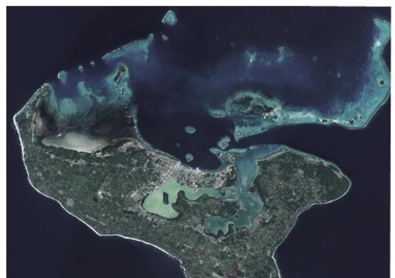
The United Nation's Climate Technology Centre and Network

Government of Tonga Energy Efficiency Master Plan



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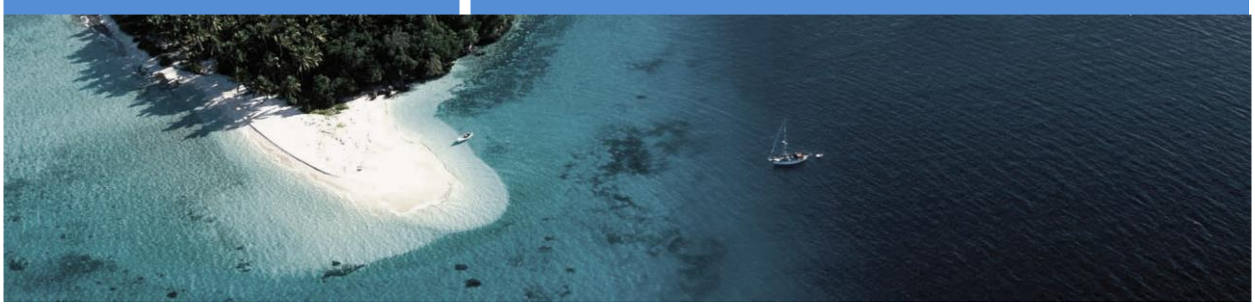

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EXECUTIVE SUMMARY

At the request of the Tonga government, the Climate Technology Centre and Network has worked closely with the 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 lowering Tonga's fossil fuel dependence through increased energy efficiency and improved supply chains to reduce price fluctuation of imported products for the purpose of reducing greenhouse gas (GHG) emissions and improving national energy security.

A baseline assessment of Tonga's GHG emissions was built off of Tonga's Intended Nationally Determined Contribution (INDC), 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 greenhouse gases: 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 towards electricity generation for building electrical use (primarly space cooling, lighting, and appliances in the residential and commercial sectors). The remainder of transportation fuel is petrol.

As of 2017, the total installed 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 PV, 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 generation, and increased electrical load primarily driven by increased ownership of electrical appliances. Tonga Power Limited (TPL), the vertically integrated utility, owns and operates the majority of Tonga's in-front-of-meter electricity generation, as well as its transmission and distribution (T&D) assets. Electricity rates have important implications for incentivizing or disincentiving energy efficiency investments. Despite differences in generation cost, the TPL tariff rates are standardized across the four main islands, and as of February 2018, the tariff was set at 0.8514 Tongan Pa'anga (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 dollar (USD) of GDP 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 as compared with 2010 levels. An estimated baseline for transportation is over 16,000 vehicles in Tonga for residential, commercial, and government use in 2016. The majority of vehicles were either cars (6,031) or light trucks/vans/SUVs (7,103). Heavy duty vehicles, taxis and rentals, motorcyles, and buses accounted for the remaining 3,690 vehicles. Current average vehicle kilometers travelled per person was estimated to be 2,289 in 2016 and is projected to grow to 5,103 by 2050, tracking with anticipated GDP increases.

Key policy options identified for transportation include vehicle import tariffs or registration fees aimed to improve fuel economy; restrictions in heavy-duty vehicle (HDV) idle time; 10% biodiesel blend; deployment of electric vehicles; and policies that reduce vehicle kilometers travelled by facilitating pedestrians, bikers, carpoolers, and bus riders.. These reductions in energy use in the transportation sector would result in an estimated 28% reduction in greenhouse gases below business-as-usual 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 behavior around energy consumption. Given Tonga's tropical climate, cooling in buildings in commercial, government, and nongovernmental buildings via use of air conditioning is widespread and increasing. There may be opportunities to reinstitute design practices from historical building, such as passive ventilation and large overhangs to provide shading. Leading energy use reduction options in the buildings sector center around increased deployment of renewable energy, reductions for implementation of minimum energy performance standards (MEPs), improvements to space cooling, increased efficiency in appliances, and reductions in energy used for lighting (in buildings and street lighting 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. This is based on 2020 as the reference year. 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.

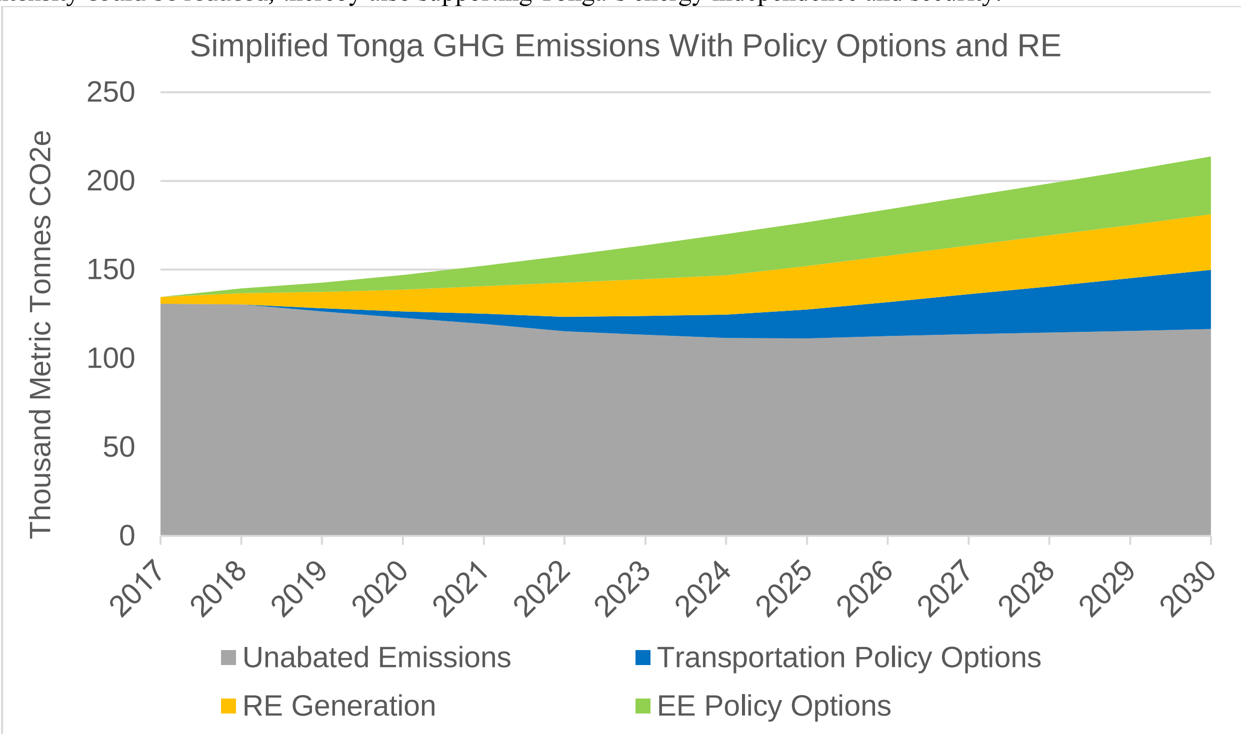

Figure E1. Wedge Analysis of Tonga's GHG Emissions

Tables E1 and E2 provide further assessments of the top ten policy options for transport and electricity in buildings and street lighting that could support GHG reductions identified in the wedge analysis (additional policy options and measures are identified in this report). The options are ranked by magnitude of GHG reductions, upfront 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 GHG Emissions from Transportation

Wedge	Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Availible
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 laguna** (and some associated dredging)	High	Med	Med	High	Med
VKT Reduction	Build a **strategic parking lot and bus stop** at intersection of Taufa'ahau Rd. and Loto Rd. and accompaly with Nuku'alofa parking policy	High	High	Med	High	High

Table E2. Top 11 Policies and Projects to Reduce GHG 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 T&D lines and power generation by burying strategic lines, and installing minigrids and onsite renewable energy, among other measures.
3. Diversifying the fuel mix from diesel to renewable natural gas and exploring procuring fuel from sources other than Singapore.
4. Improving vehicle efficiency, which enables more transport options in the event 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 effectively utilizing the bus system to support evacuations.

TABLE OF CONTENTS

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Acronyms

BAU	Business as usual
CO_2e	Carbon dioxide equivalent
COP	Conference of Parties
EE	Energy Efficiency
GDP	Gross domestic product
GHG	Greenhouse gas
GOT	Government of Tonga
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
HDV	Heavy-duty vehicle
INDC	Intended nationally determined contribution
IRP	Integrated Resource Planning
kg	kilogram
kWh	kilowatt hours
LED	light emitting diodes
LDV	light-duty vehicle
MTED	Ministry of Trade and Economic Development- MTED
MWh	megawatt hours
PRDR	Pacific Regional Data Repository
PV	Photovoltaic
TEEMP	Tonga Energy Efficiency Master Plan
T&D	Transmission and Distribution
TERM	Tonga Energy Road Map
TPL	Tonga Power Limited
VKT	Vehicle kilometers traveled
W	Watts

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Foreword

It is my pleasure to present herewith Tonga's Energy Efficiency Master Plan (TEEMP): 2020 – 2030. This document builds on Tonga's ratification of the Paris Agreement in 2016 and contains priority ambitious and urgent actions that would contribute to pursuing targets in Tonga's Nationally Determined Contribution.

