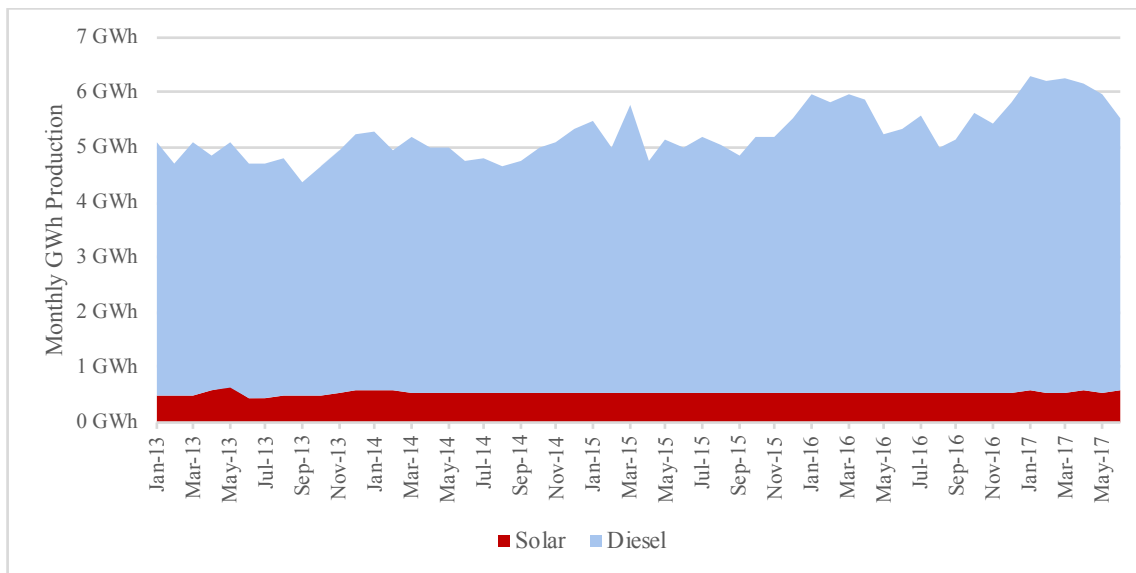
Energy conservation involves using less energy, and typically requires a change in behavior (e.g., turning off lights when not in use, walking stairs rather than using an elevator, and adjusting thermostats on air conditioners to use less energy). Behavior change can be accomplished through education and awareness programs. Implementing higher efficiency technologies or building components (e.g., cool roofing materials) is another standardized practice for conserving energy across building portfolios. EE involves consuming less energy through technological improvements while delivering the same services. An example is switching out incandescent lightbulbs with more efficient compact fluorescent lighting or light emitting diodes (LEDs), which use less energy to provide the same amount of light and produce less heat, resulting in a more energy-efficient lighting system. To understand the opportunities for efficiency and conservation, the grid system and energy consumption within Tonga are discussed in this section.

The 2017 installed capacity of the four island grid systems is shown in Table 1, by source and grid type. Tongatapu’s system represents most of the installed capacity, predominantly supplied by diesel fuel. As of June 2017, the total installed capacity on Tongatapu is 17.8 MW, with 14 MW of conventional capacity from diesel generators, 2.3 MW from PV, 0.5 MW from wind, and a 1 MW battery storage system. In 2012, Tongatapu had 12.6 MW of conventional capacity and 1.3 MW of renewables. The apparent growth in capacity is attributable to renewable-oriented policy ambitions, and increased electrical loads, primarily driven by ownership of electrical appliances. Two additional renewable projects are currently under construction: a 1.3 MW wind farm funded by the Japanese International Cooperation Agency (JICA), and a 2 MW PV project developed by Chinese investors through power purchase agreements with TPL.

Table 1. 2017 Installed Generation Sources (Sources: TPL and MEIDECC)

Location	Grid Status	Conventional Capacity	RE Capacity	Battery Capacity (MW)
Tongatapu	TPL grid (11kV)	14.00 MW	2.80 MW	1.00 MW
Vava’u	TPL grid (medium voltage)	1.87 MW	0.42 MW	0.20 MW
Ha’apai	TPL grid (medium voltage)	0.37 MW	0.50 MW	0.66 MW
Eua	TPL grid (medium voltage)	0.37 MW	0.20 MW	
Nomuka (Ha’apai)	Non-TPL (6.6 kV)	0.09 MW		
Ha’afeva (Ha’apai)	Non-TPL (6.6 kV)	0.06 MW		
Ha’ano (Ha’apai)	Non-TPL (6.6 kV)	0.06 MW		
‘Uiha (Ha’apai)	Non-TPL (6.6 kV)	0.09 MW		
Household generators & solar home systems (Tongatapu)	Off-grid		0.05 MW	
Household generators & solar home systems (Ha’apai)	Off-grid		0.06 MW	
Household generators & solar home systems (Vava’u)	Off-grid		0.13 MW	
Household generators & solar home systems (Niuas)	Off-grid		0.04 MW	
TOTAL		16.91 MW	4.2 MW	1.86 MW

Figure 6 illustrates the gradual increase in capacity to meet rising demand. The figure also shows that solar output remains consistent month-to-month, while diesel generation decreases during the cooler months (June–August), and increases during the warmer months (December–February). TPL already has at least one 11 kW small-scale wind turbine in operation, and a JICA feasibility study concluded that construction should proceed on their 1.3 MW fixed-tilt wind generator.²⁷



Source: TPL Monthly Generation Data (June 2017)

Figure 6. Energy generation mix for Tonga (monthly GWh)

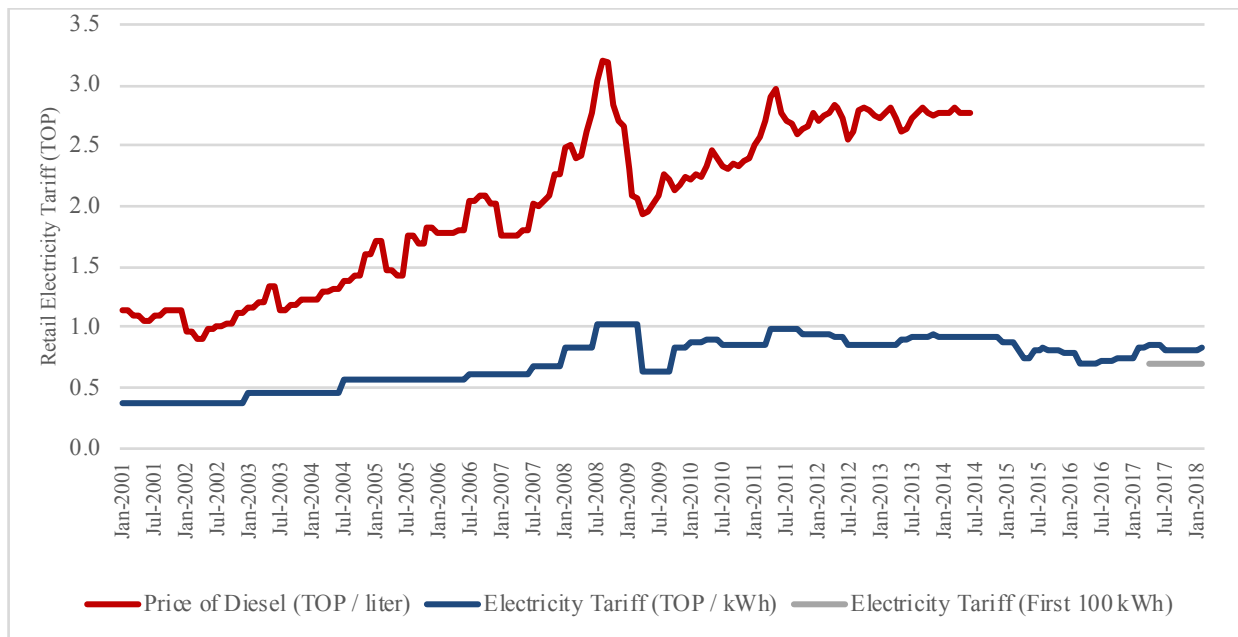
Voltages and T&D losses vary between the four grid systems. Voltages on Tongatapu are 11 kV for primary distribution; three phases: 415 V; single phase: 240 V. However on Vava'u, Ha'apai, and 'Eua, the voltages are 6.6 kV for primary distribution; three phases: 415 V; single phase: 240 V. Most of the primary distribution network on all islands consists of aerial lines supported by wooden poles, the exposure of which makes the grid vulnerable to both parasitic and line losses. Table 2 below demonstrates that although some improvements have been made on the outer islands, T&D losses still remain relatively high. Although official data have only been reported through 2016, Tongan officials have indicated that system-wide line losses stand at around 10% as of 2018.

Table 2. Transmission and Distribution Losses

(Source: TPL Annual Reports [2014/15, 15/16, 16/17])

	TPL (Total)			Tongatapu			Vava'u			Ha'apai			'Eau		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
Line Losses	9%	8%	9%	9%	8%	9%	11%	10%	4%	8%	5%	2%	11%	10%	7%
Parasitic Losses	2%	3%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Billed	89%	89%	88%	89%	89%	88%	87%	88%	94%	90%	93%	96%	88%	89%	91%

The costs of generation vary from island to island due to diesel fuel transport costs. However, in 2009, TPL changed the structure across the four islands to create a more uniform price, providing the same retail tariff across all major islands. The cost per kWh on each island as of February 2018 was 0.8514 Tongan Pa'Anga (aka TOP). Figure 7 details the monthly retail electricity rate in Tonga, along with the associated cost of diesel fuel import to Tonga where available. A spike in the cost of diesel in 2008 rapidly increased rates. In April 2017, in order to lessen the impact of rate increases on consumers, the government introduced a subsidized lifeline tariff, with a fixed rate at 0.7 TOP for the first 100 kWh of monthly consumption, applicable to all customers. Although this rate structure may provide some economic benefit, especially to low-income households, it may also reduce the motivation to install EE or RE technologies and practice energy conservation.



Source: TPL Demand and Prices, PICTS Electricity Tariff Database

Figure 7. Electricity tariff and associated fuel costs

Energy is consumed by different sectors and the load profiles change based on weather. TPL typically reads customer meters manually, taking up to 25 days to complete meter readings, whereas other meters can be read remotely the last day of every month. The difference in meter readings means that TPL uses a 12-month moving average to adjust for anomalies and determine total monthly generated power, parasitic losses, and customer consumption. To improve reporting and power delivery, TPL is completing a meter replacement program. According to TPL’s 2017 Annual Report, 3,000 single-phase meters and 500 three-phase meters were installed in 2016 as Phase 1 of a 2-year project to replace customer meters to improve smart metering capabilities (i.e., remote, automatic meter reading). TPL is planning on upgrading all meters by 2018. The new meters are intended to provide alternative methods of billing and allow TPL to detect faults and power quality issues remotely. The smart metering program may also help improve detection of parasitic losses or line losses. Line losses are determined by subtracting the power consumed by the customer from the power generated.²⁸

2.1.2 Electricity by End-Use Application

Tonga’s overall energy consumption is dictated by building design, building energy-using systems (such as appliances), and behavior around energy consumption. In tropical areas such as Tonga, building cooling loads typically are a large proportion of energy consumption. The use of mechanical air-conditioning systems is widespread and increasing. Thermal comfort and indoor air quality (e.g., managing humidity and indoor pollutants) is being achieved by air conditioning more frequently than relying on vernacular architecture. Historic buildings in Nuku’alofa were designed to use passive ventilation, have large overhangs to prevent solar gains from entering buildings, and, as a result, use less energy than the more modern office buildings, which rely on air-conditioning systems.

This section is broken into the four areas that are commonly associated with the highest energy consumption: building design, residential end uses, commercial end uses, and streetlighting.

2.1.2.1 Building Design

Typically, energy consumption is dictated by the building design and by the equipment or appliances in use within each building type. For example, churches in Tonga are mostly open-air to allow passive ventilation rather than needing air conditioning. This is a great building design to reduce the need for energy for cooling. Daytime services and activities also reduce the need for lighting. The largest energy end uses in churches are lighting, amplification systems (e.g., microphones), and electric fans in open-air buildings designed to use natural ventilation. TPL’s largest customer is a Church of Latter-Day Saints complex built in 2007, which uses an average of 116,000 kWh per month,

or 1.35% of the total billed consumption on Tongatapu.²⁹ This level of consumption indicates an architectural design with closed windows and doors, and a large air-conditioning load. Similarly, office buildings that are not designed to use passive ventilation require air conditioning to prevent mold growth, reduce humidity, and cool to a comfortable temperature. Commercial buildings such as offices use cooling and lighting technologies and also use computers, data processors, printers and facsimile machines, refrigerators, coffee pots, microwaves, etc., all of which generate heat internally, which increases the need to extract the heat for occupancy comfort or cool the interior of the building.

It requires knowledge of a building's specific context to evaluate, design, and implement EE measures. Different types of buildings require different skills, with residential buildings being fairly straightforward and uniform, whereas commercial and industrial buildings vary in their complexity. There are typically more retrofit opportunities than new construction opportunities because the building stock "turns over" very slowly, with perhaps ten times as many retrofit projects as new construction projects. Energy auditing and improved construction codes can lead to reductions in the energy consumption of buildings. Training can help prepare energy auditors, but there is no substitute for experience, and the best auditors have a long background in system installation or operations and maintenance and evaluating technical feasibility and cost-effectiveness of various technology options.

Once an auditor identifies measures, a designer can be engaged to specify the size and type of replacement components and detail how the measures will be implemented in construction drawings and specifications. This portion of the project is often opened for bidding from developers, and implemented by building trades such as electrical, mechanical, lighting, refrigeration/air-conditioning, and control system contractors. Depending on complexity, a commissioning agent may be engaged to ensure that the retrofit system is operating according to the intent of the design. Due to the fact that opportunities are distributed within buildings and varied and detailed in nature, it requires significant labor to deliver benefits compared to central RE plants, but the benefits are robust and permanent. The best kWh is a kWh not used, and EE is recognized as a prerequisite to sizing and procuring RE systems. RE and the appropriate controls and system designs within buildings may also be needed to meet supply-side management and resilience goals.

Tonga implemented building codes in 2007. The Building Control Division is responsible for enforcement and planning of related policy and regulation within the building construction sector in Tonga. A complete revision of the current building code, regulations, and implementation/enforcement of codes is being planned. The Building Control Division plans to increase building inspection activities and to improve public awareness programs to ensure the general public and key stakeholders are updated on changes to building codes and regulations. The goal of the Building Control Division is to "achieve more reliable, safe, and affordable buildings and ensure structures are more inclusive, sustainable, affordable, safe, and reliable."³⁰ One way in which the goals can be met is through updating building codes to include EE.

Energy-efficient and resilient building technologies are deployed as a result of public policy. This is even the case when the cost of EE measures may not be significantly more than traditional methods or when investments in energy-efficient technologies result in energy savings. A study conducted by the U.S. National Institute of Building Science in 2005 determined that the return on the incremental investment in resilience pays off over the life of the building.³¹ The study concludes that for every \$1 spent on hazard mitigation, an average of \$4 is saved during the disaster recovery phase. In December 2017, that report was revised to show that the savings are now a ratio of 1:6, rather than 1:4. Similarly, not only will updating building codes in Tonga save energy, but it will likely lead to fewer costs associated with disaster recovery with anticipated severe weather (e.g., increased cyclones and larger storm surges). It is recommended that climate change considerations be incorporated into building codes along with EE requirements, which will also help promote sustainable development, reduce poverty levels associated with energy bills, and accelerate recovery from severe climate-related events.

Some considerations for Tonga are to create setback zone guidelines or a policy to protect buildings from sea level rise and increasing storm surges. Elevated structures may be needed in certain areas to protect from the same threats. Additionally, mandating the secure attachment of roofs or features like PV panels can help protect against higher wind levels associated with cyclones. Tonga may need to identify threats, vulnerabilities, and risks; identify the technical measures to reduce the impacts associated with those risks; and integrate energy requirements at the same time.

Energy-efficient and resilient building codes will address the following considerations:

- For new buildings, siting to reduce impact from climate-related threats (e.g., setback from shore and building height of no more than two stories)
- Passive survivability techniques to reduce energy consumption and allow the building to be occupied without power (e.g., natural daylighting, natural ventilation, and rainwater collection)
- Energy and water storage on the site to allow for continued operation without utility services (e.g., PV with islanding controls and battery storage and cistern collectors with graywater systems)

Rolling out codes to first target critical infrastructure such as schools, hospitals/medical clinics, evacuation centers, fire stations, and police stations will help communities be more resilient during natural disasters. Focusing on residential and commercial buildings after critical infrastructure will help lower energy costs within those sectors as well as make them more resilient. Codes should address new construction and renovations. Examples of codes can be found for the region and specific sectors, as well as studies on the topic of passive design codes for specific climates. An example of a cyclone-resistant design with energy-efficient and passive design is shown in Figure 8 for illustrative purposes.³²



Source: Ecobuilding Pulse

Figure 8. Example of resilience measures for passive design and cyclone resistance

1. Design shape influences how wind moves around a building
2. Roof pitch (6/12) can reduce lift and deflect wind
3. Circular structure transfers wind pressure most efficiently
4. Radial floor and roof trusses distribute weight and wind loading
5. Wind is dispersed
6. 2400 psi framing is twice as strong as typical framing material
7. Five ply 5/8" sheathing instead of OSB exterior walls, roof and floor hardens buildings and prevents flying debris penetration
8. Reinforced windows prevent wind and water infiltration
9. Oversized truss hangers keep roof system anchored to walls
10. Multiple construction ties add structural stability and transfer shear forces
11. Continuous metal strapping increases structural stability
12. Solar water heat provides on-site hot water
13. Enhanced insulation maintains internal temperatures and reduces energy consumption; reflective coating or cool roof reflects heat gain
14. Passive solar design helps cool building through appropriate window placement and roof overhang/shading

2.1.2.2 Residential End Use

The 2016 population census indicates there are 18,005 private households in Tonga; Tongatapu has the largest population with 12,953 private households. According to TPL's 2017 data, approximately 45% of total load was from residential accounts. Residential accounts in tropical climates typically use energy for space cooling equipment

such as air conditioning and fans; lighting; domestic appliances like televisions, clothes washing machines (labeled as Elec Washer), and electric water heaters; and kitchen appliances such as refrigerators (fridges), freezers, and cooking appliances. Census data indicate that most Tongans cook with fuels rather than on electric burners, and also use a number of ancillary cooking devices (such as microwaves, electric kettles, or food processors), which are captured by the cooking category in Figure 9. Additionally, most Tongans own energy-efficient twin-tub, or nonelectric clothes washing machines. Census data indicate, however, that as GDP per capita increases, a higher percentage of Tongans are purchasing electric clothes washing machines. In order to better understand how this electricity is being consumed, residential end-use consumption was modeled using the following methodology:

1. Using a variety of census data, surveys, and proxy data, the household ownership of various appliances was estimated.
2. Data from TPL estimating average monthly consumption from appliances were used to calculate the total monthly consumption of households based on the number of households that own a given appliance.
3. These data were then normalized to TPL’s actual (and for future years, projected) billed consumption, using the 2017 portion of total consumption from residential accounts.
4. Using an estimate of appliance adoption rates tied to household GDP, residential consumption by end use was modeled through 2030. The resulting data are displayed in Figure 9.