The TEEMP represents the Tonga Government's commitment to join the global community in addressing the challenges of climate change and improving national energy security. It is a whole of government's approach to maximizing benefits from the low hanging fruits in energy efficiency.

The TEEMP is in line with the landmark Tonga Energy Road Map, the *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*. It is also in line with the Tonga Nationally Determined Contribution and its Low Emission Development Strategy.

The TEEMP therefore highlights the direct correlation between renewable energy and energy efficiency. When there are more renewable energy capacity, diesel engines are put idle and issues with the energy efficiency of the diesel engines are avoided.

The production of the TEEMP was through an open and consultative process that sought to incorporate ideas and inputs from a wide spectrum of stakeholders. It is in that similar collaborative spirit that the implementation and review of the progress with the TEEMP shall be conducted.

It is a coincidence that we are launching the TEEMP in year in which the globe has been challenged by a pandemic whose coverage and impacts were never before confronted by humanity. It is a stark reminder of the significance of the energy sector for our very existence. As people were continuously reminded to wash their hands, we are reminded of the access to affordable and clean energy that is needed to pump water and make it accessible to people. Furthermore, this is a time where we are reminded that energy supply must be very reliable to keep lifesaving equipments working without interruption.

I commend this Master Plan and the information it contained to your attention and wish that the impacts it will make would be for the benefit of all.

'Ofa atu,

Hon. Dr. Pohiva Tu'ionetoa
Prime Minister of Tonga
July, 2020

1 Context

Tonga is dependent on imported petroleum to meet its energy needs for electricity and transportation. Electricity generation consumes upwards of 13 million liters of fuel per year annually, at a cost equivalent to around 10% of total 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 in order to set an energy and emissions baseline and establish 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 was then taken as a starting point to assess options, magnitude, and feasibility of reducing Tongan 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. 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 modelling.

1.1 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 to develop 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, improving supply chains to reduce price fluctuation of imported products, reducing greenhouse gas (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 2012. The TERM includes improvements in petroleum supply chain to reduce the price and price fluctuation of imported petroleum products; efficiency of conversion of petroleum to electricity (i.e., increases in efficiency and reduced losses at TPL); efficiency of conversion of electricity into consumer electricity services (Demand Side Management measures); and replacing a portion of current or future grid-based generation with renewable energy.[3] Transportation is not a focus of the TERM.

Policies and initiatives that have been implemented since the creation of the TERM are as follows:

- 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 to develop renewable standards, conduct research, relay international obligations to the monarch, and enforce violations of renewable energy 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) which contain HCFCs 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 kWh/year.

- Public Service Building light replacements saving 158,706 kWh/year.
- Street light upgrades saving 97,219 kWh/year.

- Tonga's Intended Nationally Determined Contribution (INDC)
    - Formalizes 50% renewable electricity goal by 2020, 70% by 2030.
    - Reduce line losses to 9% by 2020.
- 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 INDC released the same year.
    - Achieve no more than 12% T&D losses by 2020.
    - Short-term goal to convert 75% diesel-based water pumping systems in Tongatapu to solar photovoltaic (PV).
    - Goal of 80% of retail stores to sell reliable compact fluorescent lightbulbs at "same cost".
    - Banning import of inefficient electrical appliances.
    - All inefficient electrical appliance banned 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 was 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 PPA 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 Figure 1[13], and is comprised of 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 distribution and transmission 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 this dependence has on Tonga and the adoption of a renewable energy target of 50% by 2020 to address the challenges created by relying on imported goods and fuels.

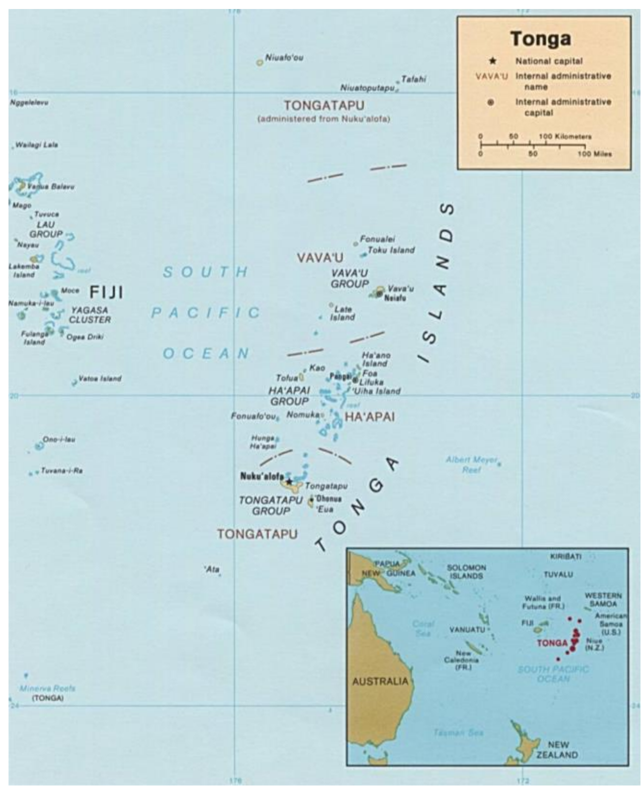


Figure 1 Map of Tonga
Source: University of Texas

Tonga is a consitutional monarchy with a government that is made up of an Executive, Legislature and the Judiciary. The current monarch is a champion for sustainable energy in Tonga, with most of the significant renewable energy installations in the Kingdom being commissioned during his reign. Both the King and Cabinet are supportive of reducing Tonga's climate impact and improving the nation's energy independence. In a move symbolic of "wider leadership," Tonga joined the Solar Head of State program at the Conference of Parties (COP) 23 in November 2017. The program will install a rooftop photovoltaic (PV) system on the residence of the King, the first Royal Palace in the world to do so.[17]

The Department of Energy under MEIDECC is responsible for coordinating and managing the Kingdom's energy sector. Other key players in the sector includes the Tonga Power Ltd, a public enterprise that is responsible for generating, transmission and distribuiton of electricity, the Tonga Electricity Commission which is the regulator in the electricity sector, the Ministry of Trade and Economic Development which is responsible for the pricing of petroleum products and the Association of Members and Registered Electricial Contractors (AMREC). MEIDECC is currently working on an Energy Act to more effectively coordinate and manage the energy sector. Data availability has important implications for MEIDECC's role - analyzing and tracking changes and opportunities in the energy sector, and thus, for the design of Tonga's Energy Efficiency Master Plan (TEEMP). Specific recommendations broached later on include engaging TPL in an Integrated Resource Planning (IRP) process, collecting sectoral data, surveying energy usage habits in future censuses, and standardize data collection of customs and annual ministerial reporting. Regional initiatives such as the Pacific Regional Data Repository (PRDR) already exist to aggregate applicable datasets, working with such initiative would open opportunities for regional knowledge sharing and project financing.

2 Baseline

As reported in Tonga's INDC 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 could be made 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 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%). It does not necessarily mean that the 21% from agriculture is not important to the TEEMP, it was simply a constraint on the data availability and the timeframe for the production of the TEEMP. Hopefully future updates of the TEEMP will include agriculture, waste and the others.

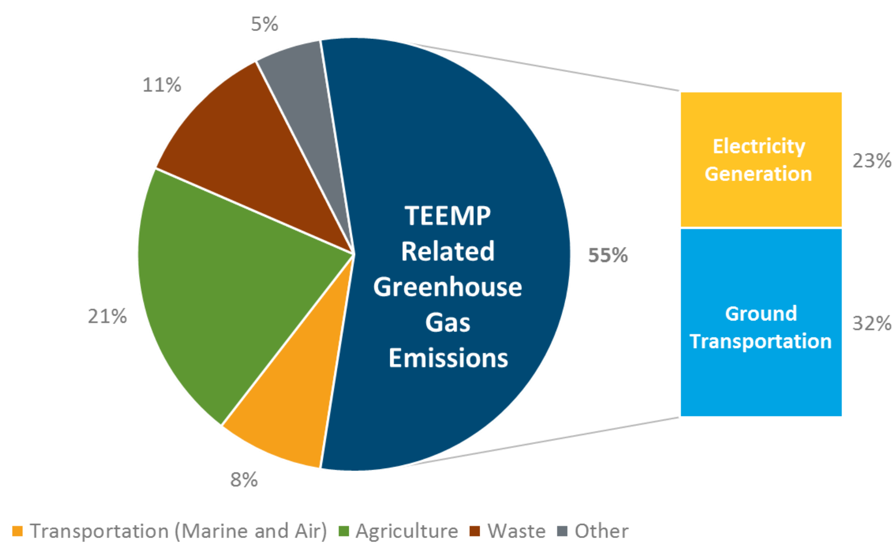


Figure 2. Tonga's INDC Reported Emissions and TEEMP Related GHG Emissions (Data Source: Tonga INDC and Ministry of Labour and Commerce [MTED])

Tonga's INDC states that transportation is responsible for 40% of emissions, and electricity generation is responsible for 23% of Tonga's overall emissions; however, the INDC uses GHG data from a 2006 inventory. Since the time that the INDC 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 INDC. 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 INDC. The transportation segment of the INDC 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 INDC.

Using the available data from MTED, 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 Figure 3. These energy flows are influenced by the climate and infrastructure of the islands.

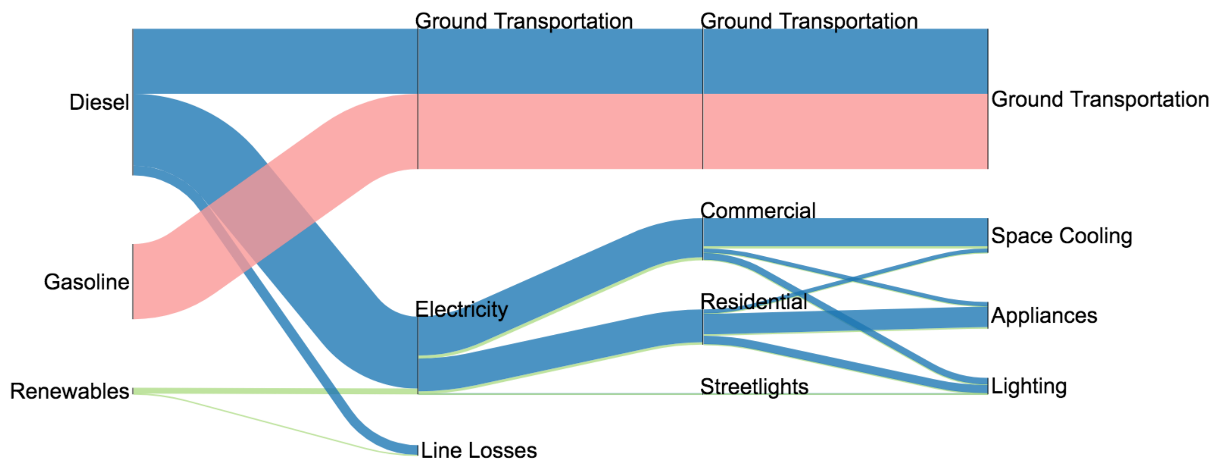


Figure 3 Tonga's Current Energy Flows by Fuel Type in the Electricity and Ground Transportation Sectors (Data Source: MTED)

2.1 Electricity Baseline

Census figures indicate the 2016 population in Tonga was 100,651.[18] 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.[19] 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.[20] In total, the residential sector accounted for 44% of electricity consumption in 2017. TPL does not further breakdown sectors, but the remaining 55% of consumption is spread across commercial, religious, government, and public service accounts. There are two peak demands during weekdays: a peak in the mornings 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 when 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 are 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 renewable energy 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 Model (GREET) Emissions Database[21] was used to estimate emissions of diesel fuel at 3.29 kilogram (kg) CO_2e / liter.[22] This number is a lifecycle emissions calculation for the United States (US) so it includes emissions associated with extraction and transportation of fuels within and to the US; emissions associated with transportation of fuel to Tonga are most likely higher. The TEEMP model also accounts for reductions in line losses; Tonga's INDC sets the target of 9% by 2020 (currently around 11%). In the model, line losses are applied evenly to all generation (diesel and renewables). In reality, renewable installations are likely to be located closer to the load and therefore will have lower line losses than diesel.

In 2009 Tonga's energy intensity was reported as shown in Figure 4.[23] Through data collected for the TEEMP, Figure 5 shows the 2018 energy intensity, indicating efficiency improvements. This analysis identified an energy intensity of 216.8 GJ of imported fuel per dollar (USD) of GDP per capita, rising under the business as usual (BAU) scenario to 259.8 GJ by 2030.

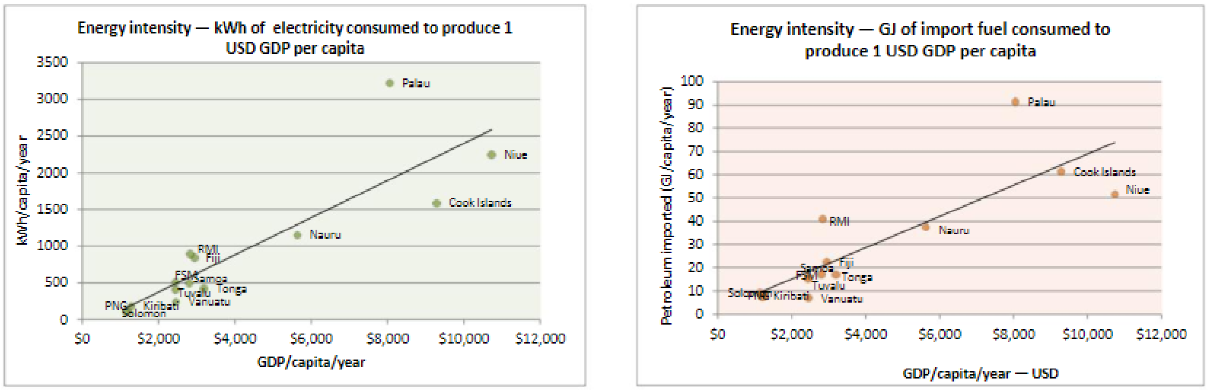


Figure 4 Tonga's Energy Intensity, 2009

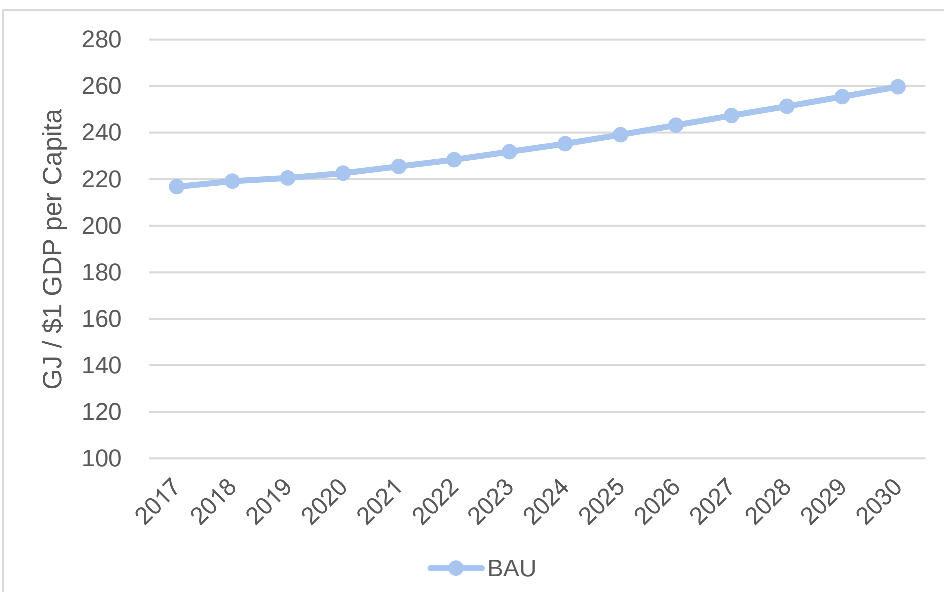


Figure 5 Tonga's Energy Intensity, 2017-2030 (BAU)

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 is available. Conservation and management of energy is important for meeting specific targets and goals. Demand side management, energy conservation, energy efficiency, 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, either higher efficiency generators, or a diversified generation portfolio to include lower emission fuels, such as natural gas, or renewable energy, 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 influence consumer choices and behavior and thereby improve energy efficiency, increase energy conservation, and reduce peak electricity demand. Rebates, incentives, and utility investments that improve building systems (such as the envelope, the efficiency of heating and cooling systems, or lighting systems) and rate structures that shift demand from times of peak energy use to off-peak hours can be deployed for demand side management activities.

Energy conservation is the process of using less energy. Energy conservation typically require a change in behavior (e.g., turning off lights when not in use, walking stairs rather than using an elevator, 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 material) is another standardized practice for conserving energy across building portfolios. Energy efficiency is the process of producing more with the same or less units of energy through technological improvements. An example is switching out incandescent light bulbs with more efficient compact fluorescent lighting or light emitting diodes (LED), which provide the same amount of light, but produce less heat, creating a more efficient light bulb. 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 the majority of the installed capacity, predominantly supplied by diesel fuel. As of June 2017, the total installed capacity on Tongatapu is 17.8MW, 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 load primarily driven byownership 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 (Source: MTED)

Location	Grid Status	Conventional Capacity	RE Capacity	Battery Capacity (MW)
Tongatapu	TPL Grid (11kV)	14.00 MW	2.8 MW	1 MW
Vava'u	TPL Grid (Medium Voltage)	1.87 MW	0.42 MW	0.2 MW
Ha'apai	TPL Grid (Medium Voltage)	0.37 MW	0.5 MW	0.66 MW
Eua	TPL Grid (Medium Voltage)	0.37 MW	0.20 MW	
Nomuka (Ha'apai)	Non TPL (6.6kV)	0.09 MW		
Ha'afeva (Ha'apai)	Non TPL (6.6kV)	0.06 MW		
Ha'ano (Ha'apai)	Non TPL (6.6kV)	0.06 MW		
'Uiha (Ha'apai)	Non TPL (6.6kV)	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).