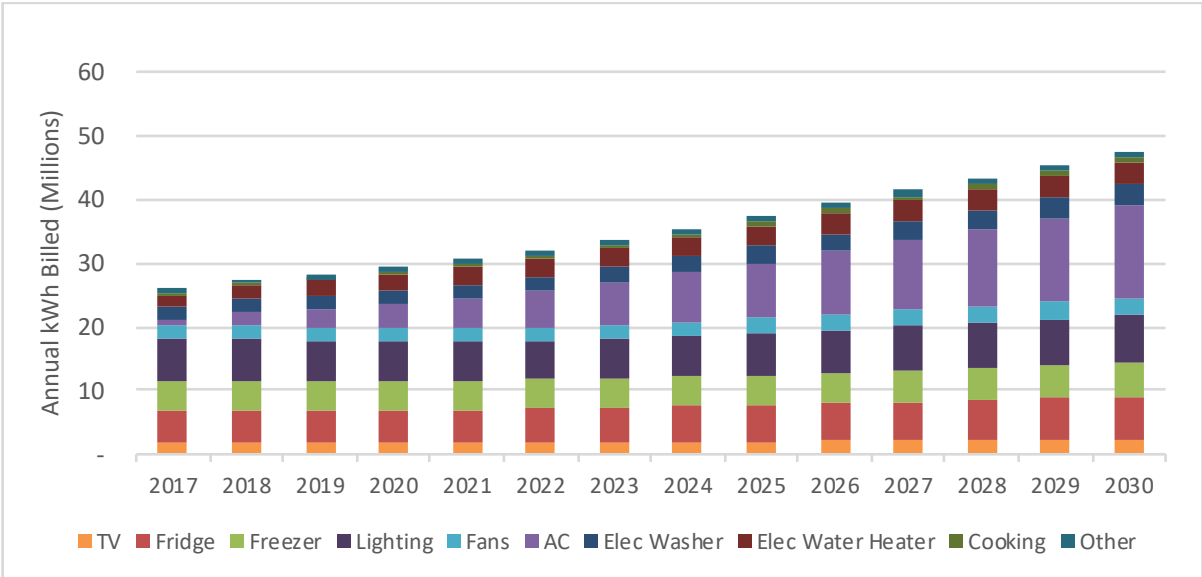


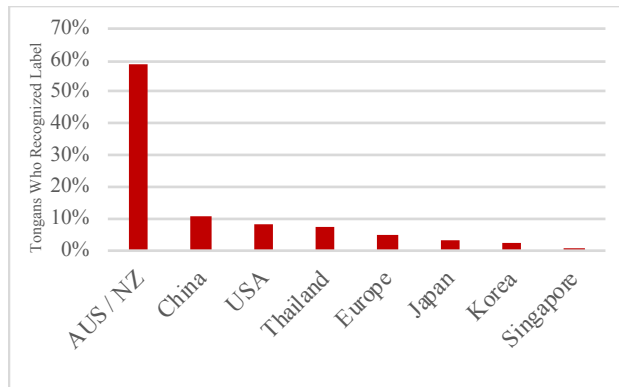
Figure 9. Residential electricity business-as-usual by end use

Due to Tonga’s geographic location, appliances are most commonly imported from Australia, New Zealand, Fiji, China, and Singapore. The minimum energy performance standards (MEPS) or energy labeling schemes vary in these countries, and the point of origin (i.e., the place where the good is manufactured) may not be the same as the country from which the good is imported. This creates a challenge when determining the energy performance of appliances imported through customs.

Australia and New Zealand have more stringent MEPS. However, less expensive products with less stringent energy standards may be available from Asia or Fiji. In a 2017 Pacific Community survey of Tongans, 58% had seen an Australian or New Zealand energy rating label, and the vast majority of these respondents said they had seen the label on an appliance in their own home, in the home of a neighbor, or on a television advertisement. Figure 10 shows the percent of Tongan respondents who recognized an energy performance label by source country when prompted with an example. An earlier study estimating the percentage of appliances in Tonga that already meet an existing standard is used as a baseline in modeling the effectiveness of new MEPS.³³ Although Tonga is currently in the process of implementing MEPS as organized by the Pacific Community,³⁴ exact performance requirements are unavailable. As such, modeling for the TEEMP uses standard efficiency requirements applied in Australia and New Zealand. In some situations, such as the curtailment of non-LED lights, the model extends beyond the MEPS imposed by Australia and New Zealand. Figure 11 shows the various labels included on appliances sold in Tonga.³⁵

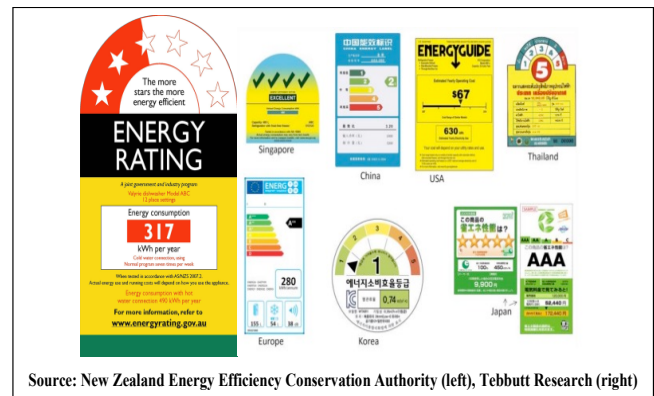
Table 3 uses customs data to filter appliances imported between 2009 and 2017 by country of origin. This is likely a good estimation of appliances that already meet another countries' MEPS.

In an assessment funded by Australian Aid, scenarios were formulated around the BAU activities in Tonga and the projected results of implementing minimum performance standards for lights and appliances. Scenarios were used to compare the energy savings in GWh consumed through 2030. Australian Aid's study demonstrated that implementing MEPS early on could achieve a 10 GWh savings by 2030. The TEEMP analysis anticipates that nearly 12.7 GWh could be saved through rigorous MEPS implementation by 2030; the difference between this figure and Australian Aid's can be attributed to different BAU consumption figures, less selective MEPS, and



Source: Tebbutt Research

Figure 10. Origin of energy performance labels by level of recognition among Tongans



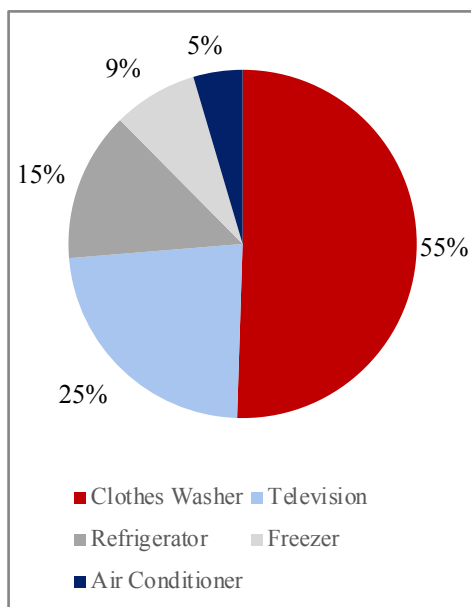
Source: New Zealand Energy Efficiency Conservation Authority (left), Tebbutt Research (right)

Figure 11. Various energy efficiency labels available in Tonga applicability to fewer appliances.³⁶

This analysis, coupled with information on the next major appliances expected to be purchased from the Pacific Community survey, informs an estimate of MEPS savings. Electric clothes washers, televisions, refrigerators, and freezers are the appliances most often purchased in Tonga and are the next anticipated appliance purchases. Focusing on MEPS for those products, as well as air conditioners, can lead to energy savings overall. Figure 12 gives an indication of the current appliances installed and anticipated appliances to be purchased.

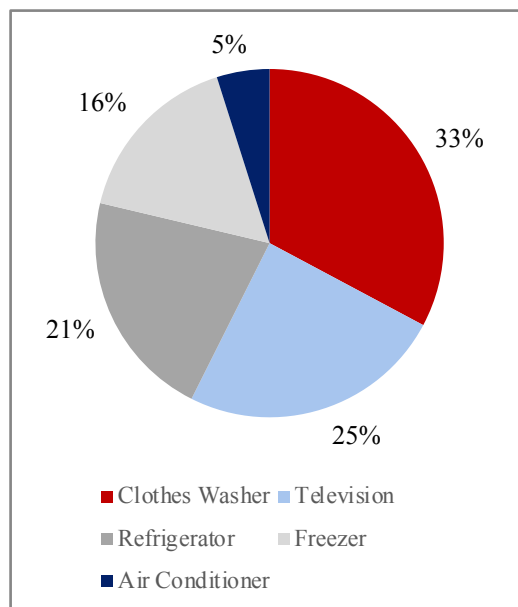
As part of the ongoing implementation of MEPS in Tonga, several Tongan Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change, and Communications (MEIDECC) staffers traveled to New Zealand for a multiday training seminar in 2018. Capacity building of this sort is vital to ensure the any implementation of MEPS in Tonga is in line with other countries in the region. Coordination should take place between the MEIDECC and the attorney general's office (which enforces MEPS) to develop informational material for Tongan customs officials to identify noncompliant appliances, and to spread awareness of the new standards among store owners.

Growth in appliance uptake is largely tied to household GDP per capita. A previous study looking specifically at Asian-Pacific countries identified an approximately 3% growth in the ownership of air conditioners for every \$1,000 U.S. dollar increase in household GDP.³⁷ In modeling, this growth percentage was applied equivocally to all appliance uptake, with caps placed on appliance ownership based on ownership in American Samoa, a country with plentiful data availability and a comparable GDP per capita to that projected for Tonga in 2030.



Source: Tebbutt Research
Figure 12. Tongans' reported last major appliance purchase (left) and next anticipated appliance purchase (right)

Table 3. Appliances Imported by Country of Origin



Item	Country of Origin	Number Imported (2009–2017)
Air Conditioner	New Zealand/Australia	325
	Singapore	15
	China/Hong Kong/Taiwan	985
	Other	2,025
Fan	New Zealand/Australia	6,137
	Singapore	510
	China/Hong Kong/Taiwan	8,455
	Other	10,941
Freezer	New Zealand/Australia	3,423
	Singapore	825
	China/Hong Kong/Taiwan	4,641
	Other	3,172
Refrigerator	New Zealand/Australia	3,281
	Singapore	853
	China/Hong Kong/Taiwan	433
	Other	1,594
Stove or Oven	New Zealand/Australia	209
	Singapore	116
	China/Hong Kong/Taiwan	673
	Other	990
Solar Components	New Zealand/Australia	1,555
	Singapore	57
	China/Hong Kong/Taiwan	5,132
	Other	8,447
Water Heater	New Zealand/Australia	325
	Singapore	16
	China/Hong Kong/Taiwan	206
	Other	256

Goods were observed to be labeled in retail spaces in October 2017 with labels indicating the amount of energy that might be consumed, which is a good practice. Expanding labeling across all appliances, and even potentially lightbulbs, could result in a nearly 11% reduction of energy consumption in Tonga according to one study.³⁸ However, the effectiveness of MEPS and labeling is highly dependent on promoting public awareness about how to read EE labels and the importance of conserving electricity.

Data were synthesized from the preceding sources, including the census, consumer research, and customs data to estimate current residential appliance ownership rates and to forecast future adoption. Figure 13 shows that some appliances with an already high ownership percentage such as fridges, freezers, fans, and televisions will see modest growth between 2018 and 2030. More electricity-intensive domestic appliances such as air conditioners, electric clothes washers, and electric water heaters were projected to have larger growth during the same period. Although these appliances do not currently represent a significant portion of residential loads, foresight in implementing MEPS on these appliances ensures that nonefficient appliances are not imported for use over a 15–20-year appliance life cycle.

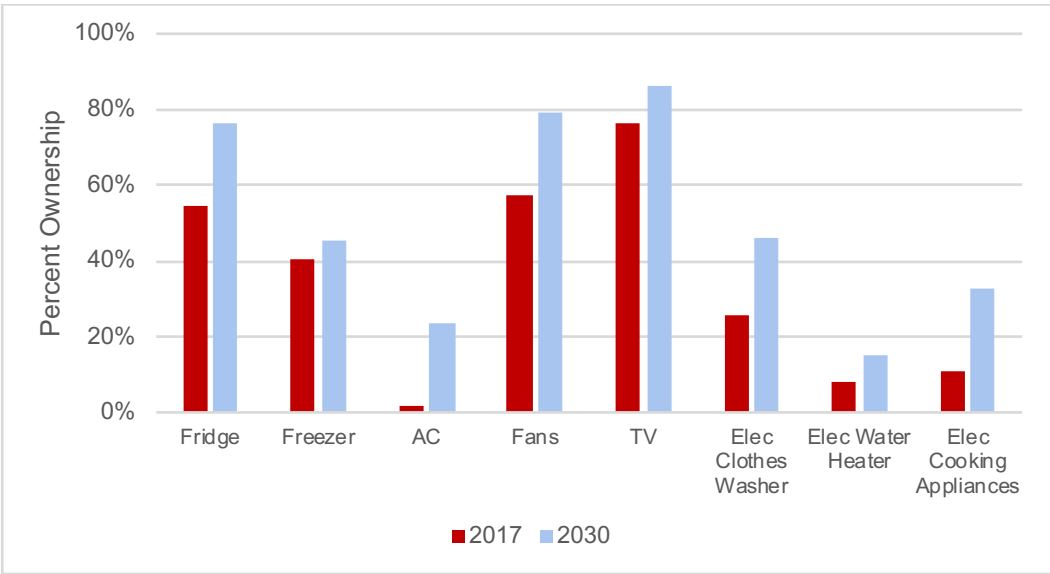
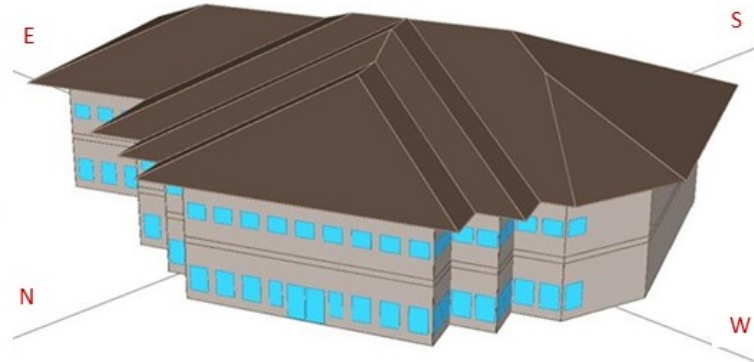


Figure 13. Residential appliance ownership by year

2.1.2.3 Commercial End Use

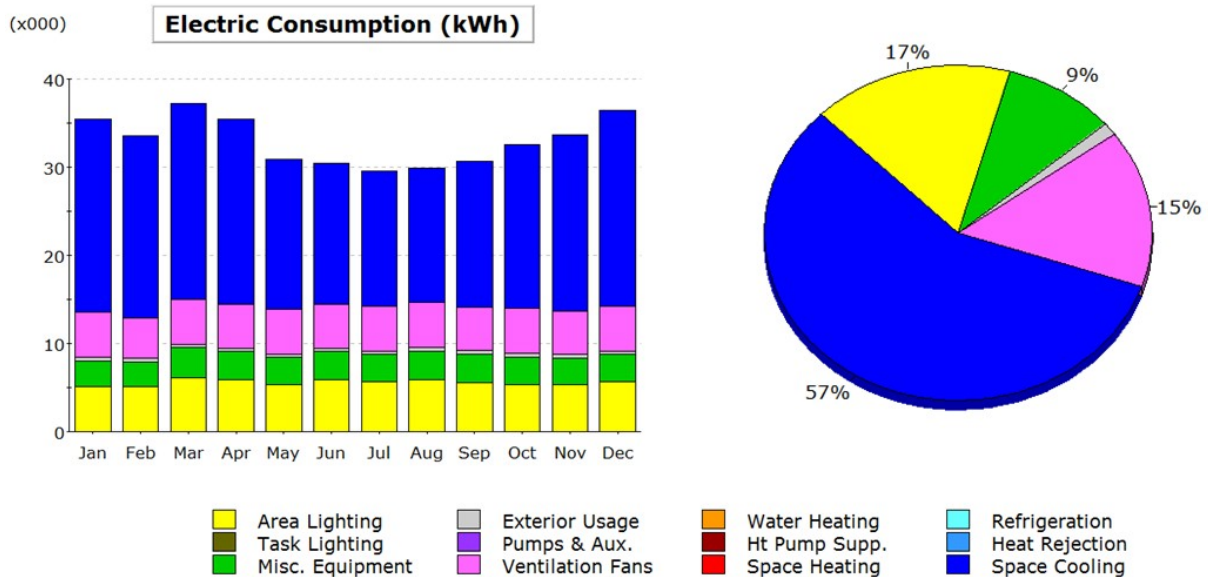
Although Tongan data were available to estimate the percentage of load by end use for residential accounts, similar data were unavailable for commercial accounts. To fill this gap, an energy model was run for a similar climate zone to understand energy end uses within a typical commercial building. Using data from an energy audit conducted in the Marshall Islands, an energy model was created to represent a sample office building in Tonga to serve as an energy baseline for commercial buildings. An energy baseline is essential to understand what the current energy consumption is and what the highest-consuming end uses are (e.g., HVAC, lights, fans, pumping, etc.) as well as to calculate potential energy savings associated with identified EE opportunities. Using the eQUEST³⁹ building energy model, the existing operating conditions of air-conditioning, lighting, and plug load systems were modeled. A graphical representation of the building energy model developed in eQUEST is shown in Figure 14. The geometry of the buildings was simplified for modeling purposes while still allowing accurate simulations of energy transfer through all surfaces in the building.



Source: Photo Jimmy Salasovich, NREL; energy model image generated using eQUEST

Figure 14. eQUEST model representation

Estimates of the current energy use breakdown at the sample office building in Tonga were generated using the eQUEST building energy model and paired with weather files to simulate realistic climate conditions, shown in Figure 15. As expected, space cooling (blue) is the largest electricity consumer followed by lighting (yellow) and ventilation fans (magenta) for a sealed, air-conditioned building. Plug loads (e.g., office equipment) are shown in green and are a smaller component of the building's energy consumption.



Source: Figures generated using eQUEST

Figure 15. eQUEST baseline energy use estimates

These data were applied uniformly to the commercial portion of TPL's projected commercial load growth to estimate the yearly appliance consumption by end use, as shown in Figure 16. TPL's highest-consuming customers are churches, government buildings, telecom companies, public services, bakeries, hotels, universities, and hospitals. The methodology used in the model applies the end-use data from a single building across all of these accounts. Although other methodologies could be used to more accurately model commercial end uses, data are unavailable to estimate what portion of the commercial load is going to different account types (government, industrial, retail, etc.) or to estimate the yearly appliance energy uptake of commercial accounts. TPL is encouraged to begin recording data of this sort in order to better understand their commercial loads and enable themselves to conduct energy audits.

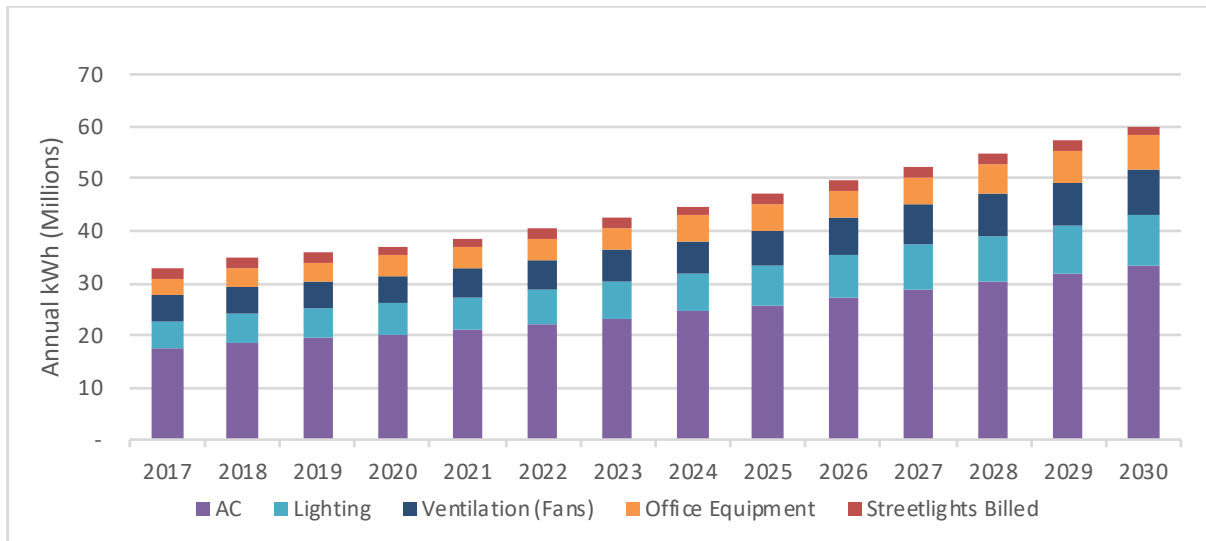


Figure 16. Commercial electricity business-as-usual by end use

2.1.2.4 Streetlighting

The last major sector of electricity use in Tonga is streetlighting. Tonga does not use traffic lights, opting for energy-efficient roundabouts. The streetlighting installed is typically near town or village centers and along major junctions or intersections. A program exists to convert older, less efficient streetlights to higher efficiency LEDs. According to various reports, Tonga has converted the following streetlights to LEDs:

- Tongatapu: 135 existing streetlights replaced with high efficiency LED units (2015)
- Tongatapu, Vava’u, ‘Eua, Ha’apai: More than 1,500 LED streetlights installed (2016)
- Tongatapu, Vava’u, ‘Eua, Ha’apai: More than 1,300 LED streetlights installed (2017)
- Outer islands: All 161 existing streetlights replaced with high efficiency LED units.

In addition to the energy savings associated with replacing less efficient lights with more efficient lights, the new lights provide more accurate color rendering. As seen in a streetlighting upgrade project in Figure 17, the light cast from the high pressure sodium light is yellow and makes it difficult to see the true colors of objects. The “AFTER” picture of the LED light shows more accurate colors, which provide better nighttime vision, increase safety, and reduce crime.⁴⁰ An additional benefit of LED lights is a longer life span, which reduces operations and maintenance costs associated with replacing bulbs.



Figure 17. Example of LED streetlight

Understanding energy generation, transmission, and consumption will assist with identifying opportunities for reductions and efficiencies in the wedge analyses. This analysis is covered in further sections.

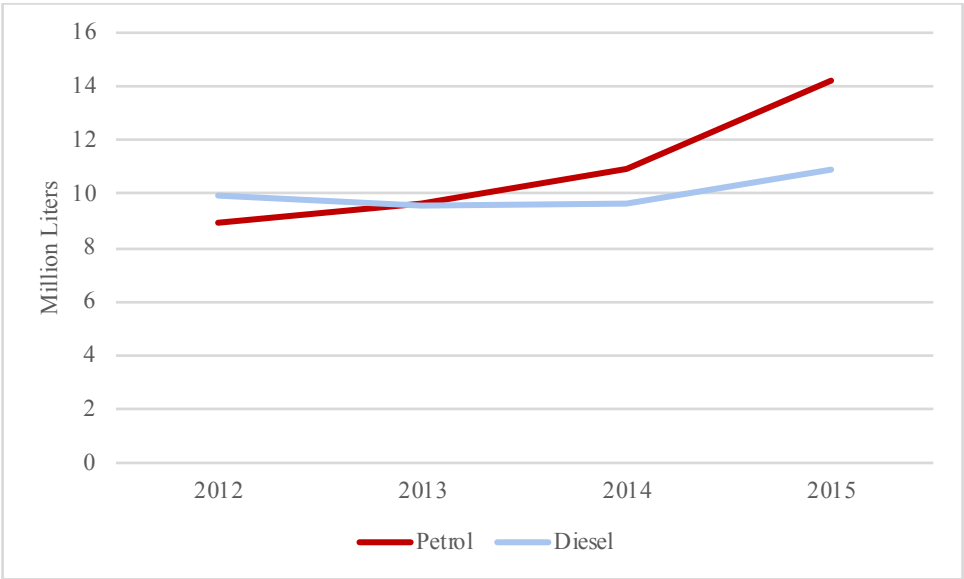
2.2 Baseline Transportation

The analysis in this section focuses on land transportation because that is the most clearly allocated to Tonga, it is the most under Tongan control, and it is growing at a much faster rate than aviation and maritime loads (as shown in Appendix A). To create a baseline for transportation fuel use in Tonga, it is important to first document the fuel used and trends thereof. Then it is possible to estimate the annual miles traveled and assess what vehicles were doing the traveling.

The baseline for Tonga’s transportation activities and fuel consumption are summarized in this section, organized by fuel usage, kilometers traveled, and other assessments. Recommendations are also made on how these data could best be collected going forward.

2.2.1 Land Transportation Fuel Usage

Fuel usage has been tracked and compiled by the MCCTIL. Starting in 2012, MCCTIL divided petroleum usage into petrol, diesel, Jet A1, and kerosene, and divided end uses into service stations, aviation, commercial, government, and power stations. It is assumed that all diesel and petrol being used in the service stations, government, and commercial sectors is land transportation fuel, and summarized consumption in millions of liters is shown in Figure 18. To improve the accuracy of fuel data, in the future MCCTIL should work with the 29 service stations to track how much of their diesel is going to boats and off-road equipment instead of land transportation.



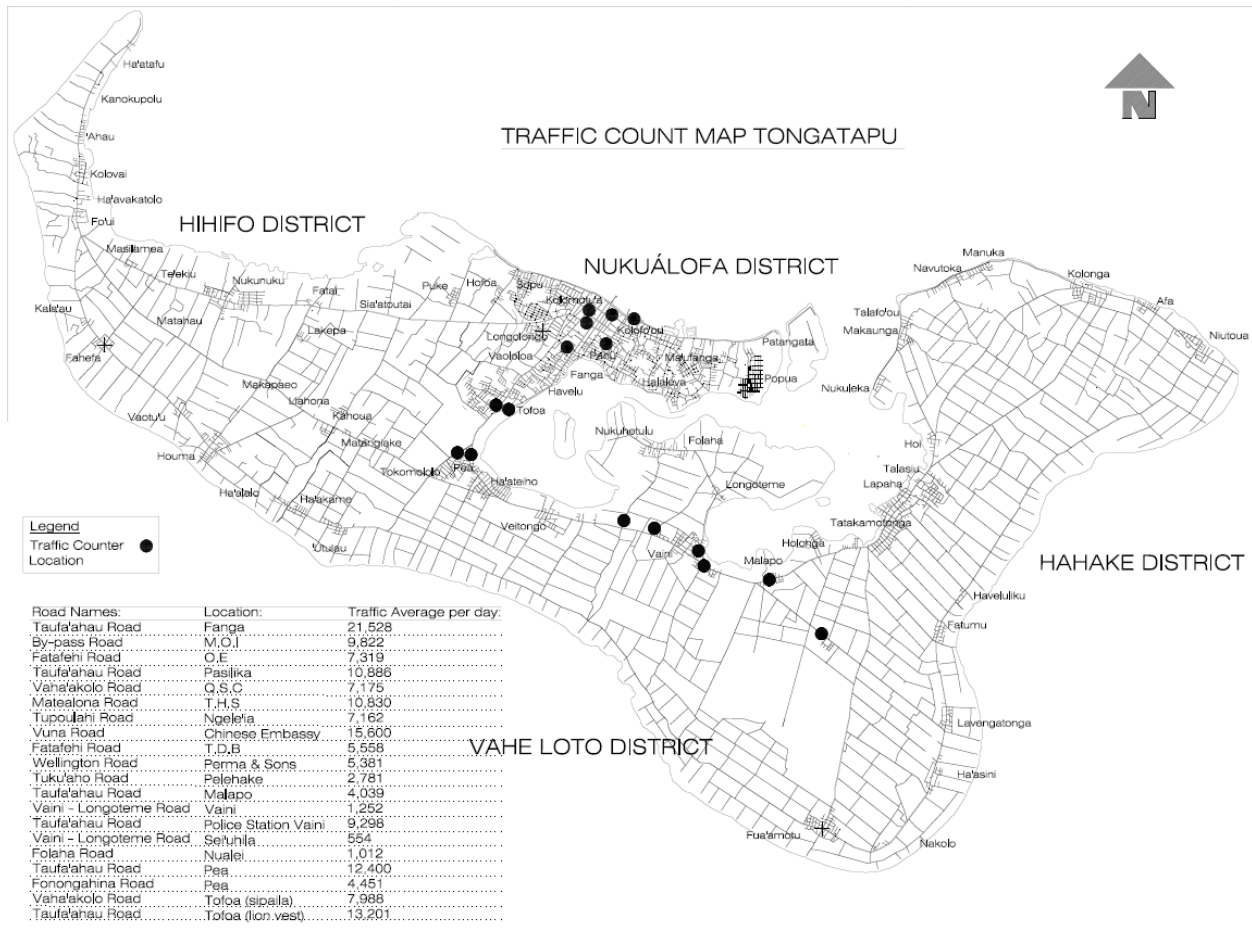
Source: MCCTIL Fuel Volume 2012-2015 Report

Figure 18. Land transportation fuel consumption in Tonga

2.2.2 Vehicle Kilometers Traveled

The fuel reported in the above section is used to propel motorized vehicles. The distance they are propelled is measured in vehicle kilometers traveled (VKT). VKT reflects simultaneously on how efficient vehicles are (getting more VKT per liter of fuel) and how dependent a population is upon motorized vehicles (extremely dependent populations have a high per capita VKT).

Tonga’s annual VKT was derived from the traffic count map of Tongatapu taken in 2016 by the Ministry of Infrastructure (MOI). The counts are admittedly incomplete, but they are the best data available to estimate VKT. Therefore, the process, assumptions needed, and data checks are outlined in this section and a map of the traffic count is shown in Figure 19.



Source: Ministry of Infrastructure
Figure 19. Traffic count map of Tongatapu

To convert the traffic counts into VKT, traffic was tracked as it was leaving Nuku'alofa. This reflects the assumption that most traffic is going and coming from Nuku'alofa (with exceptions explained later). The methodology assumes that all vehicles are departing Nuku'alofa, which is the same as acknowledging that most vehicles are counted twice daily and have the same distance on both trips (generally the morning commute and the evening commute). Table 4 shows the traffic going through given counters as it departs Nuku'alofa.

The first three columns are the same as shown on the map legend. The next column reflects the assumed primary destination (Destination A) of the vehicles going through the counter. Destination A was often a populated town, region, or the next counter. Destination B was typically a secondary population cluster beyond Destination A. The assumed number of vehicles was then multiplied by the kilometers to the destination to give the daily VKTs going to each destination. These VKTs are listed in the two "Daily VKT" columns that are then aggregated to the grand total daily VKT. The last two columns estimate the rural trips that did not go to, from, or through greater Nuku'alofa or along Taufa'ahau Road. This traffic was primarily within the Hihifo and Hahaake districts. Estimates were developed with local consultation and the end VKT accounts for 12% of all miles on Tongatapu. These numbers are the most subjective but have a limited impact on the overall estimate.

Table 4. Traffic Counts, Traffic Destinations, and Daily Vehicle Kilometers Traveled on Tongatapu

Road	Counter Location	VEHs/Day	Destination A	Kilometers to A	Vehicles to A	Daily VKT	Destination B	Kms to B	VEHs to B	Daily VKT
Taufa'ahau Road	Fanga	21,528	Tofoa	1.2	15,837	19,111	Havelu & Vaoloa	0.5	5,691	3,022
Bypass Road	MOI	9,822	Western suburbs	2.5	4,911	12,169	Hihifo district	10.0	4,911	48,991
Fatafehi Road	OE	7,319	Intra-Nuku traffic	2.5	7,319	18,135	-	-	-	-
Taufa'ahau Road	Pasilika	10,866	Intra-Nuku traffic	2.5	10,866	26,924	-	-	-	-
Vaha'akolo Road	Queen State College	7,175	Sopu	2.5	7,175	17,779	-	-	-	-
Matealona Road	THS	10,830	Western suburbs	1.2	5,415	6,535	Hihifo District	10.0	5,415	54,019
Tupoulahi	Ngele'ia	7,162	Intra-Nuku traffic	2.5	7,162	17,746	-	-	-	-
Vuna	Chinese Embassy	15,600	Ma'ufanga and peninsula	2.5	15,600	38,655	-	-	-	-
Fatafehi Road	TDB	5,558	Intra-Nuku traffic	2.5	5,558	13,772	-	-	-	-
Wellington	Perma&Sons	5,381	Intra-Nuku traffic	2.5	5,381	13,333	-	-	-	-
Tuku'aho	Pelehake	2,781	Fua'amotu, Lavengatonga, and coast towns in between	5.3	2,781	14,766	-	-	-	-
Taufa'ahau Road	Malapo	4,039	Tatakamotonga	4.8	2,020	9,748	NE coast towns	13.0	2,020	26,320
Vaini-Longoteme Road	Vaini	1,252	Accounted for in Pea line	-	-	-	-	-	-	-
Taufa'ahau Road	Vaini Police Stn	9,298	Accounted for in Pea line	-	-	-	-	-	-	-
Vaini-Longoteme Road	Sei'uhila	554	Accounted for in Pea line	-	-	-	-	-	-	-
Folaha Road	Nualei	1,012	Accounted for in Pea line	-	-	-	-	-	-	-
Taufa'ahau Road	Pea	12,400	Viani	7.2	10,550	76,387	Folaha*	10.5	1,566	16,378
Fonongahina	Pea	4,451	West on Taufa'ahau	6.4	4,451	28,647	-	-	-	-
Vaha'akolo	Tofoa	7,988	Pea	1.6	4,451	7,162	-	2.5	3,537	8,821
Taufa'ahau	Tofoa	13,201	Pea	1.6	12,400	19,952	-	2.5	801	1,998
Intra-Hihifo Trips	No Counters**	-	-	4.8	5,000	24,135	-	-	-	-
Intra-Hahake Trips	No Counters**	-	-	4.0	5,000	20,113	-	-	-	-
Total Daily VKT on Tongatapu		545,531								
*284 of these cars are assumed to continue 3.2 km past Faloha on to Vietongo and Coast										
** There were no counters in the Hihifo or Hahake districts. See text for how the vehicle numbers were estimated.										

The results of Table 4 are that Tongatapu sees 545,531 VKT per day. Assuming that this flow is consistent 6 days per week (Monday through Saturday, excluding Sunday for the religious holiday), this aggregates to nearly 171 million VKT every year. In order to extrapolate from Tongatapu to all of Tonga, a linkage was made between VKT and fuel use. Fifteen percent of land transportation fuel is used on islands other than Tongatapu, so it was assumed that 15% of VKT also occur on other islands. Taking this into account results in the estimate of 2,289 VKT per capita—a realistic number given its per capita GDP and other parameters.⁴¹ Furthermore, when dividing the fuel

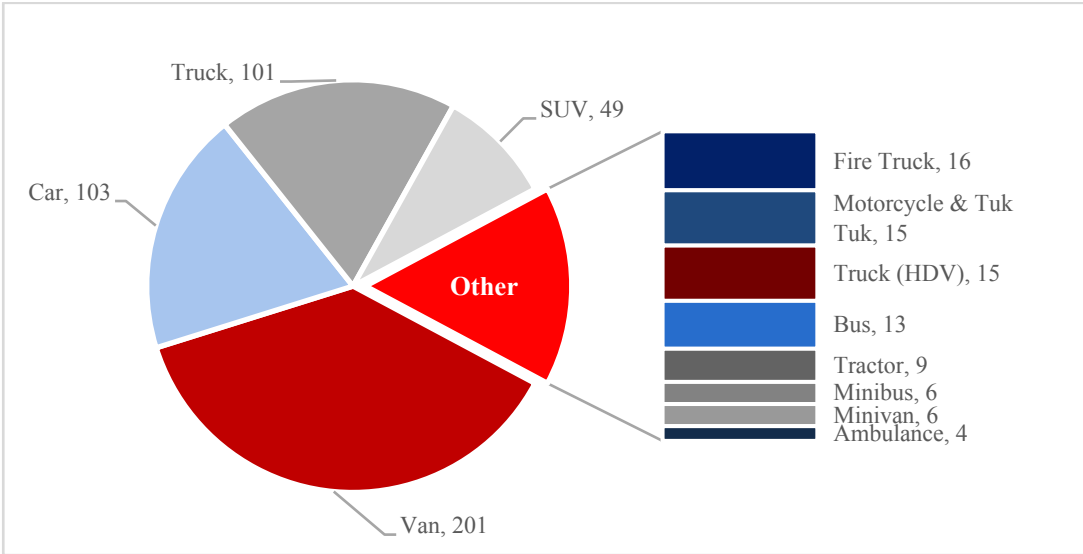
used in Tonga by this VKT, the result is an average vehicle fuel consumption rate of 12.5 liters per 100km—a figure that is quite realistic for the vehicle population.