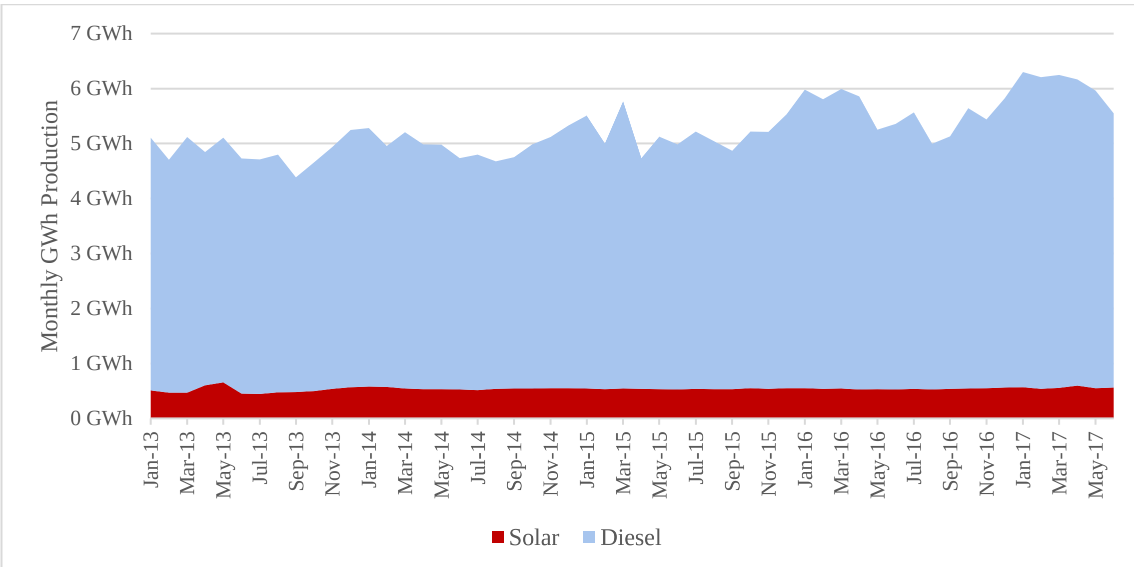


Figure 6 Energy Generation Mix for Tonga (Monthly GWh)

Source: TPL Monthly Generation Data (June 2017)

Voltages vary between the four grid systems; T&D losses vary, as well. Voltages on Tongatapu are 11kV for primary distribution; three phases: 415V; single phase: 240V, however on Vava'u, Ha'apai, and 'Eua the voltages are 6.6kV for primary distribution; three phases: 415V; single phase: 240V. 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.

Table 2. Transmission and Distribution Losses

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

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 (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. While this rate structure may provide some economic benefit, especially to low-income households, it may also hinder motivations for installing energy efficiency or renewable energy technologies and practicing energy conservation.

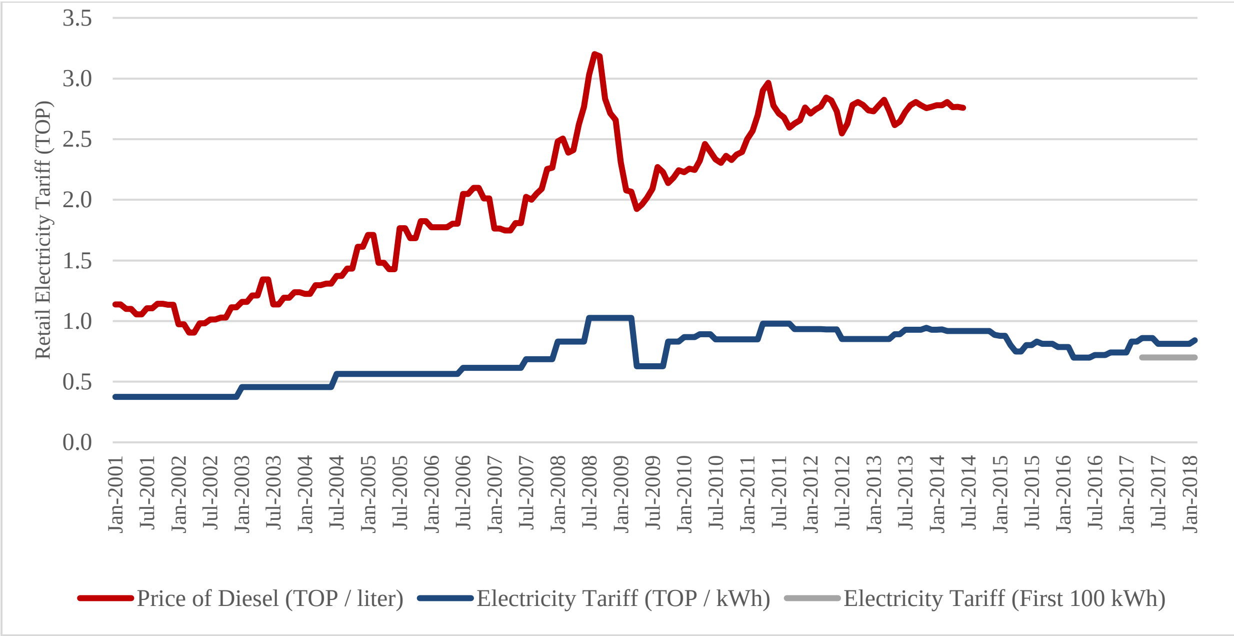


Figure 7 Electricity Tariff and Associated Fuel Costs

Source: TPL Demand and Prices, PICTS Electricity Tariff Database

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 determines 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 two-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 customer from power generated .[24]

2.1.2 Consumption

Tonga's overall electricity consumption is dictated by building design, building energy using systems (such as appliances), and behavior around electricity consumption. In tropical areas such as Tonga, cooling loads in buildings has become critical where the buildings are sealed and not open, especially in offices, supermarkets, banks, etc. The use of mechanical air conditioning systems is widespread and increasing. Thermal comfort and indoor air quality (e.g., managing humidity and indoor pollutants) are being achieved by air conditioning more frequently rather than relying on vernacular architecture. The older, historic buildings in Nuku'alofa were designed to utilize 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 electricity consumption: building design, residential end-uses, commercial end-uses, and street lighting.

2.1.2.1 Building Design

Typically, electricity 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 for 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 reduces the need for lighting. The largest energy end-use in churches is lighting, amplification systems (e.g., microphones), and electric fans in buildings which are designed to use natural ventilation and are open-air. 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 13.5% of the total billed consumption on Tongatapu.[25] This level of consumption indicates an architectural design with closed windows and doors, and a dominance of air conditioning loads. 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 facsimiles, 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.

Building codes were implemented in Tonga in 2007. The Building Control Division (BCD) of the Ministry of Infrastructure 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. BCD 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 code and regulations. The goal of the BCD is to "achieve more reliable, safe and affordable buildings and ensure structures are more inclusive, sustainable, affordable, safe and reliable."[26] One way in which the goals can be met is through updating building codes to specifically include energy efficiency and resilient buildings rather than vaguely referring to it under "safe and affordable."

Energy efficient and resilient building technologies are deployed as a result of public policy. This is even the case when the cost of energy efficiency measures may not be significantly more expensive 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.[27] 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 severity of storm surges). Climate change considerations are usually incorporated into building codes along with energy efficiency requirements, and these will also help with sustainable development and lower poverty levels associated with energy bills and recovering from severe climate-related events.

Some measures for Tonga to consider are to create setback zone guidelines or a policy to protect buildings from sea level rise and increasing storm surges, as demonstrated by tropical cyclone Harold on 9 April 2020 . Elevated structures may be needed in certain areas to protect from the same threats. Also requiring the installation of attached features, such as roofing materials or solar 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, building height of no more than two stories tall)
- Passive survivability techniques to reduce energy consumption and allow the building to be occupied without power (e.g., natural daylighting, natural ventilation, rainwater collection)
- Energy and water storage on site to allow for continued operation without utility services (e.g., solar PV with islanding controls and battery storage, cistern collectors with graywater systems)

Rolling out codes in a way to target critical infrastructure, such as schools, hospitals/medical clinics, evacuation centers, fire stations, and police stations first will help communities be more resilient during natural disasters. Focusing on residential and commercial buildings after critical infrastructure will help to 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.[28]

Figure 8 Example of Resilience Measures for Passive Design and Cyclone Resistance (Source: Ecobuilding Pulse)

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 with Tongatapu having 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 utilize energy for space cooling such as air conditioning and fans; lighting; domestic appliances like televisions, clothes washing machines (labeled as Elec Washer), electric water heaters; and kitchen appliances such as fridges, freezers, and cooking appliances. Census data indicates that the majority of Tongans cook with fuels rather than on electric burners, and also utilize a number own ancillary cooking devices (such as microwaves, electric kettles, or food processers) which are captured by the Cooking category. Additionally, the majority of Tongans own energy efficient twin-tub, or non-electric clothes washing machines, however census data indicates that as GDP per capita increases a higher percentage of Tongans are purchasing 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 of appliances were calculated to estimate the total monthly consumption of households based on the number of households that own a given appliance.
3. This data was then normalized to TPL's actual (and for future years, projected) total 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 is displayed in Figure 9.