It is recommended that in the future MOI set up more traffic counting stations (including Vava’u and Ha’apai) and take daily fluctuations into account. These data could also help them plan infrastructure improvement projects. They could also take annual odometer readings as part of a vehicle registration program. In addition, the Ministry of Statistics should add a set of questions to the census asking Tongans what their average daily travel distance is and their primary means of transportation.

2.2.3 Vehicles

The third key piece of information for defining the land transportation picture of Tonga is the number and type of vehicles. Tonga has four sources of vehicle information, each with certain strengths and weaknesses:

1. *Census data of household goods (from the 2011 and 2016 census).* This has the clear advantage of showing vehicle stock instead of incremental vehicles. However, it is focused on households and therefore misses many of the corporate, government, and religious institution vehicles. Furthermore, its vehicle types are not as refined as the vehicle registrations (2011 only has two categories for motor vehicles, while 2016 breaks them down into 6).
2. *New vehicle registrations (2010–2016), as tracked by the MOI and reported by the National Reserve Bank of Tonga.*⁴² This source has the advantage of good categorization, which enables us to better estimate the impact of policies and projects that target specific vehicle categories. However, it only reports new vehicle registrations, when data about the entire Tongan vehicle stock are needed.
3. *Vehicle imports tracked by Tonga customs.* These data are not divided into vehicle categories and are therefore not as useful for fuel use estimates. However, they do provide a good data check on the registrations.
4. *Government fleet tracked by the MOI.* These data shows 538 vehicles in the government fleet, broken down by vehicle type in Figure 20.



Source: Ministry of Infrastructure 2016/17 Government Vehicle Inventory
Figure 20. Government vehicle inventory by type

The following steps were employed to use the available data to estimate the rolling stock of vehicles in Tonga:

1. Focus was placed on vehicle registrations enhanced with the government fleet data, because both of these data sets were broken down by vehicle type and they were largely in agreement with vehicle imports.
2. In order to convert new registrations into vehicle stock, the amount of time a vehicle had been in Tonga and is used before retirement was taken into account. For this, 2016 census data were used showing that 59% of households owned vehicles and 8% had purchased them within the past year. This would indicate that the average vehicle lasts 59/8=7.3 years after being imported.

3. The 2010 data were removed because it was an outlier year of heavy vehicle replacement after Cyclone Rene. This outlier would have inaccurately affected the vehicle stock calculations because many of the additional vehicle registrations were replacing destroyed vehicles.
4. Vehicles that predate the data set are still part of the current stock, so an estimate was calculated as to what registrations occurred before the data set. Therefore, the projected sales patterns were calculated backwards from 2011 to 2003 based on later year registrations and money spent on vehicle imports as tracked by Tonga customs.⁴³
5. The “government vehicles” category was replaced by more granular data on government vehicles, and these vehicles were allocated to their weight-based categories.

Table 5. Tally of Vehicles in Tonga by Type

Vehicle Type	Number of Vehicles
Cars	6,031
Light trucks, vans, SUVs	7,103
Heavy duty vehicles	2,099
Taxis and rentals	953
Motorcycles	306
Buses	225
Total	16,717

6. Comparisons were run between the new data set, the imports data, and the 2016 census data. The total number of vehicles is 3.5% fewer than if the calculations had been based on the annual vehicle imports. Conversely, the total number of vehicles is 13% greater than the combination of 2016 census data and the government fleet data. It is expected that the actual number of vehicles would be greater than that derived from the census data because many of the vehicles are owned by corporations (which were not included in the census) and not households.

It is recommend that in the future the MOI issue an annual vehicle registration that will feed an updated database of operational vehicles. This registration should provide information on the vehicle type, fuel type, and odometer reading.

2.2.4 Other Baseline Data of Interest

Although the 2006 and 2011 censuses asked Tongans about the “availability” of mobile telephones in households, the 2016 census asks about household ownership of cell phones. The difference in this methodology accounts for a reported decrease in the number of cell phones, from 73% in 2006 to 94% in 2011 and then down to 89% in 2016. It’s unclear what proportion of these phones are “smart phones” capable of accessing the internet for transportation purposes. This clarification should be made in the next census.

The 2016 Tonga census asked respondents about the number of bicycles owned. It reported that 4,695 households (26%) own a bicycle, and that 7,009 bicycles are owned overall. Previous censuses did not ask respondents about ownership of bicycles.

The MOI has provided yearly data on the number of domestic ferries and their passengers, along with the volume of cargo delivered to various wharves. These data are of interest to land transportation when ferries are used as a replacement for buses and trucks.

Tonga residents reported 695 motorcycles in the 2011 census, yet that number dropped to 275 motorcycles in the 2016 census—a decline of 38%. The reasons that people gave up this efficient mode of transportation should be understood as a part of a multifaceted approach to improve transportation fuel efficiency.

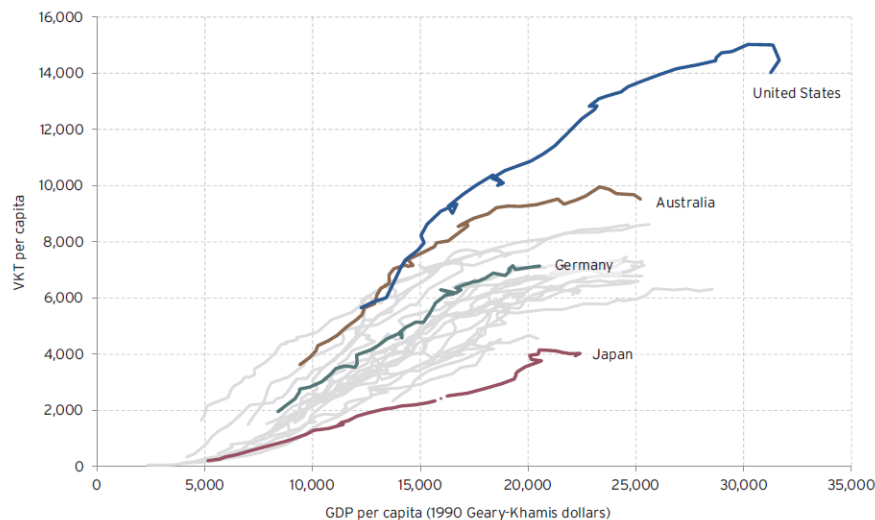
The ideal data collection system would consist of an annual vehicle registration that includes odometer readings of the vehicle. This would provide two key pieces of information, namely vehicle stock and annual VKT.

3 Business-as-Usual Projections

In order to identify areas of reduced energy use and assess the effectiveness of various conservation scenarios, it is important to create BAU projections. Where data were available, the information was used to create historic trend lines to help with projections. Where data were not available for both the energy and transportation sectors, assumptions were made and have been documented in this section.

3.1 Tonga Transportation Fuel Business-as-Usual Projection

Historically, the period of greatest growth in VKT, and therefore land transportation fuel use, is when a country's per capita GDP (in international dollars⁴⁴) is \$5,000–\$20,000 U.S. dollars.⁴⁵ In other words, this is the range within which VKT growth is on the steep part of the S-curve (see Figure 21 below). Tonga's per capita GDP crossed into that zone in 2015 (see Figure 22). Therefore, Tonga's VKT should now be very sensitive to increases in per capita GDP. Furthermore, because Tonga has shifted into this rapid growth phase, it is better to base projections on what other countries have done throughout this phase rather than Tonga's previous growth rates.

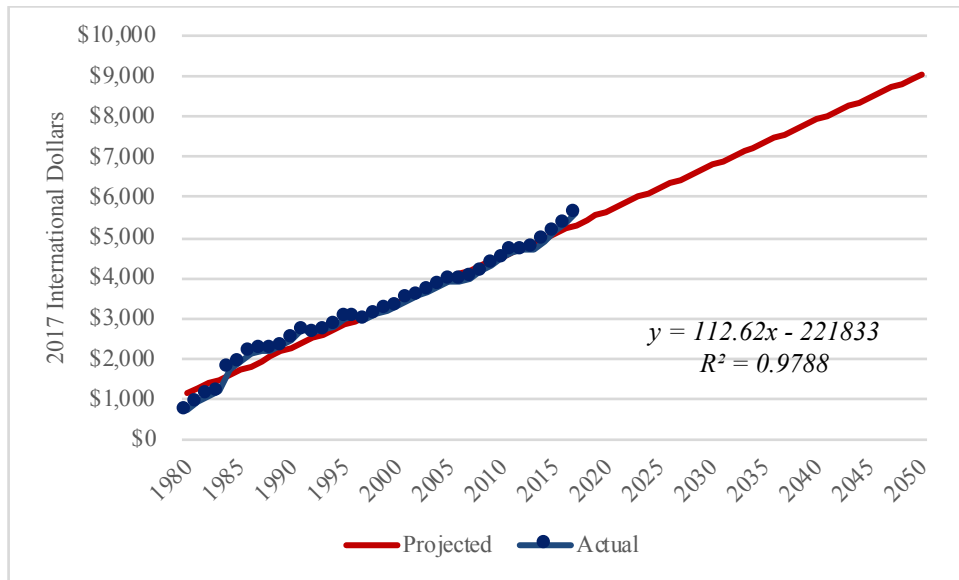


Source: Rand, 2014 (Note: these numbers omit freight and focus on passenger travel. Geary-Khamis dollars are the same as the international dollars described earlier in this report)

Figure 21. Vehicle kilometers traveled of motorized passenger travel and per capita gross domestic product for 22 developed countries

Because land transportation fuel use is most closely tied to VKT, and VKT is most closely tied to per capita GDP in international dollars,⁴⁶ a projection of Tonga's per capita GDP is needed into the future. The per capita GDP data from 1980 to 2017 are shown in Source: Rand, 2014 (Note: these numbers omit freight and focus on passenger travel. Geary-Khamis dollars are the same as the international dollars described earlier in this report)

Figure 22 (in blue). The line of best fit is linear (with $R=0.979$) and therefore future projections are based upon that line. This line shows Tonga's per capita GDP reaching \$9,000 in 2050.



Data Source: Knoema Tonga GDP per capita⁴⁷

Figure 22. Tonga per capita gross domestic product with purchasing power parity

Next, it is essential to convert the projected per capita GDP into VKT. To do that, it is crucial to translate the starting point of 2,289 VKT per capita (including freight) into a number that excludes freight and only includes passenger travel. In New Zealand, approximately 23% of the total VKT are freight, so it is assumed that this ratio is the same for Tonga.⁴⁸ Subtracting 23% from the total Tongan VKT leaves 1,750 motorized passenger VKT per year.

In order to project the starting point of 1,750 VKT/year to 2050, the correlation between Tonga and other countries developing and growing their per capita GDP from \$5,000 to \$9,000 is considered (as shown in Figure 22). Countries represented on the chart showed different relationships between GDP and VKT, and these differences were largely due to spatial dispersion, car infrastructure, fuel prices, and alternatives to driving. Using a simplified version of the process described in RAND 2014, it was determined that in 2050, assuming that Tonga will have a per capita GDP of \$9,000, it will have a VKT of 3,900 per person. This number appears slightly high when comparing to Figure 21 for two reasons. First, Tonga GDP is in 2017 \$Intl instead of 1990 \$Intl as is the rest of the figure. Second, the Tonga VKT appears high when compared to the other countries charted in Figure 21 because Tonga is starting its VKT growth spurt decades later. Therefore, developments in vehicles, infrastructure, and the shipping of materials and fuel have positioned Tonga for more rapid growth than the countries that developed in the 1960s and 1970s. This relative advantage is validated by the fact that Tonga VKT is already well above where other countries were when they had a GDP of \$5,000. Using the same assumption that 24% of a country's VKT is due to freight, that factor was added back in to bring Tonga's total 2050 VKT to 5,103 per person.

Growing VKT from 2,289 VKT/person in 2016 to 5,103 in 2050 requires a compounded annual growth rate of 2.4% per year. This growth rate was applied to the 2015 fuel consumption quantities, which resulted in the fuel projections shown in Figure 21. In order to do so, the following assumptions were made:

1. Tonga's population remains constant between 2017 and 2050. This is a reasonable assumption given that Tonga's average annual growth between 2011 and 2016 was -0.5%.
2. Tonga's vehicle efficiency remains the same as it is now, with an average of 12.5 liters per 100 km. This is a standard assumption when developing a BAU scenario.
3. Tonga's fuel use ratio remains the same as it is now, with 57% petrol and 43% diesel.
4. Tonga's growth in VKT, and its growth in fuel use, grows at 2.4% per year, compounded annually.

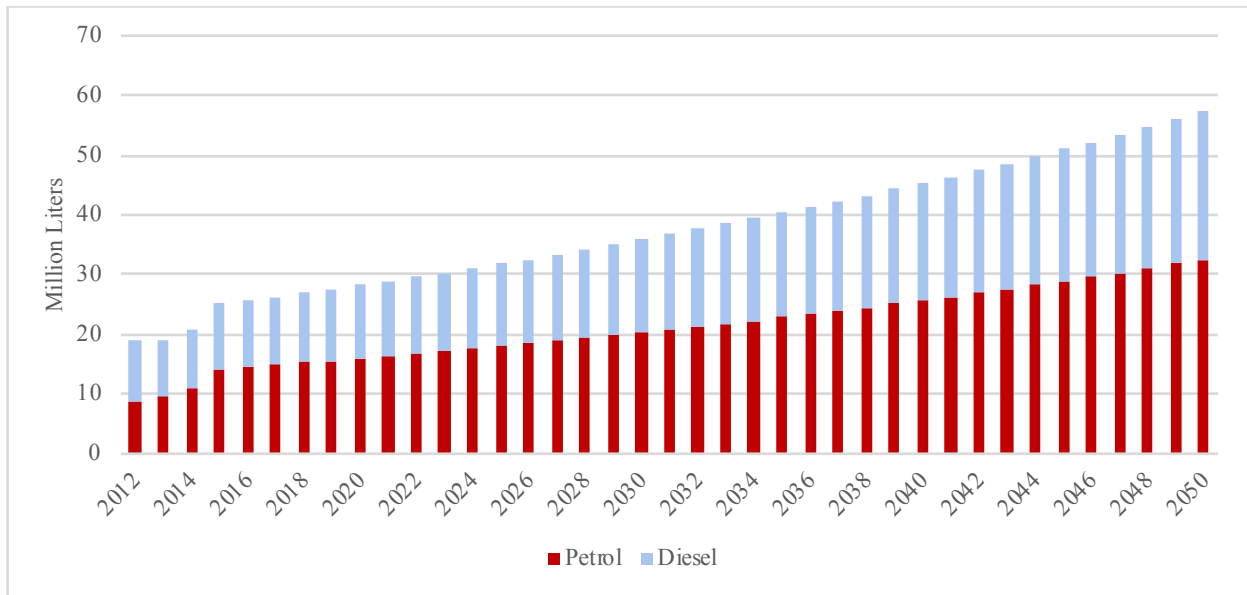


Figure 23. Tonga business-as-usual transportation fuel usage

Fuel use was then converted to life cycle GHG emissions, based on conversion factors in EPA 2016 and EIA 2016. The end result of this projection, with associated assumptions, can be seen in Figure 24.

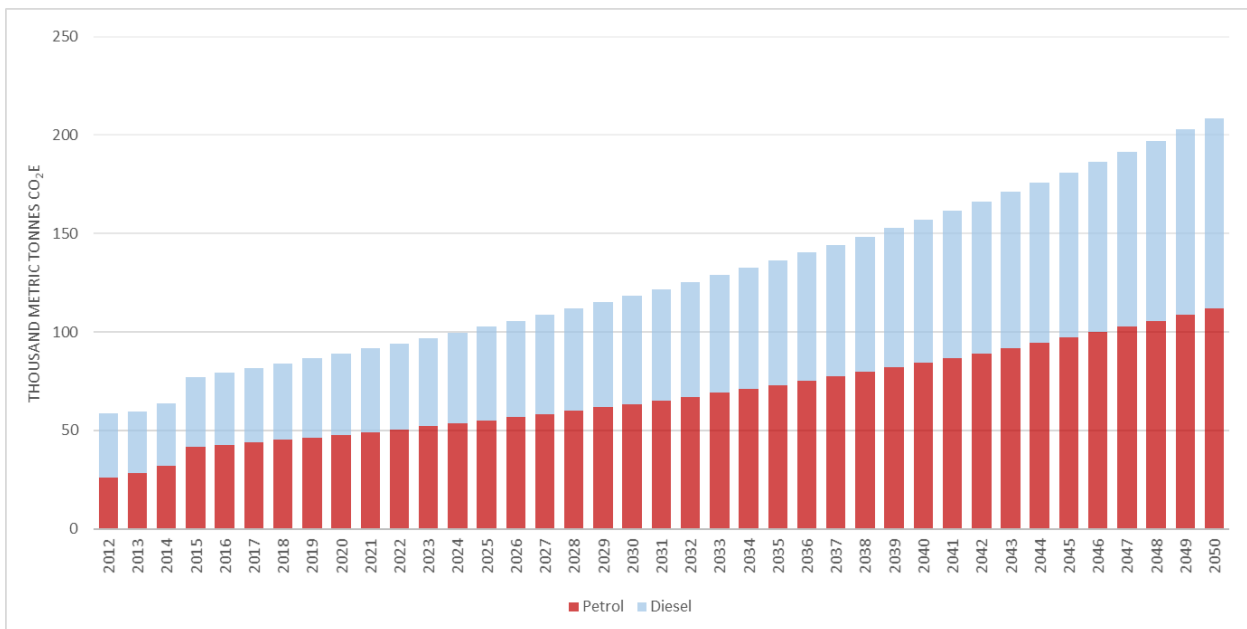


Figure 24. Tonga business-as-usual land transportation greenhouse gas emissions

3.2 Tonga Electricity Business-as-Usual Projection

The historical energy billed and peak demand for each of Tonga’s four island groups is shown in Table 6. As remote islands are electrified, populations may shift on those islands as young adults choose to move closer to family or new businesses open (e.g., tourism or resorts with access to power). Historical data show fluctuations in billed energy at the customer level with a -6.72% change from June 2009 to June 2010 and a 7.53% increase from June 2015 to June 2016, as shown in Table 7. Projections in the TERM indicate an estimate of projected growth by 2020 of 28% from 2010 consumption levels.

Table 6. Billed Energy (MWh) and Peak Demand (MW) in Tonga's Four Island Groups

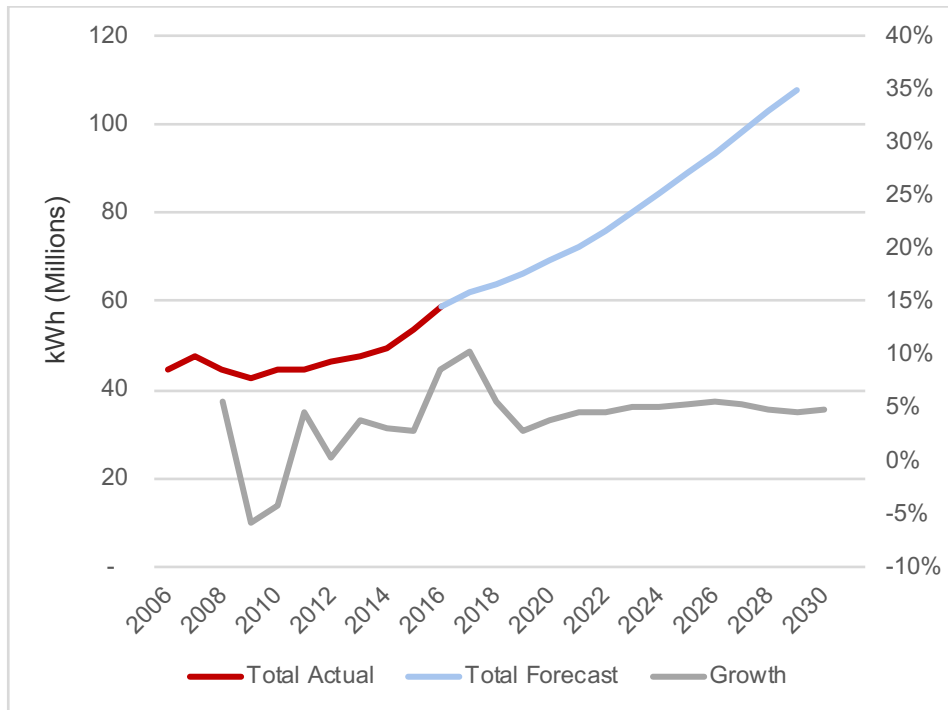
Source: TERM

	2010	2011	2012	2013	2014	2015
Tongatapu Grid						
Billed Energy, MWh	36,759	36,223	36,001	36,760	38,230	40,142
Peak Demand, MW	7.903	7.654	7.5	7.565	7.815	8.152
Vava'u Grid						
Billed Energy, MWh	4,037	3,978	3,953	4,037	4,198	4,408
Peak Demand, MW	1.02	0.99	0.97	0.98	1.01	1.06
Ha'apia Grid						
Billed Energy, MWh	1,237	1,240	1,255	1,294	1,346	1,413
Peak Demand, MW	0.3	0.3	0.3	0.31	0.33	0.34
'Eua Grid						
Billed Energy, MWh	882.1	884.6	895.6	923.3	960.2	1,008.20
Peak Demand, MW	0.23	0.23	0.23	0.23	0.24	0.25
Total, All Grids						
Billed Energy, MWh	42,915	42,326	42,106	43,015	44,735	46,972

Table 7. Historical Tonga Power Limited Reports on Energy Billed and Consumed by Customer (2008–2017)

	July 2008– June 2009	July 2009– June 2010	July 2010– June 2011	July 2011– June 2012	July 2012– June 2013	July 2013– June 2014	July 2014– June 2015	July 2015– June 2016	July 2016– June 2017
<i>Total billed (MWh)</i>	44,539	42,625	44,566	44,731	46,388	49,165	49,165	53,342	58,823
<i>Total generated (MWh)</i>	54,659	51,845	53,160	52,391	53,313	55,405	55,405	60,037	66,519
<i>Customers</i>	20,338	20,773	20,758	20,498	20,580	20,633	20,932	20,999	22,929
<i>MWh billed per customer</i>	2.19	2.05	2.15	2.18	2.25	2.38	2.35	2.54	2.57
<i>Percent change</i>		-6.72%	4.42%	1.6%	3.18%	5.4%	-1.45%	7.53%	0.98%

TPL provided their internal projection of load growth, which is replicated below in Figure 25. Ultimately, these data were chosen to represent the total yearly generation in the BAU scenario because of TPL's firsthand experience operating Tonga's grid. When compared with the preceding tables, TPL's projection appears to match a moving average of historical growth, making it inclusive of factors like population growth. Because of varied population growth estimates, this was not included in the model as a separate variable to model load growth. Household appliance ownership data and commercial load models were then used to estimate yearly consumption by end use as described in Section 2.1. Using the same methodology as the transportation BAU scenario, the electricity BAU scenario was brought to the common metric of CO_{2e} emissions shown in Figure 26.



Source: TPL

Figure 25. Tonga Power Limited projected load growth

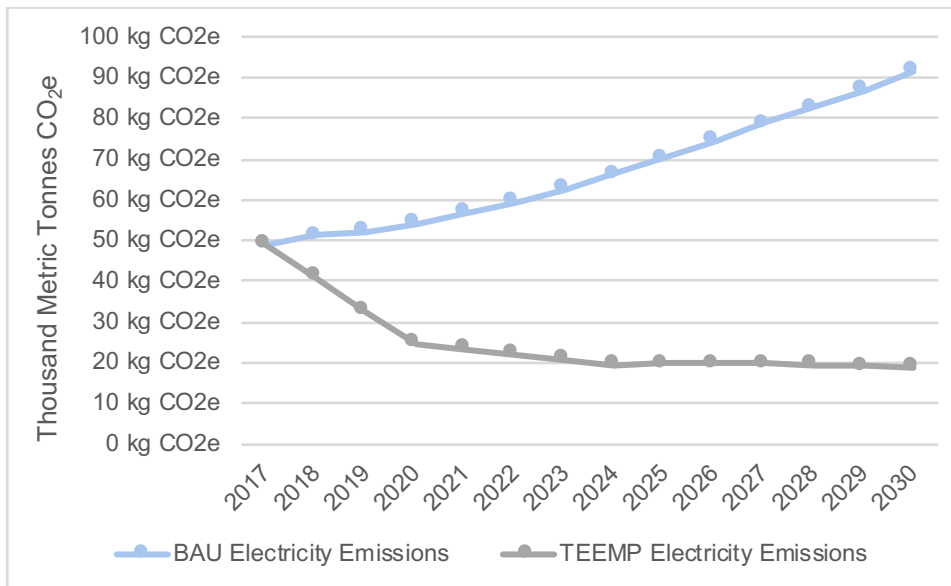


Figure 26. Projected electricity emissions under business-as-usual and with policy changes

4 Proposed Reduction Targets

Tonga’s NDC calls for 50% renewables penetration in the electricity generation sector by 2020, but does not account for the GHG emissions from transportation or efficiency improvements. This section aims to incorporate these two sectors and propose new GHG reduction targets. It will do so by dividing the targets into smaller subcomponents and presenting them in a way that Tonga can deem as realistic or unrealistic and adjust accordingly. This part is known as a wedge analysis due to the visual aids (Figures 27–29) that track the difference between BAU scenarios and the path to target achievement. It will then discuss policy and project options that enable the achievement of these targets.

4.1 Transportation Wedge Analysis

GHG emissions from land transportation in Tonga can be reduced through VKT reductions, vehicle efficiency improvement, idle reduction, and alternative fuels such as electricity or biodiesel. This section introduces each of these approaches, proposes related goals, and assesses the contribution of each approach through a wedge analysis. These related goals are a middle step between the overall GHG reduction target and the projects and policies to achieve that goal. As such, these subgoals are a tangible way to check the feasibility of an overall GHG reduction target. Each subgoal, as reflected in Figure 27, aggregates to achieve the overall emissions reduction target. It should be noted that improving vehicle efficiency through traffic flow improvement is another method for reducing GHG emissions, but this has not been included because at Tonga's stage of development there is a large and uncertain takeback effect in which traffic flow improvements lead to increased VKT.⁴⁹

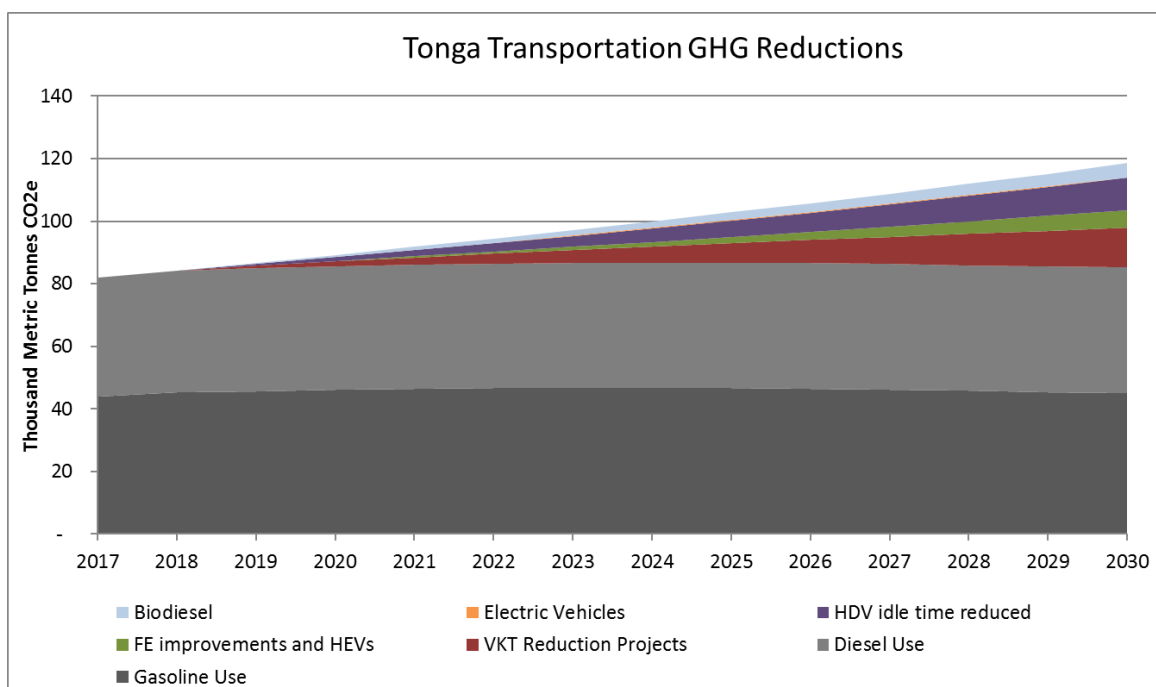


Figure 27. Transportation wedge analysis, thousand metric tonnes of CO₂e

Figure 27 shows that if each of the subgoals is achieved, it would lead to a 28% reduction in GHGs below BAU by 2030. This is actually a 1% increase above the 2018 baseline. The proposed subgoals all refer to reductions from the 2030 BAU case and are as follows:

1. Twenty percent reduction in VKT of light-duty vehicles (LDVs) through walking, biking, public transit, ridesharing, and telecommuting. This subgoal focuses on LDVs because these vehicles are responsible for most of the emissions increases as a country develops. It should be noted that a 20% reduction from the 2030 BAU VKT is equivalent to a 15% reduction from the 2018 VKT. These reductions will occur through projects outlined in section 5.
2. Thirty percent improvement in fuel economy for new LDVs through registration fees, import tariffs, or fuel economy standards. This would be an improvement from 10.1 liters per 100 km in 2016 to 7 liters per 100 km in 2030. This subgoal is realistic because it is slightly less ambitious than what the United States achieved through its Corporate Average Fuel Economy program between 2010 and 2017 (34% improvement in 7 years, starting at 10 liters per 100 km⁵⁰).
3. HDV idle time reduced by 1 hour per day. HDVs use about 3.5 liters of diesel per hour and LDVs about 1.5.⁵¹ This high consumption rate is due to the fact that engines are not operating within their optimal range when idling. Auxiliary loads such as air conditioning or hydraulic lifts only require a fraction of the power that is delivered from an idling vehicle engine. Many cities around the world have successfully implemented idle bans that have reduced HDV idle time by much more than 1 hour per day.⁵² Tonga is at an advantage, because its

warm temperatures enable easy diesel start-up without concerns about gelling fuel. Numerous technologies can enable significant idle reduction, including automatic engine shutoff, storage cooling, auxiliary power units, electrified parking spaces, and batteries.⁵³

4. All road transportation diesel contains 10% biodiesel. This amount would be sourced from all available waste oil and grease in the country (which could provide an estimated 77% of the targeted biodiesel in 2030⁵⁴) and the rest would come from coconut oil. The Philippines are quickly approaching 5% coconut biodiesel in their large diesel market and have advanced the science and production methods along the way. In this example, coconuts were the preferable source of biodiesel because they are symbiotic with many other crops.⁵⁵
5. Ten percent of new LDVs are electric by 2030. This is a very conservative goal for two reasons. First, batteries are the dominant cost of electric vehicles (EVs), and these costs are dropping quickly.⁵⁶ Secondly, the efficacy of EVs as a GHG-mitigating technology largely depends upon the electricity mix. Figure 28 compares the carbon emissions of EVs, conventional vehicles, and a Prius hybrid electric vehicle (HEV). The Nissan Versa and Nissan Leaf are the conventional and EV versions of the same model. Likewise, the Toyota Highlander and Tesla Model X are conventional and EV versions of SUVs of similar size. Both EVs are lower-emitting than their conventional counterparts even with 0% renewable electricity. However, this chart also highlights the fact that HEVs such as the Toyota Prius have low emissions regardless of the electricity mix. Therefore, the EV-promoting policies and projects highlighted in Table 8, such as the purchase rebates and the mechanic training, should be inclusive of HEVs, plug-in hybrid electric vehicles, and EVs and the market can determine which is favored at any given time.

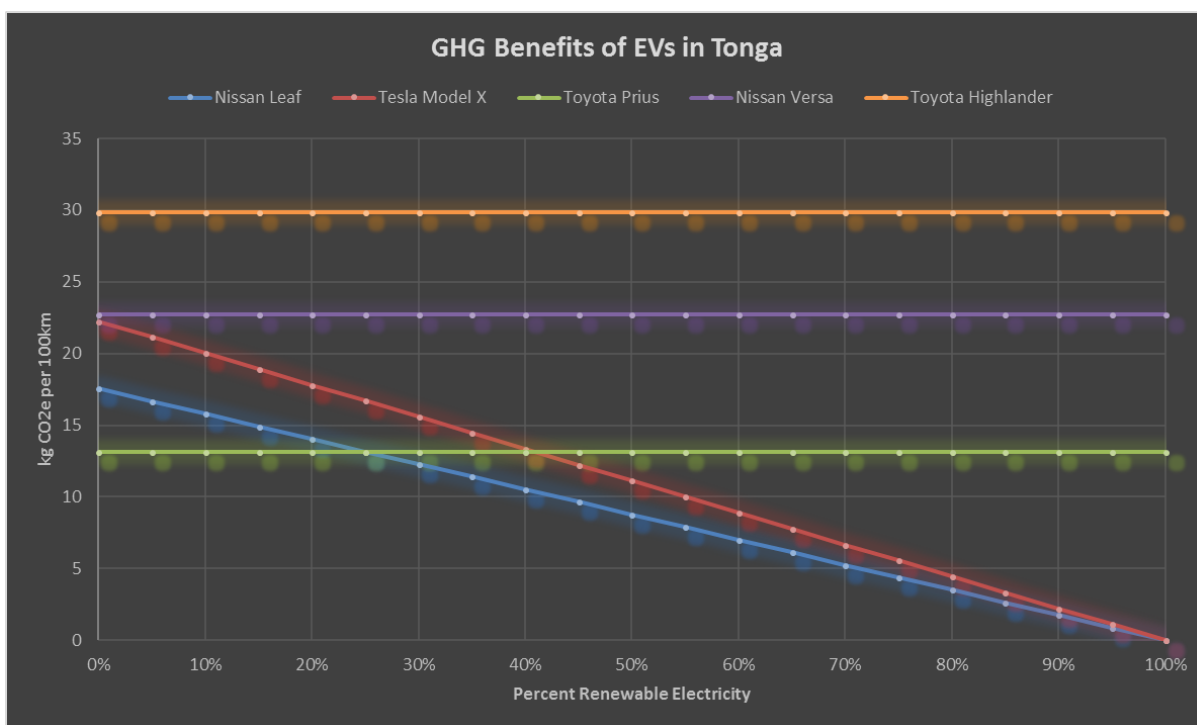


Figure 28. Greenhouse gas emission benefits of electric vehicles in Tonga

4.2 Electricity Wedge Analysis

Tonga’s NDC includes a commitment to replace 50% of electricity with renewables by 2020 and 70% by 2030; the TEEMP model assumes that these goals will be met. In 2017, 7% of TPL’s generation was supplied by renewable resources. To achieve the 2020 goal will require high levels of immediate investment; several large wind and solar projects are currently planned or under construction. It’s unclear what the exact output of these projects will be, but it is apparent that successful completion of these projects and more will be needed to meet the 2020 and 2030 RE

penetration goals. Tonga should be applauded and assisted by the international community in their efforts to meet these ambitious goals.

Tonga’s ambitious renewables plan will already significantly reduce the country’s GHG emissions from electricity. Pairing this plan with a suite of EE policy options offers the potential to not only further reduce Tonga’s emissions, but to also reduce the amount of new renewable capacity needed to meet penetration targets. To achieve 50% renewables by 2020 without any MEPS or policy options, Tonga would need the equivalent generation from approximately 120,213 solar panels; when the suggested EE policy options and MEPS are implemented, that number drops to 79,260 panels, a capacity reduction of 34%. In this model, a 70% reduction in Tonga’s 2030 electricity emissions—from 91,500 metric tonnes CO_{2e} to 18,900 metric tonnes CO_{2e}—is possible. This signifies a reduction of 76,400 metric tonnes CO_{2e}, of which 58% is from increased RE penetration, 13% is from stringent MEPS reductions, and 28% is from a suite of other policy options.