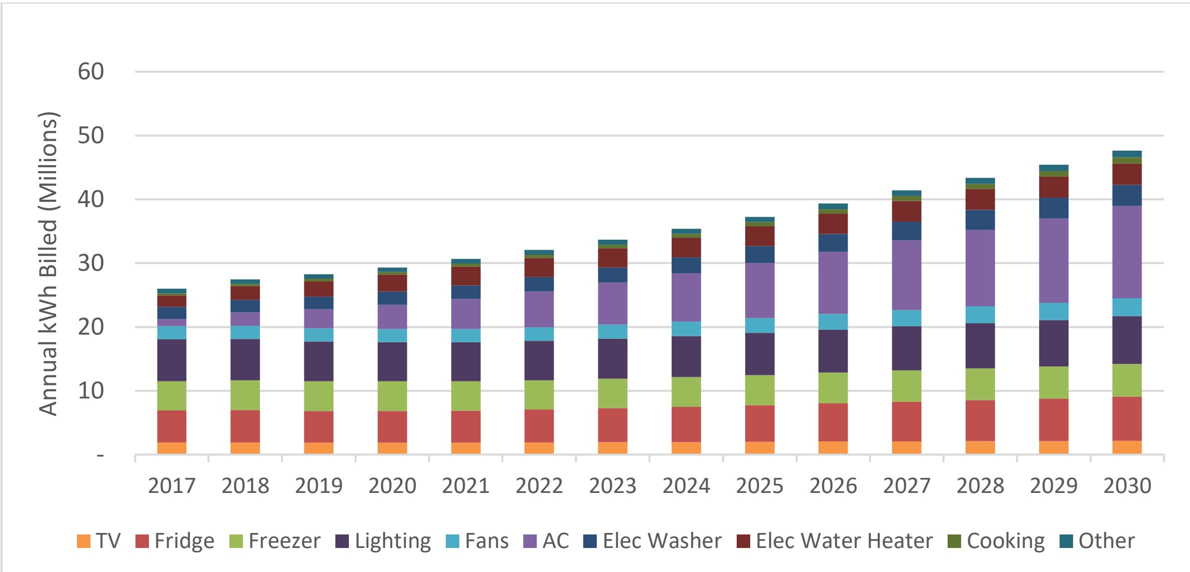


Figure 9 Residential Electricity Business-as-Usual by End-use

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 from each of these countries and the points of origin (e.g., places of manufacturing of the goods) may not be the same as the country from which the good was imported. This creates a challenge when determining the energy performance of appliances that are imported through Customs. Australia and New Zealand may have more stringent MEPS.

However, less expensive products with less stringent energy standards may be available from Asia or via Fiji. In a 2017 Pacific Community (SPC) survey of Tongans, 58% had seen an Australian or New Zealand Energy Rating Label before, 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 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 a MEPS is used as a baseline in modeling of the effectiveness of new MEPS.[29] Although Tonga is currently in the process of implementing MEPS as coordinated by the Pacific Community under it's Pacific Appliance Labelling and Standards (PALS) programme,[30] exact performance

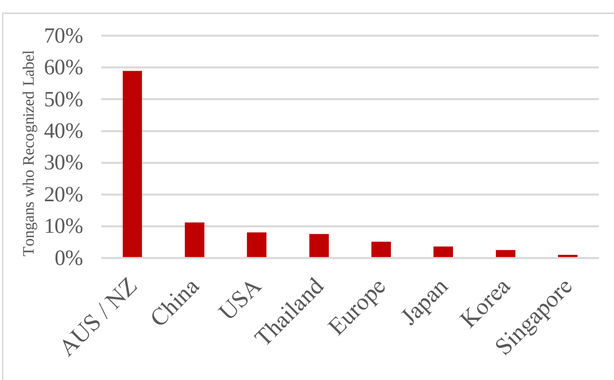
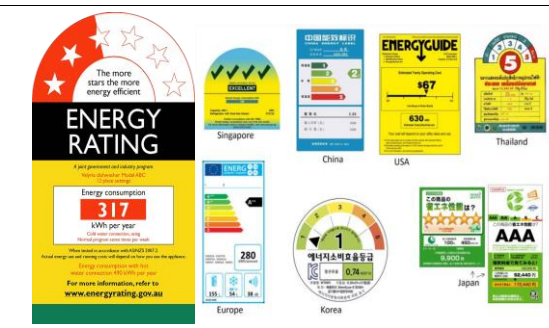


Figure 10 Origin of Energy Performance Labels by Level of Recognition among Tongans (Source: Tebbutt Research)

Figure 11 Various Energy Efficiency Labels Available in Tonga



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

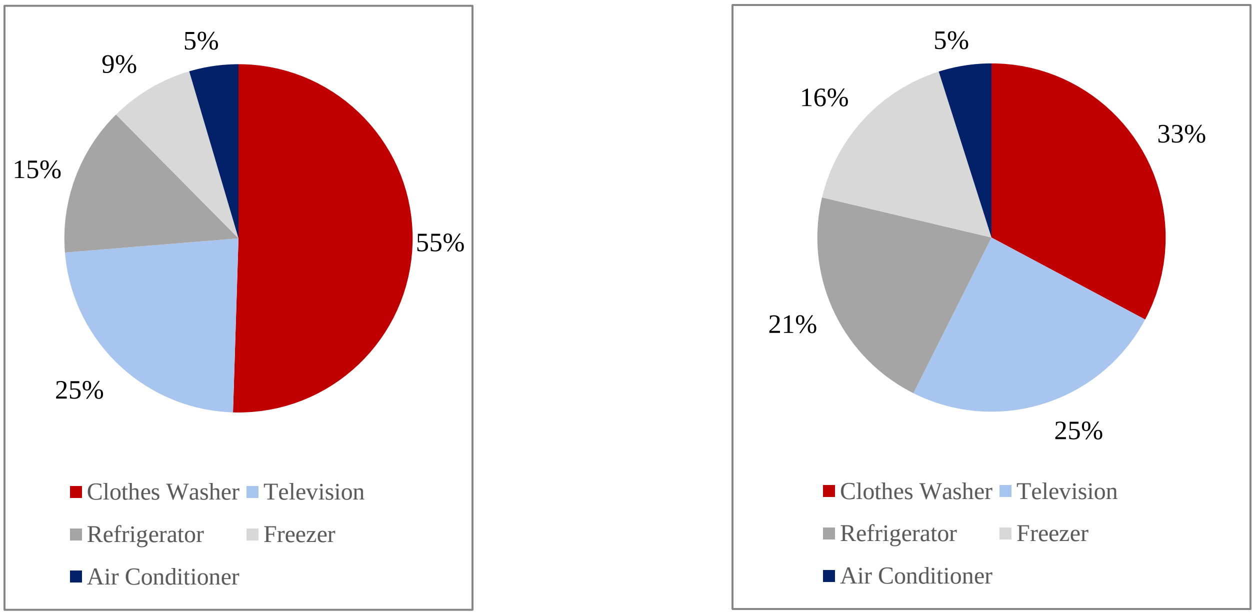


Figure 12 Tongans Reported Last Major Appliance Purchase (left) and Next Anticipated Appliance Purchase (right)

requirements are unavailable. As such, modelling for the TEEMP uses standard consumption limits applied in Australia and New Zealand. In some areas, 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.[31] 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 business as usual (BAU) activities in Tonga and implementing minimum performance standards for lights and appliances. Scenarios were used to compare the energy savings in GWh consumed through 2030. In Australian Aid's study, implementing MEPS early on will achieve a 10GWh savings by 2030. The TEEMP analysis anticipates upwards of 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 applicability to fewer appliances.[32]

This analysis, coupled with information on the next major appliances expected to be purchased from the SPC survey, can lead to further anticipation of MEPS savings. Clothes washers, televisions, refrigerators and freezers make up most appliances purchased by Tongans and the next anticipated appliance purchases. Focusing on MEPs for those areas, 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.

Growth in appliance uptake is largely tied to household GDP per capita. A previous study looking at specifically at Asian-Pacific countries identified an approximate 3% growth in the ownership of air conditioners for every $1,000USD increase in household GDP.[33] In the modelling 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 of Tonga in 2030.

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	2025
Fan	New Zealand / Australia	6137
	Singapore	510
	China / Hong Kong / Taiwan	8455
	Other	10941
Freezer	New Zealand / Australia	3423
	Singapore	825
	China / Hong Kong / Taiwan	4641
	Other	3172
Fridge	New Zealand / Australia	3281
	Singapore	853
	China / Hong Kong / Taiwan	433
	Other	1594
Stove or Oven	New Zealand / Australia	209
	Singapore	116
	China / Hong Kong / Taiwan	673
	Other	990
Solar Components	New Zealand / Australia	1555
	Singapore	57
	China / HK / Taiwan	5132
	Other	8447
Water Heater	New Zealand / Australia	325
	Singapore	16
	China / HK / Taiwan	206
	Other	256

Source: Tebbutt Research

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 labelling across all appliances, and even potentially lightbulbs, could have upwards of an 11% reduction of energy consumption in Tonga according to one study.[34] However, the effectiveness of MEPS and labelling is highly dependent upon spreading public awareness of how to read energy efficiency labels and understanding the importance of conserving electricity.

Data was 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 percent such as fridges, freezers, fans, and televisions will see modest growth between 2018 and 2030. More electric intensive domestic appliances such as air conditioners, electric clothes washers, and electric water heaters were projected to see larger growth over the same period. Although these appliances do not currently represent a significant portion of residential load, foresight in implementing MEPS on these appliances ensures that non-efficient appliances are not imported for use over a 15-20-year appliance life cycle.