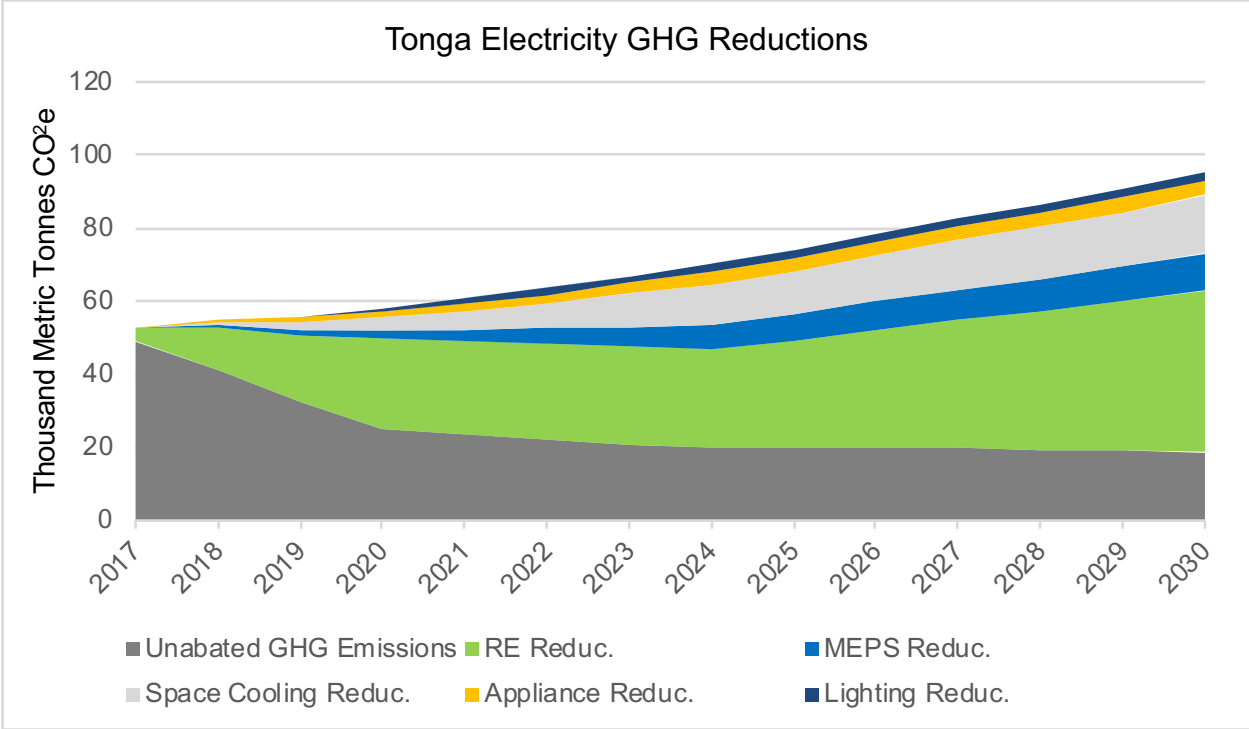


Figure 29. Electricity wedge analysis

In order to meet this target, a number of subtargets should be established, including:

1. One hundred percent adoption of MEPS by 2022 (based on 7-year phase-in of policies); extend MEPS to Australian/New Zealand standards for all refrigerators and freezers, air conditioners, water heaters, TVs, computers, clothes washing machines/dryers, and cooking appliances as well as curtailing importation of non-LED bulbs. Implement 100% labeling of appliance efficiency.
2. Achieving 50% RE implementation by 2020 and 70% by 2030. Utility-scale solar projects will be vital in achieving these targets (Tongan officials indicate that six projects are currently in various stages of development), but incentivizing customer uptake of on-site renewables will also be needed to meet these ambitious goals. Additional incentivizes can be offered through TPL’s existing net metering program, especially for high use customers such as churches, schools, water pumping stations, etc. By generating electricity on-site at high load locations, additional benefit can be realized while avoiding line losses. Consider the establishment of subsidy or revolving loan programs—potentially with funding from sources like the Green Climate Fund—to assist large users in converting to on-site solar.
3. Reduce line losses to the lowest feasible amount by 2030. Great strides have already been made at this in recent years, and the introduction of smart meters should help identify the largest problem areas.
4. Implement new EE and cyclone-resistant building standards and perform energy audits on all large customers by 2025.

5. Reduce the uptake of electric hot water heaters, particularly those with tanks, by incentivizing the purchase of solar hot water heaters.
6. Replace 100% of streetlights with LED bulbs, and use LED bulbs in government facilities wherever possible.
7. Establish a Green Hotel Accreditation program and leverage the Ministry of Tourism’s existing accommodation guide to review hotels based on these standards.
8. Implement a revolving loan program through the Tonga Development Bank to assist private entities in financing EE and net metering projects.
9. Develop an IRP with TPL to identify how EE and renewables targets will be met in specific detail. Use this planning process to identify the cost-effectiveness of other potential options, such as refurbishing or replacing diesel generators to increase efficiency.

4.3 Combined Wedge Analysis

When combined, the suite of policy options from electricity and transportation offer a reduction of 106,000 metric tonnes of CO₂e a year by 2030. This represents a 43% reduction from the BAU emissions of 210,000 metric tonnes of CO₂e. Action taken in the ground transportation field is responsible for 30.4% of the projected emissions reductions, renewable electricity is responsible for 40%, and EE in the electric sector is responsible for 29.6% of the reductions. Figure A-2 in the Appendix contains a figure with a breakdown of reductions by sector and policy.

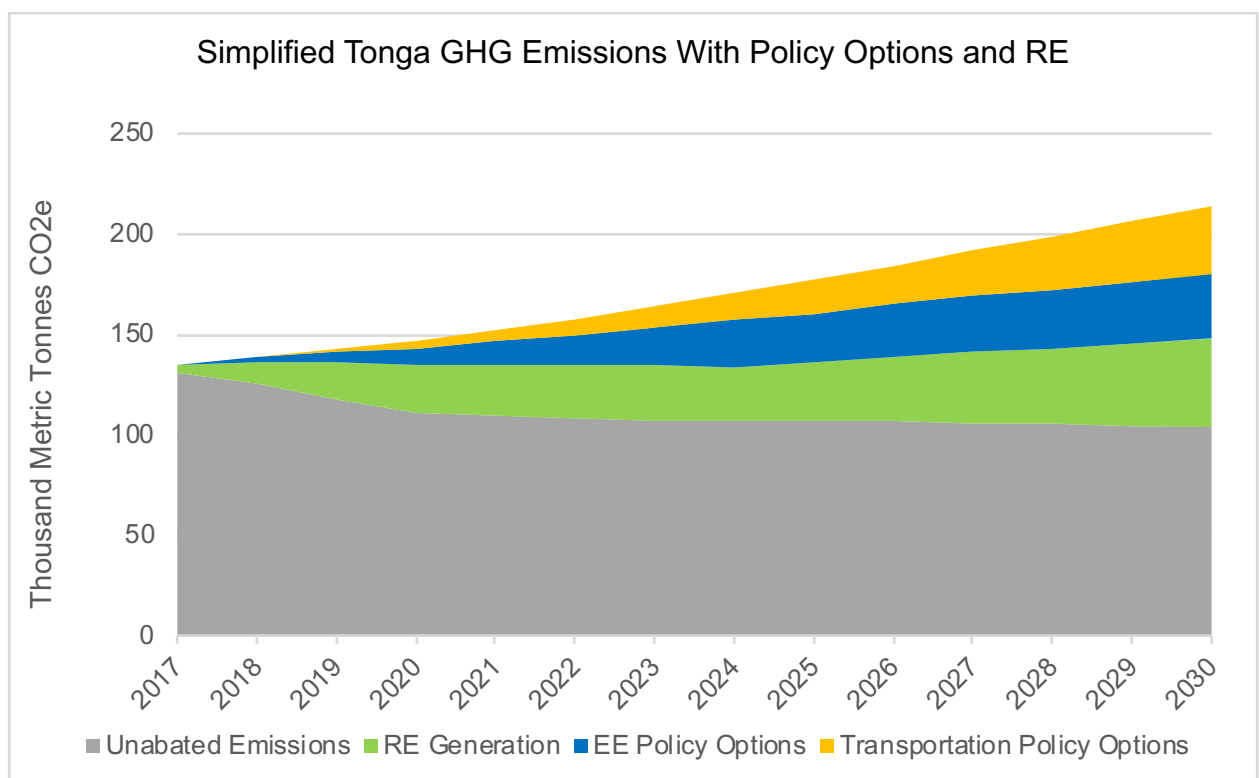


Figure 30. Simplified combined wedge analysis

4.4 Energy Flow Diagram of 2030 Goal

The changes that these emissions-reducing policies and projects would have on the energy usage and infrastructure of Tonga is best viewed through a Sankey energy flow diagram. Figure 31 illustrates the flow in 2030 if all goals are met. It should be noted that these Sankey diagrams in the TEEMP only cover the electric and ground transportation sectors, and are thus only a portion of the energy used and GHGs emitted in Tonga. Therefore, the breakdown of sectoral fuel use does not compare directly, when looking at percentages, to Tonga’s NDC.

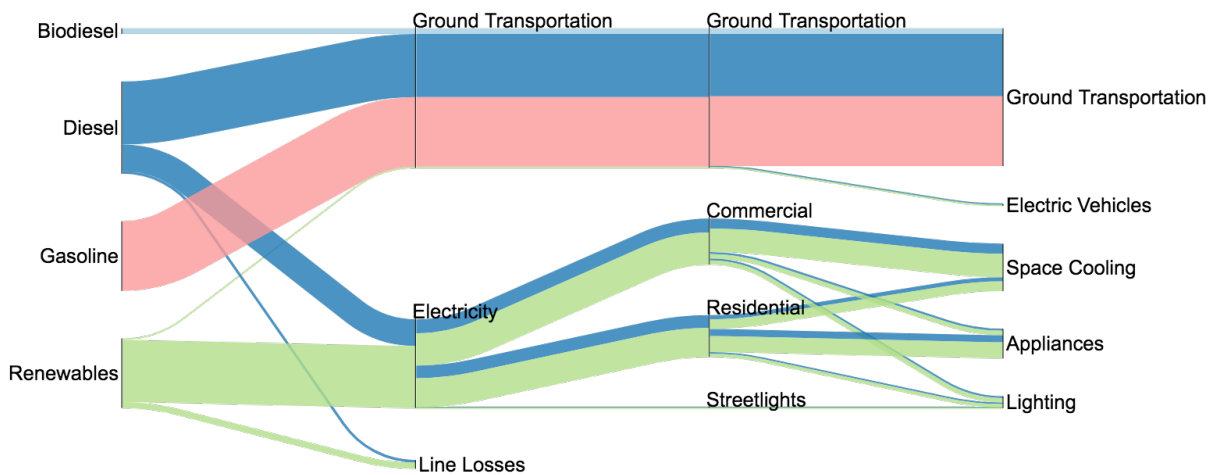


Figure 31. Tonga 2030 energy flows with goals achieved in the electricity and ground transportation sectors

The major changes between this and the Sankey diagram displayed earlier in the TEEMP is the addition of large quantities of RE, and the associated reduction in diesel use. Although space cooling grows in the residential sector, the amount of growth is substantially less under the TEEMP than under the BAU scenario. Similar measures are also able to reduce the portion of Tonga’s electricity used to power space cooling. Biodiesel also emerges as a fuel source for transportation; although it would be possible to mix biodiesel into fuel for use in TPL’s generators, this has not been included in the model due to limited knowledge of TPL’s generator fuel requirements. Although a reduction in line losses is indicated, the impact of these efforts would most likely be more dramatic. Renewable projects are likely to be located closer to the loads they serve, and thus less likely to be susceptible to substantial line losses.

4.5 Energy Intensity with TEEMP Policy Changes

Although the energy intensity of Tonga is projected to rise at a linear rate under the BAU scenario, the policies outlined in TEEMP stabilize Tonga’s reliance on imported fuel. Figure 32 shows the difference between these two scenarios; the TEEMP scenario continues to decrease Tonga’s energy intensity to around 160 GJ per \$1 of GDP per capita. An increase in Tonga’s energy intensity represents additional reliance on foreign fuel imports to power Tonga’s economic growth. EE measures like those detailed in the TEEMP reduce Tonga’s vulnerability to volatility in fuel markets or supply chain issues.

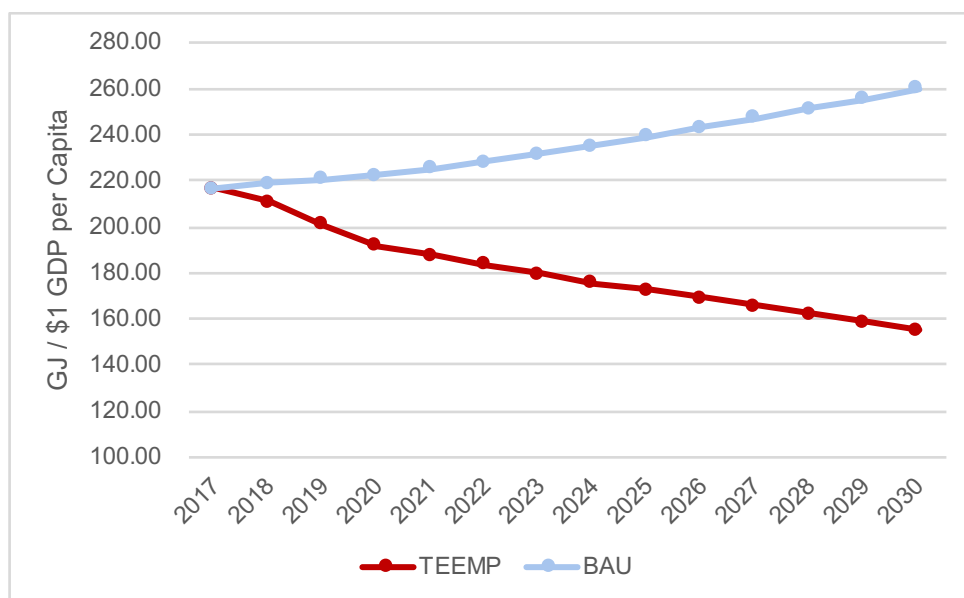


Figure 32. Energy intensity of Tonga following TEEMP policy implementation

5 Projects and Policies to Reduce Greenhouse Gas Emissions

The next step in the path towards achieving the goals laid out in Section 4, and to further verify the feasibility of these goals, is to detail policies and projects that would achieve them.

It should be noted that the scope of this study is only the transportation and electricity sector, and a large portion of Tonga's total emissions are from industrial processes, the agricultural sector, and other nonenergy sources. Emissions reduction potential likely exists in these sectors as well and should be addressed when adopting a comprehensive plan to meet Tonga's emission targets under their deposited NDC.⁵⁷

Tables 8 and 9 represent the transportation and EE (respectively) policies and projects that can deliver the GHG emissions reductions called for in the wedge analysis. The policies and projects are prioritized in each table in an effort to indicate which projects should be pursued first, given limited resources. The rating systems is good (green), medium (yellow), and bad (red) in the following categories:

- GHG reduction size represents the quantity of GHGs that a given project reduces by 2030. This is deemed the most important factor.
- Up-front cost is the next most important factor. We chose to focus on up-front cost instead of life cycle cost because the government can only take on a limited number of projects, and this limit is determined by its up-front cost. Many projects pay themselves off and are even cost-negative when viewing life cycle costs. For divisible projects such as pedestrian paths or bus route expansion, Table 8 represents the cost of the less expensive projects rather than the cost of all projects.
- Time to implement considers how quickly the project can begin reducing GHG emissions.
- Ancillary benefits reflect other side benefits such as cost savings, time savings, convenience, safety, and healthfulness associated with a project. It also applies to employment increases and equality across genders and age groups. These benefits usually lead to increased popularity from citizens (voters), which translates to political viability.
- Support available indicates if there is likely to be a champion of the policy/project within Tonga and if it is likely to receive support from international organizations.

5.1 Transportation Policies and Projects

Table 8 lists some transportation policies and projects to help achieve the goals laid out by the wedge analysis. In this table, a green cell is worth two points, yellow worth one, and red worth zero. In the event of a tie, columns to the left are prioritized over the ones to the right.

Table 8. Policies and Projects to Reduce Greenhouse Gas Emissions from Ground Transportation

Wedge	Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Available
VKT Reduction	Use a platform such as NextBus to track and coordinate busses	High	Low	Low	High	High
VKT Reduction	Enact a safe bicycle passing law	High	Low	Low	Med	High
EV and HEV	Send a mechanic to HEV/EV maintenance training in Japan or New Zealand	High	Low	Low	Med	High
VKT Reduction	Provide pedestrians (particularly school children) and cyclists with safety reflectors and lights	Med	Low	Low	High	High
VKT Reduction	Install rumble strips and painted lines demarcating lane boundaries parallel to sidewalks to increase pedestrian safety	High	Low	Low	Med	Med
Idle Reduction	Limit idle time with the help of fleet partners and idle reduction technologies	Med	Low	Low	High	Med
Vehicle Efficiency	Adjust vehicle registration tax and import tariff according to vehicle weight, displacement, or fuel economy	High	Low	Low	Med	Low
Biodiesel	Blend diesel fuel with waste grease and coconut oil biodiesel at 10% blend	High	Low	Med	Low	High
VKT Reduction	Begin a water taxi in the lagoon (and some associated dredging)	High	Med	Med	High	Med
VKT Reduction	Build a strategic parking lot and bus stop at intersection of Tafua'ahau Rd. and Loto Rd. and accompaly with Nuku'alofa parking policy	High	High	Med	High	High
Vehicle Efficiency	Fuel economy and fuel cost labeling requirements	Med	Low	Low	Med	Med
Vehicle Efficiency	Implement motorcycle/scooter safety program and vest requirements	Med	Low	Low	Med	Med
VKT Reduction	Incentivize tuk tuks to queue at major bus stops in the countryside to complete the last-mile travelled	Med	Med	Low	High	Med
EV and HEV	Introduce rebates on HEVs and EVs , including low-speed electric vehicles such as GEMs and EV scooters	Med	Low	Low	High	Low
EV and HEV	Rebates on the installation of public EV chargers with timers, then smart meters to smooth the load of 50% renewable	High	High	High	High	High
VKT Reduction	Construct a toll bridge across the top of the lagoon, with parking lots at either end	High	High	High	High	Med
VKT Reduction	Coordinate taxis (with a common dispatch and/or coordination apps such as FlyWheel) to increase the convenience of not owning a vehicle	Med	Med	Med	Med	Med
Flow Improvements	Construct left hand turn lanes at key intersections to improve traffic flow	Med	Med	Med	High	High
Flow Improvements	Construct bus pull-offs to improve traffic flow	Low	Med	Med	High	High

- Use a platform such as [NextBus](http://www.nextbus.com)ⁱ to **coordinate busses**:
 - Leading Organization*: MCCTIL
 - Modeled Impact*: GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO₂e per year.
 - Trackable buses greatly reduce time wasted due to arrival-time unpredictability, especially on routes such as those in Tonga, where buses don't circulate frequently. This also reduces the stress and time associated with riding the bus, encouraging more ridership. Furthermore, predictable buses could dampen the current perverse incentive that bus owners have to delay departure as long as possible (and therefore pick up more riders). Census data indicate that a significant (and growing) portion of Tonga's population owns a cell phone, which can be leveraged to provide transportation data to customers on demand.
 - Resource*: [How NextBus Works](https://nextbus.cubic.com/About/How-NextBus-Works)ⁱⁱ
 - Resource*: [Urban Bus Services in Developing Countries and Countries in Transition](http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1140&context=jpt).ⁱⁱⁱ
- Enact a **safe bicycle passing law** for drivers passing cyclists or pedestrians:
 - Leading Organization*: MOI

ⁱ www.nextbus.com

ⁱⁱ <https://nextbus.cubic.com/About/How-NextBus-Works>

ⁱⁱⁱ <http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1140&context=jpt>

- *Modeled Impact:* GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO_{2e} per year.
 - A minimum passing distance law sends a signal that pedestrians and bikers have the right to be on the road, and that it is the responsibility of drivers to avoid hitting them. Of course, the law is only effective if police actively enforce it. One study found that in a state with such a law, although violations were plentiful, enforcement was rare.⁵⁸
 - *Resource:* [League of American Bicyclists--Model Safe Passing Law](https://bikeleague.org/content/model-safe-passing-law-0)^{iv}
 - *Resource:* [Public Policies for Pedestrian and Bicyclist Safety and Mobility](http://www.pedbikeinfo.org/cms/downloads/PBSPolicyReview.pdf).^v
- 3. Send a mechanic to HEV/EV maintenance training** in Japan or New Zealand:
- *Leading Organization:* Ministry of Education and Training (MET)
 - *Modeled Impact:* GHG reduction from *all* electric vehicle projects by 2030 of 300 metric tonnes of CO_{2e} per year.
 - This facilitates the adoption of both HEVs and EVs. Toyota operates a training program in Japan specifically for foreign nationals, and MITO is developing a similar technical program in New Zealand. Scholarships could be available through Toyota, MITO, or JICA to make this a low-cost option to ensure that Tonga has the technical capacity to repair and maintain new vehicle technologies. As the market for EV mechanics expands, one of the graduates from these programs could work with a college or trade school in Tonga to develop a program to teach other students.
 - *Resource:* [Toyota Tajimi Service Center](http://blog.toyota.co.uk/tajimi-service-centre-where-world-class-toyota-mechanics-are-trained)^{vi}
 - *Resource:* [MITO Automotive Electrical Engineering Program](http://www.mito.org.nz/get-qualified/our-industries/automotive/automotive-electrical-engineering/).^{vii}
- 4. Provide pedestrians (particularly schoolchildren) and cyclists with safety reflectors and lights:**
- *Leading Organization:* MET
 - *Modeled Impact:* GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO_{2e} per year.
 - VKT will increase so long as pedestrians feel safer in cars than on foot. Traveling on foot at night is a particular concern as 75% of U.S. accidents resulting in a pedestrian casualty occurred in the dark.⁵⁹ Various pilot programs to distribute reflectors or lights to schoolchildren have proven effective at reducing accidents. Studies identify that reflector vests are the most effective option for increasing the visibility of cyclists to drivers.⁶⁰
 - *Resource:* [A Road Safety Manual for Decision-Makers and Practitioners \(Pages 78–81\)](http://apps.who.int/iris/bitstream/10665/79753/1/9789241505352_eng.pdf?ua=1).^{viii}
- 5. Install rumble strips and painted lines demarcating lane boundaries to increase pedestrian and biker safety:**
- *Leading Organization:* MOI
 - *Modeled Impact:* GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO_{2e} per year.
 - As most countries develop, they initiate a negative feedback loop. Cars are prioritized, VKT increases, and pedestrian and biker safety decreases, which incentivizes travel by car instead of walking or biking. Tonga therefore needs to safeguard pedestrian and biker space before this feedback loop commences. Rumble strips are a relatively inexpensive and effective way to keep drivers off the shoulder of the road, providing pedestrians with a reassurance of safety. In areas where the road is too narrow, “sharrows” reserve space for bikers and increase driver awareness.
 - *Resource:* [Decision Support Guide for the Installation of Rumble Strips on Non-Freeways](http://apps.who.int/iris/bitstream/10665/79753/1/9789241505352_eng.pdf?ua=1)^{ix}
 - *Resource:* [A Road Safety Manual For Decision-Makers and Practitioners \(Page 28\)](http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/fhwasa16115/fhwasa16115.pdf).^x

^{iv} <https://bikeleague.org/content/model-safe-passing-law-0>

^v <http://www.pedbikeinfo.org/cms/downloads/PBSPolicyReview.pdf>

^{vi} <http://blog.toyota.co.uk/tajimi-service-centre-where-world-class-toyota-mechanics-are-trained>

^{vii} www.mito.org.nz/get-qualified/our-industries/automotive/automotive-electrical-engineering/

^{viii} http://apps.who.int/iris/bitstream/10665/79753/1/9789241505352_eng.pdf?ua=1

^{ix} http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/fhwasa16115/fhwasa16115.pdf

^x http://apps.who.int/iris/bitstream/handle/10665/79753/9789241505352_eng.pdf;jsessionid=8F65AB2C61A5A6BB A0B12BB467918D13?sequence=1



Sources: Caley Johnson and Kevin Collington (NREL)

Figure 33. Pedestrians in Tonga with limited right-of-way, compared to road with designated bicycle/pedestrian lane

6. Limit idle time with the help of fleet partners and idle reduction technologies

- *Leading Organization:* MEIDECC
- *Modeled Impact:* GHG reduction by 2030 of 10,300 metric tonnes of CO₂e per year.
- Fleets can greatly reduce their fuel and maintenance costs by reducing their idle time. Outreach and partnerships that help them realize these savings generally well accepted—especially when they are affiliated with schools, because children are particularly susceptible to air pollution. In addition, many states and municipalities around the world successfully restrict idling due to air quality and noise concerns.⁶¹ Numerous technologies are available that allow vehicles to reduce their idle time while performing the tasks required of the idling vehicle.
- *Resource:* [SmartWay Verified List of Idling Reduction Technologies^{xi}](#)
- *Resource:* [Idle Reduction for Long-Haul Trucks^{xii}](#)
- *Case Studies:* [Clean Cities Fleets Using Idle Reduction Technologies.^{xiii}](#)

7. Set vehicle registration fee and/or import tariff according to fuel consumption:

- *Leading Organization:* Ministry of Revenue and Customs
- *Modeled Impact:* GHG reduction from *all* fuel efficiency improvements by 2030 of 5,700 metric tonnes of CO₂e per year.
- People are most responsive to up-front costs when purchasing vehicles; they are less responsive to life cycle ownership costs. Therefore, registration fees and import tariffs can be set to make efficient vehicles much less expensive than inefficient ones. Countries have implemented such registration fees that are based on CO₂ emissions, fuel consumption, fuel economy, engine displacement, or vehicle size. Some have even implemented a “feebate” system that actually pays people that register the most efficient vehicles.⁶² The recommended registration policy for Tonga would be based on GHG emissions (which allows for alternative fuels), be constant across size categories (to avoid perverse incentives to increase size), and be a “feebate,” which is much more politically feasible.
- *Resource:* [Vehicle Registration Fees Implemented by Countries^{xiv}](#)

^{xi} www.epa.gov/verified-diesel-tech/smartway-verified-list-idling-reduction-technologies-irts-trucks-and-school

^{xii} <https://anl.app.box.com/s/ordxowhccqr7fe3yd3oy2fqpw3fpiw>

^{xiii} www.afdc.energy.gov/case

^{xiv}

www.globalfueleconomy.org/transport/gfei/autotool/approaches/economic_instruments/varied_registration_fees.asp

- *Resource:* [Fuel Economy State of the World 2016^{xv}](#)
- *Tool:* [New Zealand Fuel Economy Rating Database.^{xvi}](#)

8. Blend 10% biodiesel into all diesel fuel

- *Leading Organization:* MEIDECC
- *Modeled Impact:* GHG reduction by 2030 of 4,500 metric tonnes of CO₂e per year.
- As described in section 4.1, by 2030 this quantity of biodiesel would be supplied mostly by waste grease supplemented by about 25% coconut oil. 10% biodiesel is compatible with nearly all diesel vehicles in a warm climate and provides lubricity and cetane benefits.⁶³ To take full advantage of its waste grease resources, Tonga would need to build biodiesel production facilities with a total of about 1 million liters per year capacity, likely divided between a few islands. The economics of such small-scale waste-grease-to-biodiesel production facilities can be favorable, depending on numerous factors.⁶⁴
- *Resource:* [Economics of Small-Scale Biodiesel Production^{xvii}](#)
- *Resource:* [European Biodiesel Board^{xviii}](#)
- *Resource:* [National Biodiesel Board of the U.S.^{xix}](#)
- *Resource:* [Philippines Shell Foundation Inc. Project COCONUT^{xx}](#) (they are working with farmers in the Philippines to improve coconut productivity for biodiesel).

9. Develop a water taxi in the laguna (which would require some associated dredging):

- *Leading Organization:* MOI
- *Modeled Impact:* GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO₂e per year.
- Transporting passengers via water taxis can be more efficient than road transportation on an energy per passenger-kilometer basis, depending largely on the size and occupancy of the vehicles.⁶⁵ Furthermore, the distance from Nuku'alofa to various towns lining the laguna is much shorter traveling across the laguna rather than around the laguna on Taufa'ahau Road. Ancillary benefits include time and traffic reductions. However, the laguna would likely require dredging in some locations.
- *Resource:* [Sarasota Water Taxi Feasibility Study^{xxi}](#)
- *Resource:* [Forget Flying Cars: We Need Floating Ones.^{xxii}](#)

10. Build a strategic parking lot and bus stop at intersection of Taufa'ahau Rd. and Loto Rd.

- *Leading Organization:* MOI
- *Modeled Impact:* GHG reduction from *all* VKT reduction projects by 2030 of 12,700 metric tonnes of CO₂e per year.
- Strategic parking lots are often located at bottlenecks where traffic gets worse or at confluences of roads. They provide good locations where people can park their vehicles and catch a bus or carpool into congested areas with limited parking. This intersection in Pea meets these requirements, with nearly 17,000 vehicles passing through it per day on their way to and from Nuku'alofa. Furthermore, it has a shopping center nearby with a parking lot that could be used during initial stages of this project. Parking lots in this location could alleviate the need for additional parking in Nuku'alofa as vehicle ownership increases and could enable the city to remain dense and pedestrian-friendly. This parking lot also sets the stage for reducing the parking in Nuku'alofa through a new parking policy.
- *Resource:* [Washington DC Park & Ride System^{xxiii}](#) facilitates carpooling and mass transit.

^{xv} www.globalfueleconomy.org/media/203446/gfei-state-of-the-world-report-2016.pdf

^{xvi} <https://rightcar.govt.nz/find.html>

^{xvii} <http://articles.extension.org/pages/30024/economics-of-small-scale-biodiesel-production>

^{xviii} <http://www.ebb-eu.org/>

^{xix} <http://biodiesel.org/>

^{xx} <https://news.mb.com.ph/2018/06/06/project-coconut-launched-in-quezon/>

^{xxi} www.floridajobs.org/fdcp/dcp/waterfronts/Communities/BradentonBeach/WaterTaxiStudy.pdf

^{xxii} www.citylab.com/transportation/2017/05/forget-flying-cars-we-need-floating-ones/526944/

^{xxiii} www.commuterconnections.org/commuters/transit/park-ride-locations/

11. Introduce fuel economy and fuel cost labeling requirements:

- *Leading Organization:* MEIDECC
- *Modeled Impact:* GHG reduction from *all* fuel efficiency improvements by 2030 of 5,700 metric tonnes of CO₂e per year.
- Economics provide a powerful reason for people to purchase more efficient vehicles. However, this is not clear unless people know the fuel economy of vehicles that they are considering purchasing. Stickers on vehicles at dealerships that clearly state the expected annual fuel cost of the vehicle further illustrate this point. Using fuel economy on the Japanese test cycle would be a good start or combining test cycles from multiple countries the way New Zealand does. However, to maximize accuracy, Tonga could develop their own test drive cycle, perhaps with the DRIVE tool.⁶⁶
- *Example:* [Fuel Economy Labeling, Focus on non-EU Countries^{xxiv}](#)
- *Review:* [Evaluation of Vehicle Fuel Efficiency Labeling and Consumer Information Programs.^{xxv}](#)

^{xxiv} www.iea.org/media/workshops/2013/gfeilabelling/02.ICCT.130430ICCTCO2labelingoutsideEU.pdf

^{xxv} www.theicct.org/sites/default/files/publications/VFEL%20paper%20ICCT_%20for%20APEC%20-%202012%20Nov%202015%20FINAL.pdf

5.2 Electricity Energy Efficiency Policies and Projects

Table 9 details least-cost policy option to achieve EE targets in more detail.

Table 9. Rubric of Least-Cost Building/Appliance Energy Efficiency Policy Options

Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Available
Implement building standards for resilience and energy efficiency (e.g. passive ventilation and daylighting with appropriate external shading)	High	Low	Med	High	High
Perform energy audits of buildings to create baselines and implement energy conservation measures	High	Low	Med	High	Med
MEPs for equipment and appliances	High	Low	Med	Med	High
Set packaging and recycling standards to limit the amount of waste imported to Tonga	High	Low	Med	High	Med
Implement a public awareness campaign on energy efficiency and conservation	High	Low	Med	Med	Med
Establish a demand-side management revolving loan or rebate program to aid in financing more efficient equipment (residential, commercial and industrial)	High	Med	Med	High	Med
Prioritize on-site RE with islanding controls and energy storage within critical infrastructure	High	High	Med	High	High
Implement distributed energy generation projects that incorporate RE and fossil fuels to enhance resilience and reduce emissions associated with diesel generation, particularly when electrifying new areas or islands	High	High	Med	High	Med
Work with TPL to create an integrated resource plan to incorporate RE, EE, and more efficient reciprocating engines that can be dual fuel	High	Med	High	Med	High
Data collection exercise/database to manage energy data by sector	Med	Med	Low	High	Med
Work with TPL to underground lines along the coast that are susceptible to cyclone damage	Med	High	High	High	High
Work with TPL to ensure grid hardening is adequately carried out (e.g., pole depth and composition can impact survival rate of T&D lines during cyclones)	Med	High	High	High	High
Continue to reduce T&D losses	Med	High	High	High	Med
Create or implement a certification process for sustainable/green hotels for the tourist industry	Med	Med	Med	Med	Med
Continue the street lighting upgrade program and using roundabouts rather than traffic lights	Med	Med	High	Med	High
Create a cool roof program to reflect heat from rooftops and save energy on air conditioning loads where buildings are air tight and have AC units installed	Med	Med	High	Med	High
Explore waste-to-energy options to reduce the landfill capacity challenges	Med	High	High	High	Med

Details and selected case studies for some of these policy options are listed below; in most cases, these detailed breakdowns are not examining the projects that will generate the largest emissions reductions (those projects are space cooling reductions such as passive shading, cool roofs, and MEPS). Rather, the policy options listed below are intended to create the prerequisite environment to support those projects and create a framework to enforce and finance compliance:

1. Implement **building standards** for resilience and EE (e.g., passive ventilation and daylighting with appropriate external shading):
 - o *Leading Organization:* MEIDECC develops energy components of codes, the MOI implements, and the attorney general's office approves permits.
 - o *Modeled Impact:* 1,100 metric tonnes CO_{2e}, with several secondary effects (passive shading or cool roofs, resilience benefits, identifying energy saving opportunities).
 - o As GDP per capita increases, more power is used to supply loads that could be better satisfied by mindful construction practices such as orienting windows to optimize passive ventilation, strategic shading, and insulating building shells if air conditioning is to be installed. Additionally, reviewing building codes provides an opportunity to ensure that new construction is well-engineered to withstand the worsening effects of tropical cyclones. Tonga can learn best practices from international partners to develop standards that are both easy to interpret and consistent with UN Sustainable Development Goals 7, 9, and 11.

- Tongan officials indicated during in-person training sessions that no ministry currently has the capacity to assess building standards; this comment is being clarified, and, if it's true, should be remedied legislatively to ensure that new building standards are appropriate for the climate and EE necessities of Tonga. To begin implementation of new building standards, the first step involves assembling a working group of stakeholders and reviewing the current building codes.
 - *Ongoing Project:* [Review, Strengthening & Updating Of the Tonga Building Code^{xxvi}](#)
 - *Example:* [Guidelines for Cyclone Resistant Construction of Buildings in Gujarat \(India\)^{xxvii}](#)
 - *Resource:* [Mainstreaming Building Energy Efficiency Codes in Developing Countries.^{xxviii}](#)
2. Implement a **public awareness campaign** on EE and conservation:
- *Leading Organization:* MET
 - *Modeled Impact:* 600 metric tonnes CO₂e, with several secondary effects (identifying other EE options). 10,100 metric tonnes CO₂e possible through MEPS.
 - Creating an EE public awareness campaign focusing on both the environmental and personal economic benefits to rate payers who reduce their consumption. The introduction of a MEPS program goes hand-in-hand with this; although 80% of Tongans said appliance running costs are important to them, only 34% plan on looking for an Australian/New Zealand MEPS label next time they purchase an appliance.⁶⁷ Introducing a program that is easy to understand and educating customers as part of a broader EE public awareness campaign is critical. Empower customs agents to halt any imports of inefficient appliances and establish packaging and recycling standards to ensure that any public awareness campaign is backed by meaningful action.
 - *Example:* [Raising Awareness of Energy Efficient Light Bulbs Pays off in Rwanda^{xxix}](#)
 - *Resource:* [Creating an Awareness Campaign.^{xxx}](#)
3. Establish a demand-side management **revolving loan or rebate program** to aid in financing more efficient equipment (residential, commercial, and industrial):
- *Leading Organization:* Tonga Development Bank
 - With a small initial investment—potentially funded in part by development banks—the existing capabilities of the Tonga Development Bank could be leveraged to provide ultra-low interest loans to projects that demonstrate they can generate energy savings. These savings are used to pay off the full amount of the loan in a 5 to 10-year period, at which point the fund is redistributed to subsequent projects. Rebate programs similarly encourage customer uptake of efficient technologies.
 - Outreach is a critical aspect of a revolving loan program; raising awareness among rate payers that the program exists and highlighting the fact that substantial EE savings could provide long-term savings is important.
 - *Example:* [The Thai Energy Efficiency Revolving Fund^{xxxi}](#)
 - *Resource:* [Exploring the Case for Revolving Funds for Domestic Energy Efficiency Programs.^{xxxii}](#)
4. Work with TPL to create an **IRP** to incorporate RE, EE, and more efficient reciprocating engines that can be dual fuel:
- *Leading Organization:* MEIDECC, Tonga Electricity Commission, TPL
 - Although TPL is eagerly working towards Tonga's RE goals, the company publishes little long-term planning details about how these goals will be achieved. An IRP provides an opportunity for the company to lay out a long-term, realistic framework outlining how goals will be met in a scope not

^{xxvi}<http://projects.worldbank.org/procurement/noticeoverview?lang=en&id=OP00040895>

^{xxvii}http://www.tn.gov.in/tsunami/digitalibrary/ebooks-web/31/Guideline_for_Cyclone_Resistant_Construction_of_Building.pdf

^{xxviii}<http://documents.worldbank.org/curated/en/284341468324865236/pdf/578770PUB0Main101public10BOX353783B.pdf>

^{xxix} <http://www.worldbank.org/en/news/feature/2014/11/06/raising-awareness-energy-efficient-light-bulbs-pays-off-rwanda>

^{xxx}https://www.carbontrust.com/media/13089/ctg056_creating_an_awareness_campaign.pdf

^{xxxi}<http://fs-unep-centre.org/sites/default/files/publications/fs-unepthaieerffinal.pdf>

^{xxxii} https://ac.els-cdn.com/S0301421515300562/1-s2.0-S0301421515300562-main.pdf?_tid=6243bcdc-17ec-4fb7-b7b8-55705a829aec&acdnat=1520985623_f0c7505b6aaa4d165f739f5da008bb87

captured by annual reports. Use modeling such as PLEXOS or SAM to integrate cleaner energy generation sources to provide peaking power, and limit Tonga’s exposure to fluctuations in the price of diesel.