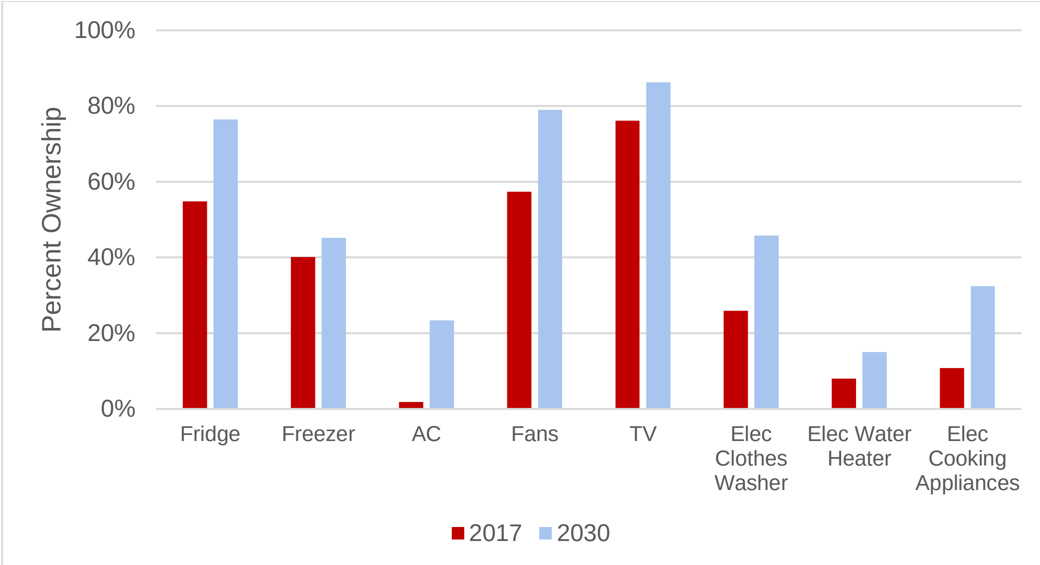


Figure 13 Residential Appliance Ownership by Year

2.1.2.3 Commercial End-Use

While Tongan data was available to estimate the percentage of load by end-use for residential accounts, similar data was unavailable for commercial accounts. To fill this gap, an energy model was run for a similar climate zone to understand energy end-use 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 understanding what the current energy consumption is, where the highest consumers are (e.g., HVAC, lights, fans, pumping, etc.), and to calculate potential energy savings associated with identified energy efficiency opportunities. Using the eQUEST[35] 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.

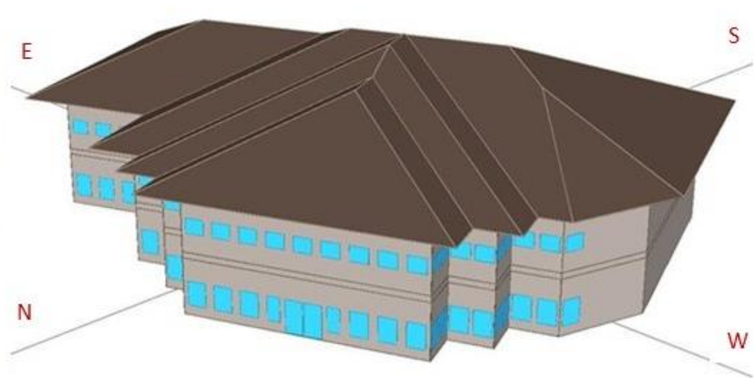


Figure 14 eQUEST Model Representation
Source: Photo Jimmy Salasovich, NREL; Energy model image generated using eQUEST

Estimates of the current energy use breakdown at the sample office building in Tonga were generated using the eQUEST building energy model, 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.

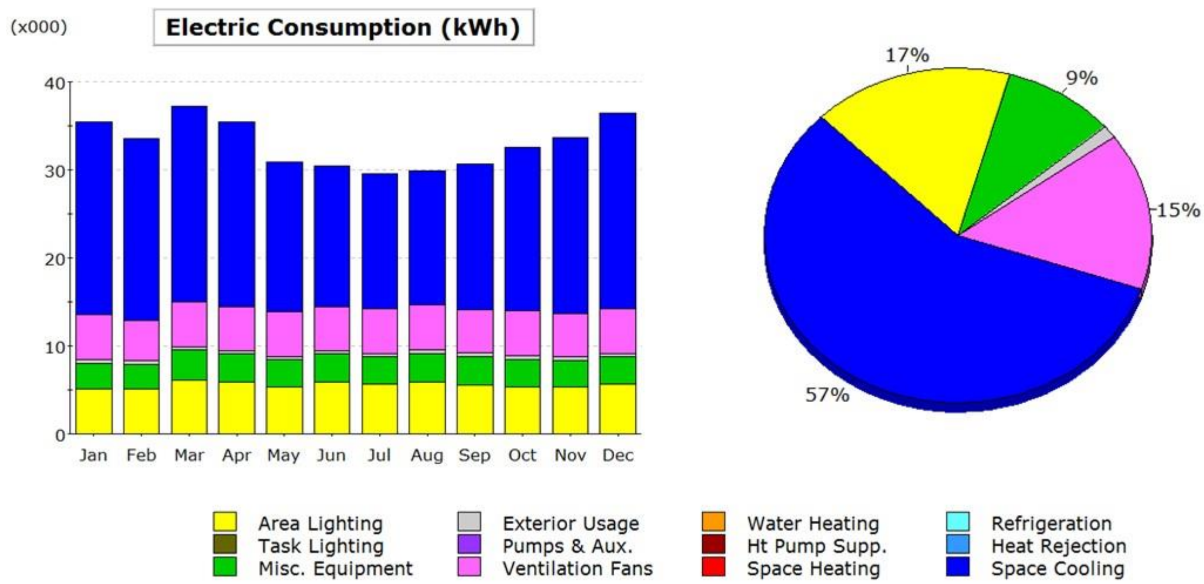


Figure 15 eQUEST Baseline Energy Use Estimates
Source: Figures generated using eQUEST

This data was applied uniformly to the commercial portion of TPL's projected commercial load growth to estimate the yearly appliance consumption by end-use, this is 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. While other methodologies could be used to more accurately model commercial end-use, data is unavailable to estimate what portion of commercial load is going to different account types (government, industrial, retail, etc.), or to estimate yearly appliance uptake of commercial accounts. It is encouraged for TPL to begin recording data of this sort in order to better understand their commercial load and enable themselves to conduct energy audits.

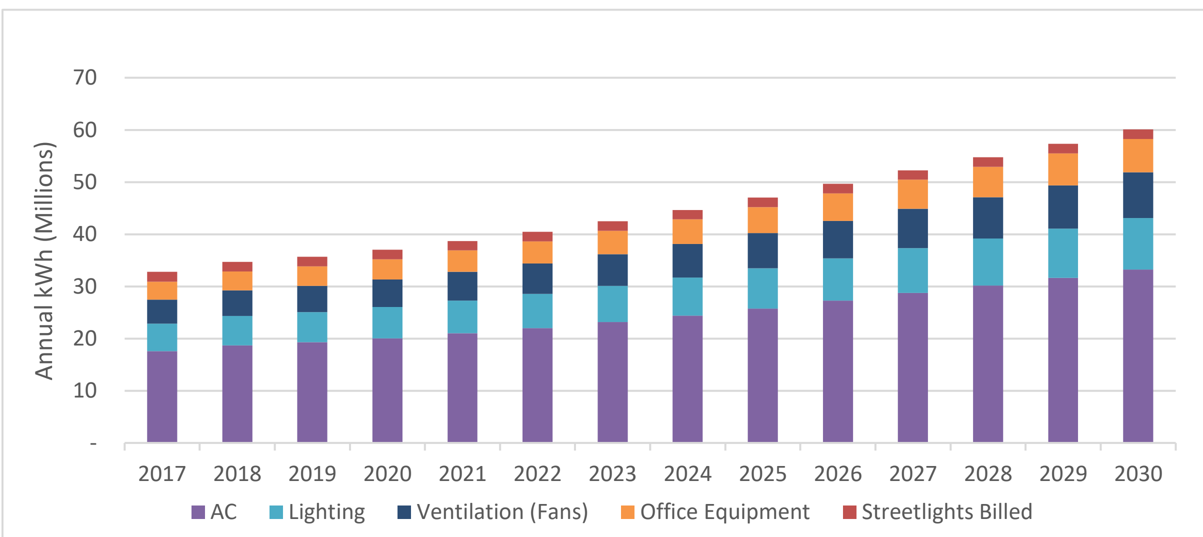


Figure 16 Commercial Electricity Business-as-Usual by End-Use

2.1.2.4 Street Lighting

The last major sector of electricity use in Tonga is street lighting. Tonga does not use traffic lights, opting for energy efficient roundabouts. The street lighting installed is typically near town or village centers and along major junctions or intersections. A program exists to convert older, less efficient street lights to higher efficiency LED lamps to save energy. According to various reports, Tonga coverted the following number of street lights to LED each year:

- Tongatapu: 135 existing street lights replaced with high efficiency LED units (2015)
- Tongatapu, Vava'u, 'Eua, Ha'apai: over 1,500 LED lights installed (2016)
- Tongatapu, Vava'u, 'Eua, Ha'apai: over 1,300 LED street lights installed (2017)
- Outer islands: all 161 existing street lights replaced with high efficiency LED units

Besides energy savings associated with replacing higher energy use lights with more efficient lights, an added benefit associated with these projects is more accurate color rendering. As seen in a streetlighting upgrade project in Figure 17, the light cast from high pressure sodium is yellow and makes it difficult to see true colors of objects. The after picture shows more accurate colors, which is beneficial not only for better night-time vision, but also increases safety and reduces crime.[36] One additional benefit of LED lights is a longer lifespan, which also reduces operations and maintence costs associate with replacing bulbs.

Figure 17 Example of LED Street Light

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 identified priority 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 properly baseline the 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 travelled and assess what vehicles were doing the travelling.

The baseline for Tonga's transportation activities and fuel consumption are summarized in this section, organized by fuel usage, kilometers travelled, and other assessments.