- *Example:* [Hawaiian Electric Companies IRP^{xxxiii}](#)
- *Resource:* [Greening the Grid—Grid Integration Studies^{xxxiv}](#)
- *Resource:* [Best Practices in Electric Utility Integrated Resource Planning.^{xxxv}](#)

5. Perform energy audits of buildings to create baselines and implement energy conservation measures:

- *Leading Organization:* MEIDECC, with consultation of the attorney general’s office (which approves and enforces the building code)
- *Modeled Impact:* 700 metric tonnes CO₂e, with several secondary effects (identifying other EE opportunities, encouraging net metering).
- According to one study, up to 3.5% of total consumption on Tongatapu originates from a Church of Later-Day Saints temple, most likely a result of superfluous air conditioning.⁶⁸ Strengthening energy-efficient building standards and performing audits on the largest consumers—including government buildings—can play a large role in reducing overall demand.
- *Example:* [Caribbean Hotel Energy Efficiency Action Program^{xxxvi}](#)
- *Resource:* [A Guide to Energy Audits.^{xxxvii}](#)

6. Data collection exercise/database to manage energy data by sector:

- *Leading Organization:* MEIDECC (to potentially house the data), Ministry of Statistics, MCCTIL, TPL—working with regional organizations like PCREEE and the PRDR.
- Standardize annual reports and increase reporting of data to include figures such as sectoral consumption and load profiles by source of generation.
- *Example:* [Fiji Electric Authority, 2016 Annual Report^{xxxviii}](#)
- *Resource:* [Energy Analytics for Development.^{xxxix}](#)

5.3 Resilience Considerations

Tonga needs electricity and transportation systems that are resistant to damage from, and can recover quickly from, cyclones. Many of the projects proposed in previous sections can enhance resilience if steps are taken to ensure that projects or policies add to the systems’ resilience to cyclones and other natural hazards.

Tonga’s electric and transportation system can be made more resilient by following the basic steps listed below, which are tied to the policies and projects above.

1. **Incorporate resilience into building codes.** Many features that support EE in buildings also contribute to cyclone resilience. Examples of efficiency and resilience include planting trees and building verandas, which provide natural shading and also buffer wind gusts; ensure that such objects are close enough to provide shading, but far enough away to avoid presenting a risk of damaging buildings or other infrastructure in high winds; installing cool roofs with cyclone-resistant materials, ensuring hardened materials that also enhance insulation levels to reduce energy needs; and incorporating building designs (as shown in Figure 8) that shed wind loads.
2. **Continue to harden T&D lines and power generation.** TPL staff should continue to work with the government of Tonga to bury lines in cyclone-prone areas to reduce the number of aerial lines with the potential for wind damage. Prioritizing areas that are frequently disrupted may help with strategic planning. Installing

^{xxxiii}https://www.hawaiianelectric.com/Documents/about_us/our_vision/dkt_2014_0183_20161223_companies_PSI_P_update_report_1_of_4.pdf

^{xxxiv}<http://greeningthegrid.org/integration-in-depth/grid-integration-studies>

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microgrids with on-site RE technologies in key areas to reduce the need for centralized power, raising/elevating substations or equipment in flood-prone areas, and moving assets away from areas susceptible to storm surge or sea level rise can all be beneficial techniques to hardening the generation and distribution system for more reliable power.

3. **Diversify fuel choices.** More fuel sources increase the likelihood that portions of a transportation system will be able to function even if the main source of fuel (petroleum from Singapore) is inaccessible. The proposed projects that do this for Tonga are biodiesel and electric vehicles (with electricity coming from renewables rather than from petroleum). Renewable natural gas from farms, landfills, and sewage treatment facilities is another option that wasn't proposed in this plan due to budget considerations but could be favorable if Tonga places a high value on the resilience benefits this fuel offers.
4. **Improve vehicle efficiency.** In disaster scenarios, efficient vehicles can get more work done with a limited amount of fuel. A vehicle import policy requiring more efficient vehicles would then make Tonga's ground transportation system more resilient to disaster-caused fuel limitations.
5. **Reduce dependence on roads.** Cyclones can render roads unpassable by blowing debris onto them or washing water over them. Therefore, any project that reduces the distance needed to travel on roads in order to perform basic transportation functions will make the system more resilient. One such project is the proposed water taxi system in the Laguna. These water taxis do not rely on roads and could provide invaluable service when the roads are blocked. Another such project is the bridge over the north side of the laguna. As can be seen in Figure 19, such a bridge could enable traffic from the east side of Tongatapu to reach Nuku'Alofa even if the Taufa'ahau and Liku roads were blocked. Even if these roads were passable, the distance and fuel that this bridge could save would be even more important in times when fuel is limited due to a cyclone.
6. **Optimize the use of appropriate vehicles.** When roads are flooded and covered with debris, regular cars only further clutter the roads. Therefore, it is good to replace them with vehicles that have higher clearance and can carry more passengers. Buses have these characteristics, and two proposed projects can help make them more effective during cyclones. First, a software platform such as NextBus makes any given bus more effective at passenger transport by making it more trackable, especially in situations where the usual bus routes and timing need to be changed. Secondly, the strategic parking lot at the intersection of Taufa'ahau and Loto Roads could make evacuation procedures easier during/after a cyclone by keeping them from stalling and clogging the roads of Nuku'alofa.

5.4 Gender and Income Equality Considerations

Tonga's power system transformation provides a unique entry point for additional female participation in Tonga's workforce—particularly in science, technology, engineering, and math (aka STEM) fields. This transformation could also reduce the cost of electricity for all Tongan households, which will be especially impactful for lower income or single parent households with constrained budgets. Tonga, like much of the world, has a lower female than male workforce participation rate due to traditional role fulfillment of women as homemakers. In 2016, 26.8% of Tongan females described themselves as unemployed and willing to begin work (compared with 7.6% of males), but only 1.4% of females are unemployed and actively seeking work (compared with 0.7% of males). This gap of Tongan women who are willing and available to begin work, but are not actively seeking labor persists despite the fact that Tongan women are more likely to hold tertiary education (11.8% vs 9.8% of males).⁶⁹ It is likely that a number of educated women choose to work in the traditional role of housemaker despite a desire and ability to work outside the home. Creating domestic energy jobs opens the door for these women to pursue a career, and could benefit Tonga's overall economy by improving labor force participation rates. The suite of policy proposals in the TEEMP provide opportunity for Tonga to provide domestic investment in RE, transportation sector transformation, and EE. Technicians, installers, auditors, and analysts are all new positions that will be created and could be fulfilled by Tongans of all genders. The TEEMP needs to be implemented with these statistics in mind—efforts should be made to encourage gender parity in hiring for these new positions. Additionally, reducing local pollution created by diesel generators and vehicles creates better health outcomes, particularly for vulnerable populations such as the elderly, pregnant women, and children.

At the consumer level, spending on fuel accounts for 6% of Tongan household expenditures, and spending on electricity accounts for 3%.⁷⁰ For rural households, households with a high number of occupants, or households with limited income (or only a single provider of income), the cost of energy likely makes up a significantly higher proportion of household expenditure. The Gini coefficient is a good measurement of economic inequality within a

country's economy. Tonga has a moderate Gini coefficient of 0.417 nationally (measured as a decimal value between 0 and 1), but it is more pronounced in urban areas of Tongatapu (0.444).⁷¹ Access to clean and resilient energy sources such as those provided by solar or wind resources is increasingly seen as a guaranteed human right by international organizations, and Tonga has reaffirmed its commitment to this tenet through its ardent participation in the UN's Millennium Development Goals. Failures in the electrical grid due to storms, drastic variations in fuel or electricity prices, or fuel shortages all threaten universal access to these resources. Tonga's exposure to energy shortages requires particular attention be paid to the nexus of income level, gender balance, and energy security. Across Tonga, 44% of households own a generator—presumably most households reserve its usage for backup power. Although these households have access to independent electricity production in the event of grid outages, it is the responsibility of Tongan officials and TPL to ensure that resilient electricity is delivered to the 56% of Tongans who might not be able to afford the purchase of a backup generator.⁷² By fostering an environment of energy independence and resiliency, Tonga is ensuring equitable energy security for all of its residents.

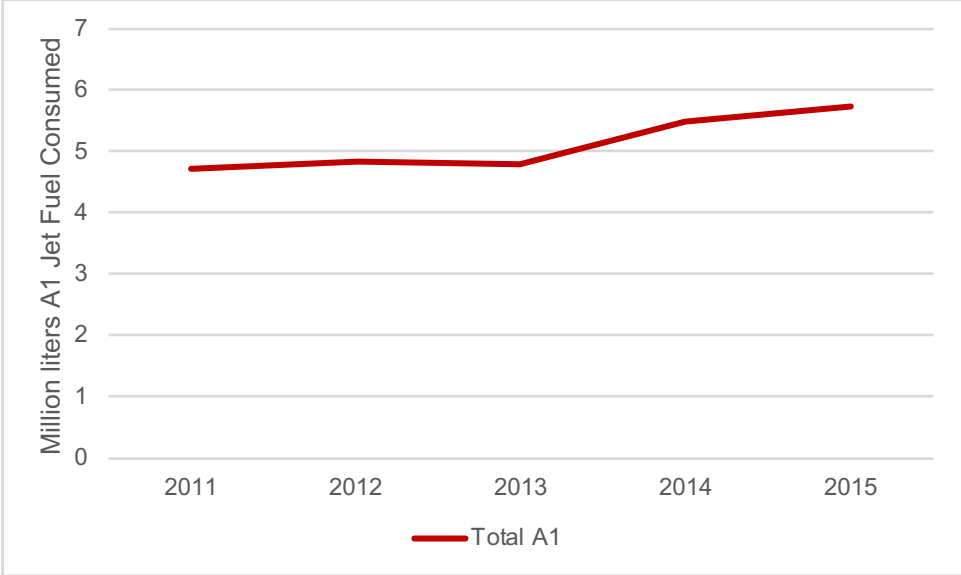
6 Conclusion

Through the outlined suite of policy options, a reduction of 106,000 metric tonnes of CO_{2e} a year by 2030 is possible. That represents a 50.5% reduction from the BAU emissions of 210,000 metric tonnes of CO_{2e}. Action taken in the ground transportation field is responsible for 30.4% of the projected emissions reductions (33,400 metric tonnes CO_{2e}), renewable electricity is responsible for 40% (43,500 metric tonnes CO_{2e}), and EE in the electric sector is responsible for 29.6% of the reduction (32,500 metric tonnes CO_{2e}).

These reductions will have three primary effects: lowering emissions, improving climate resilience, and improving energy independence. Although Tonga's NDC does not lay out specific emissions reduction goals, ambitious national goals target a high renewable penetration. By engaging in EE measures, total capacity requirements are reduced, and the cost associated with new generation declines. The best way to reduce emissions is to reduce load, and so it makes sense to harmonize Tonga's ambitious renewable goals with equally ambitious EE goals. Secondly, recent history has shown that tropical cyclones and other natural disasters can have devastating effects upon small island developing states. Tonga has intimate experience with this and has voiced strong support for policies to curb climate change at the international level. Despite these valiant efforts, damage to the earth's climate presents immediate risks to Tonga's infrastructure and power grid. Many of the EE projects outlined by the TEEMP work to improve Tonga's climate resilience by reducing unnecessary grid and road load, distributing power generation, diversifying the fuel mix, and strengthening vulnerable infrastructure while identifying opportunities for EE improvements. As such, mainstreaming climate resilience is deeply integrated in the TEEMP. Finally, by increasing renewables penetration and decreasing fuel consumption from the BAU scenario, Tonga's dependence on imported fuel—as measured by energy intensity—stabilizes. Volatile fuel prices need not affect Tonga's cost of electricity, transportation, or cost of living; this results in better public welfare outcomes.

The next steps to achieve these outcomes should be coordinated through a working group headed by MEIDECC, and members should include MOI, TPL, MCCTIL, PCREE, the Department of Statistics, and other Tongan organizations. A memorandum of understanding for data sharing and other coordination would need to be signed early in the process. The working group should also strengthen ties with international organizations and financing partners that have demonstrated a strong interest in Pacific island data and regional organizations such as the UN ESCAP, PRDR, the Green Climate Fund, Asian Development Bank, and the CTCN. The working group and international partners could then ensure that necessary data are centrally reported and stored. It could then implement EE and transportation efficiency improvements like those outlined in this report alongside infrastructure and RE developments. Such cooperation and progress is key to ensuring that Tonga's power and transportation system transformation is manageable and capable of meeting the emission reduction and energy independence goals laid out in the TERM in an expedient, organized, and cost-efficient manner.

Appendix A. Supporting Documentation



Source: MCCTIL Fuel Volume 2012-2015 Report
Figure A-1. Yearly A1 jet fuel consumed in Tonga

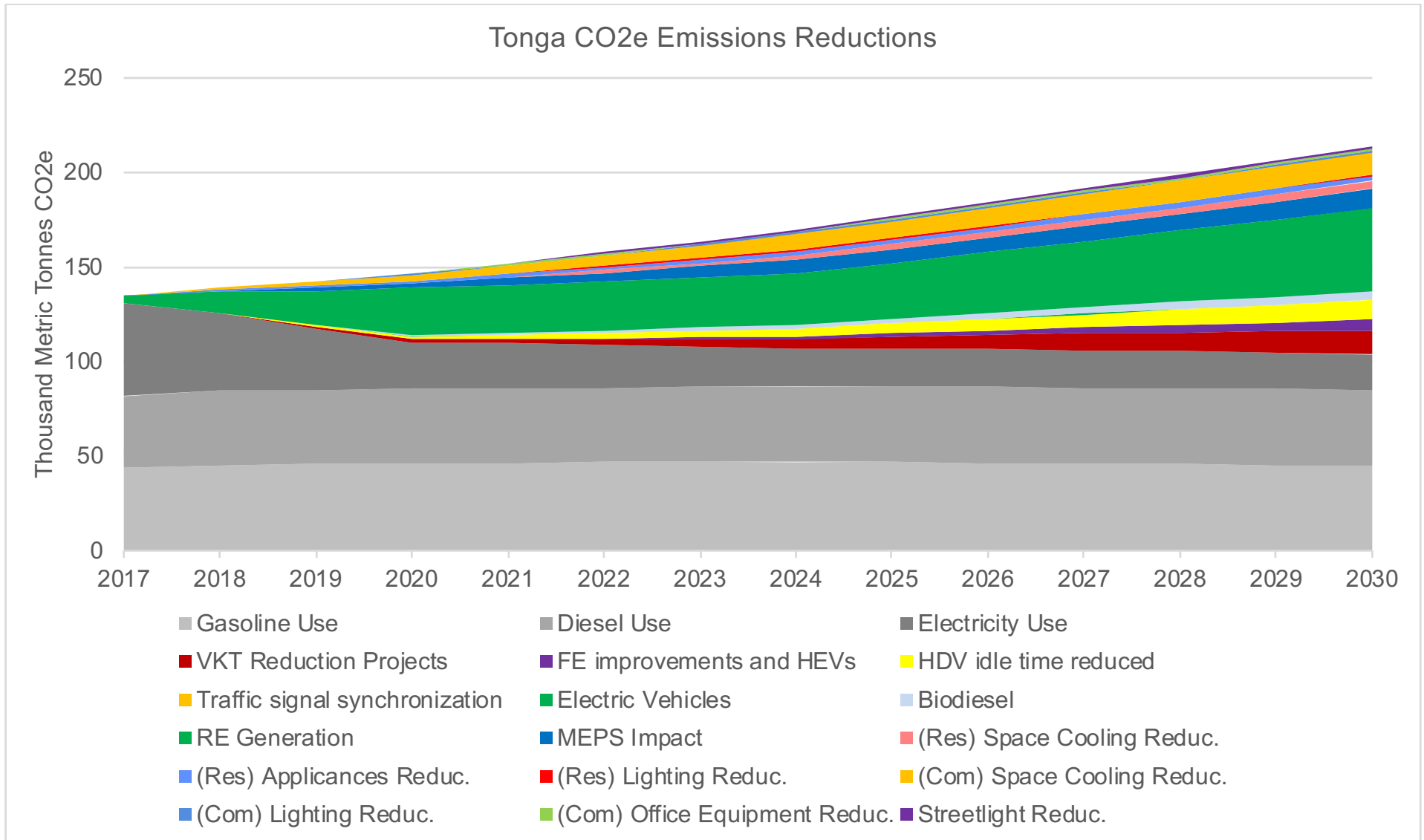


Figure A-2: Tonga CO₂e emissions reductions with sectoral breakdown

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