2.2.1 Land Transportation Fuel Usage

Fuel usage has been tracked and compiled by the MTED. Starting in 2012, MTED 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 million liters is shown in Figure 18.

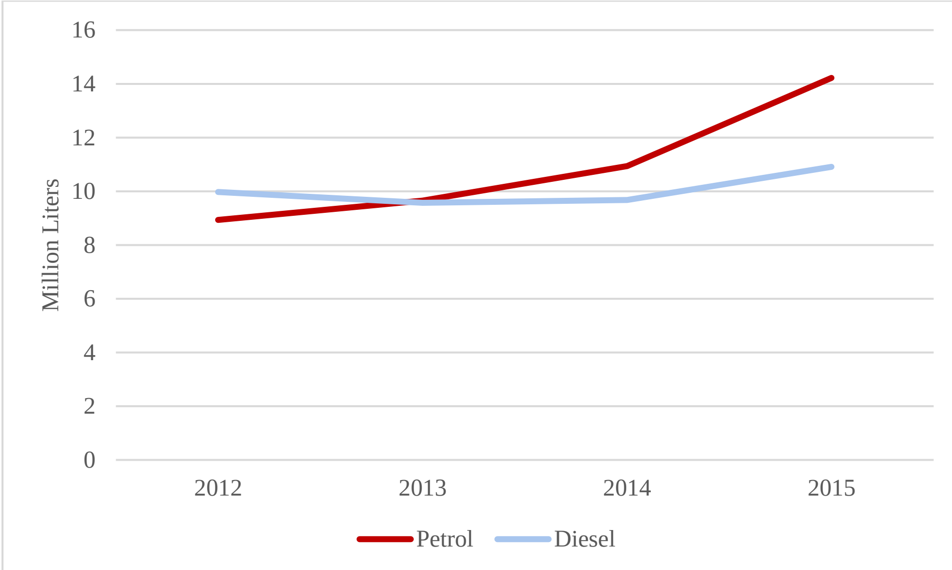


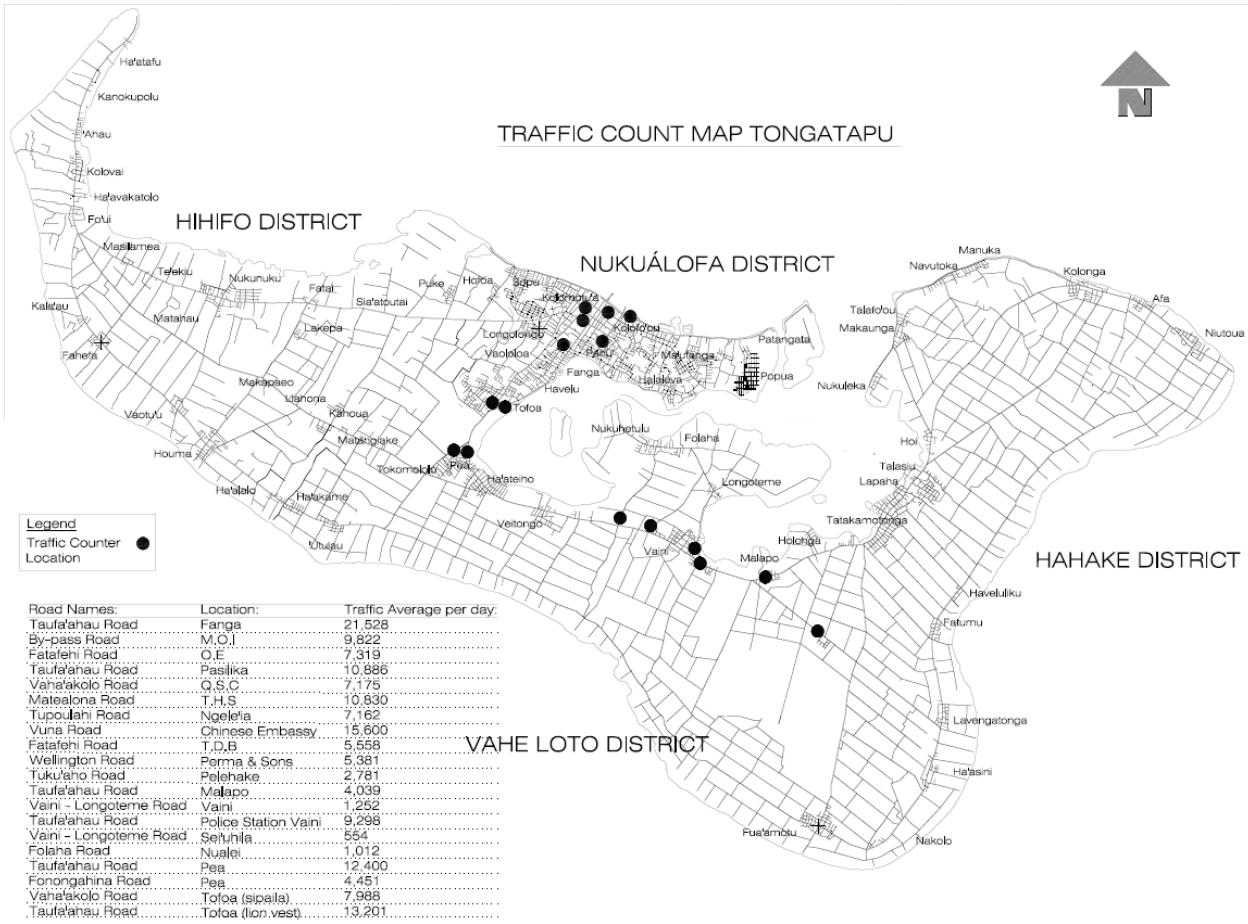
Figure 18 Land Transportation Fuel Consumption in Tonga

Source: MTED Fuel Volume 2012-2015 Report

2.2.2 Vehicle Kilometers Travelled

The fuel reported in the above section is used to propel motorized vehicles. The distance they are propelled is measured in vehicle kilometers travelled (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. 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.



Road Names:	Location:	Traffic Average per day:
Taufa'ahau Road	Fanga	21,528
By-pass Road	M.O.I	9,822
Fatafehi Road	O.E	7,319
Taufa'ahau Road	Pasilika	10,886
Vaha'akolo Road	Q.S.C	7,175
Matealona Road	T.H.S	10,830
Tupoulahi Road	Ngele'ia	7,162
Vuna Road	Chinese Embassy	15,600
Fatafehi Road	T.D.B	5,558
Wellington Road	Perma & Sons	5,381
Tuku'aho Road	Pelehake	2,781
Taufa'ahau Road	Malapo	4,039
Vaini - Longoteme Road	Vaini	1,252
Taufa'ahau Road	Police Station Vaini	9,298
Vaini - Longoteme Road	Sei'uhila	554
Folaha Road	Nualei	1,012
Taufa'ahau Road	Pea	12,400
Fonongahina Road	Pea	4,451
Vaha'akolo Road	Tofoa (sipaila)	7,988
Taufa'ahau Road	Tofoa (lion vest)	13,201

Figure 19 Traffic Count Map of Tongatapu

Source: Ministry of Infrastructure

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 were 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 Hahake 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 VKT on Tongatapu

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

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

The results of Table 4 are that Tongatapu sees 545,531 VMK every 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 to fuel use. Fifteen percent of land transportation fuel is used on islands other than Tongatapu, so it was assumed that 15% of VKT did also. Taking this into account results in the estimate of 2,289 VKT per capita—a realistic number given its per-capita Gross Domestic Product (GDP) and other parameters.[37] Furthermore, when dividing the fuel used in Tonga by this VKT, the result is an average vehicle fuel consumption rate of 12.5 L/100km—a figure that is quite realistic for the vehicle population.

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 Ministry of Infrastructure and reported by the National Reserve Bank of Tonga.[38] 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 while vehicle stock is needed.
3. Vehicle Imports tracked by Tonga Customs. This data is not divided into vehicle category and is therefore not as useful for fuel use estimates. However, it does provide a good data check on the registrations.
4. Government Fleet, tracked by the Ministry of Infrastructure. This data shows 538 vehicles in the government fleet, broken down by vehicle type in Figure 20.

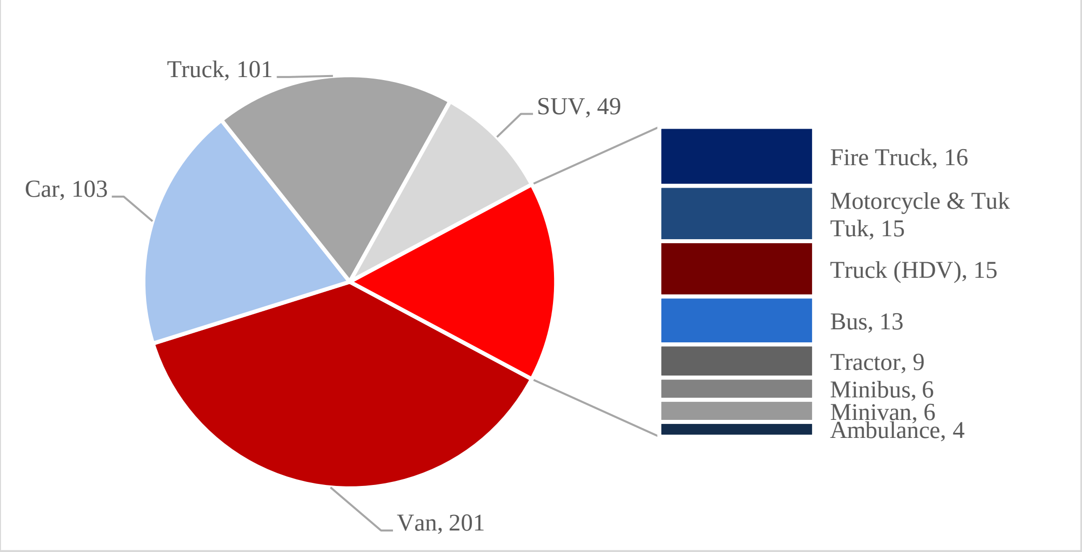


Figure 20 Government Vehicle Inventory by Type

Source: Ministry of Infrastructure 2016/17 Government Vehicle Inventory

The following steps were employed to utilize 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 datasets 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, Census 2016 data was 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 was 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 pre-date the dataset are still part of the current stock, so an estimate was calculated as to what registrations were before the dataset. 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.[39]
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 dataset, the imports data, and the 2016 census data. The total number of vehicles is 3.5% less than if the calculations had been based on the annual vehicle imports. Conversely, the total 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 since many of the vehicles are owned by corporations (which were not included in the census) and not households.

2.2.4 Other Baseline Data of Interest

While 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, down to 89% in 2016. It’s unclear what proportion of these phones are ‘smart phones’ capable of accessing the internet for transportation purposes. The 2016 Tonga Census asked respondents about the number of bicycles owned. It reported that 4,695 households (26%) own a bike, and that 7,009 bikes are owned overall. Previous censuses did not ask respondents about ownership of bicycles.

The Ministry of Infrastructure has provided yearly data on the number of domestic ferries and their passengers, along with the volume of cargo delivered to various wharfs. This data will be incorporated to examine how additional ferry and domestic sea travel could impact Tonga’s fuel use and carbon emissions.

Tonga residents reported 695 motorcycles in the 2011 Census, yet that number dropped to 275 motorcycles in the 2016 Census—a drop of 38%. The reasons that people gave up this efficient mode of transportation should be understood as a part of a multi-faceted 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 that was derived above: vehicle stock and annual VKT.

3 Business-as-Usual Projections

In order to identify areas of reduction and effectiveness of various conservation scenarios it is important to create business as usual (BAU) projections. Where data was available the information was used to create historic trend lines to help with projections. Where data was 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 dollars[40]) is between $5,000 and $20,000 USD.[41] In other words, this is the range where 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, since 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.

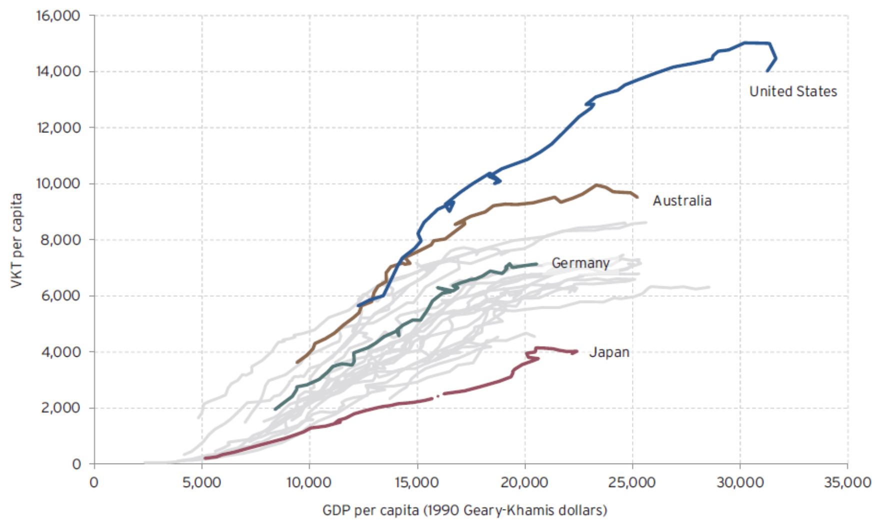


Figure 21 VKT of Motorized Passenger Travel and per-capita GDP for 22 Developed Countries

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)

Since land transportation fuel use is most closely tied to VKT, and VKT is most closely tied to per-capita GDP in international dollars[42], a projection of Tonga's per-capita GDP is needed into the future. The per-capita GDP data from 1980 to 2017 is shown in Figure (in blue). The line of best fit is linear (with R^2=0.979) and therefore future projections are based upon that line. This line shows Tonga's per-capita GDP reaching $9,000 in 2050.

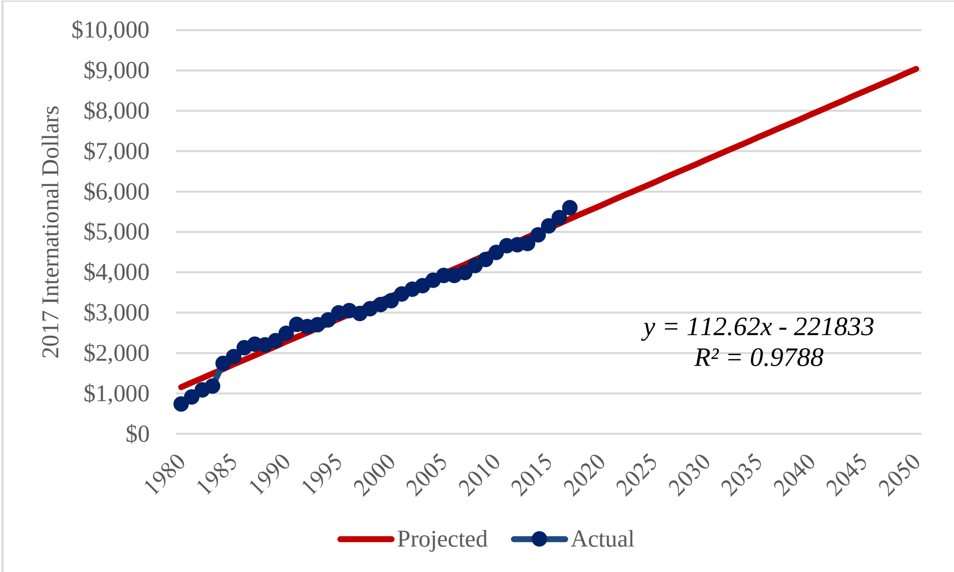


Figure 22 Tonga per-capita GDP with Purchasing Power Parity

Data Source: Knoema Tonga GDP per-capita[43]

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 the New Zealand, approximately 23% of the total VKT are freight, so it is assumed that this ratio is the same for Tonga.[44] Subtracting 23% from the total VKT of Tonga leaves 1,750 VKT of motorized passenger travel 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 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 1960's and 1970's. 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 L/100km. This is a standard assumption when developing a business-as-usual 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.

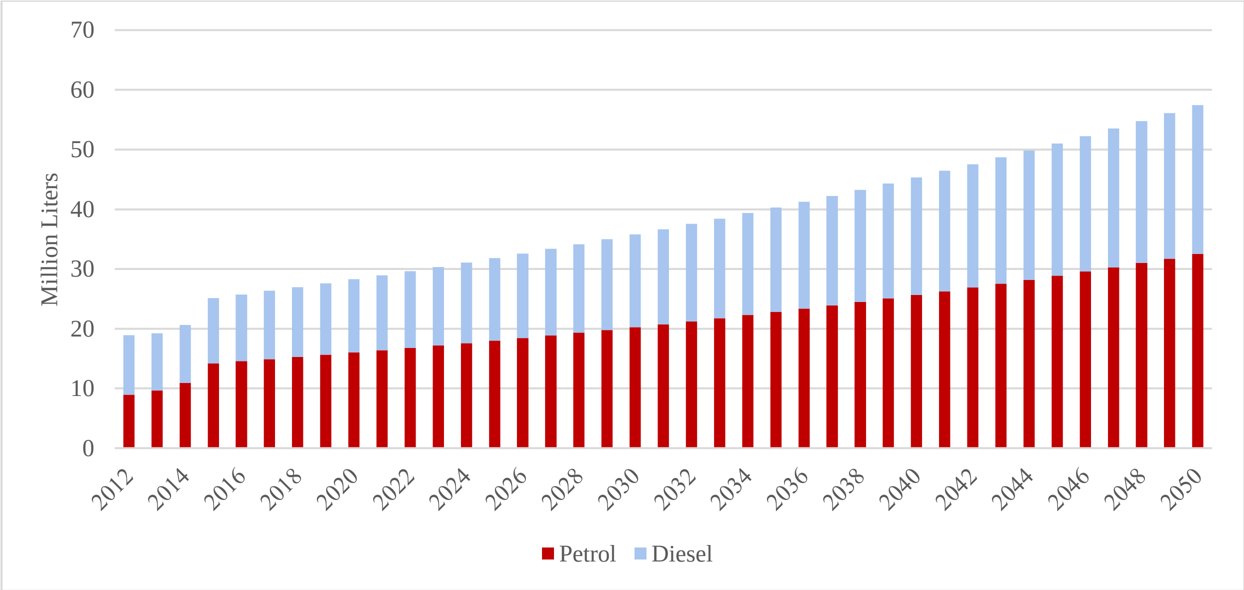


Figure 23 Tonga BAU Transportation Fuel Usage

Fuel use was then converted to lifecycle 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. It is important to note that the BAU in terms of diesel is based on 500 ppm diesel while the current diesel used in land transport is now 10 ppm since 2018.

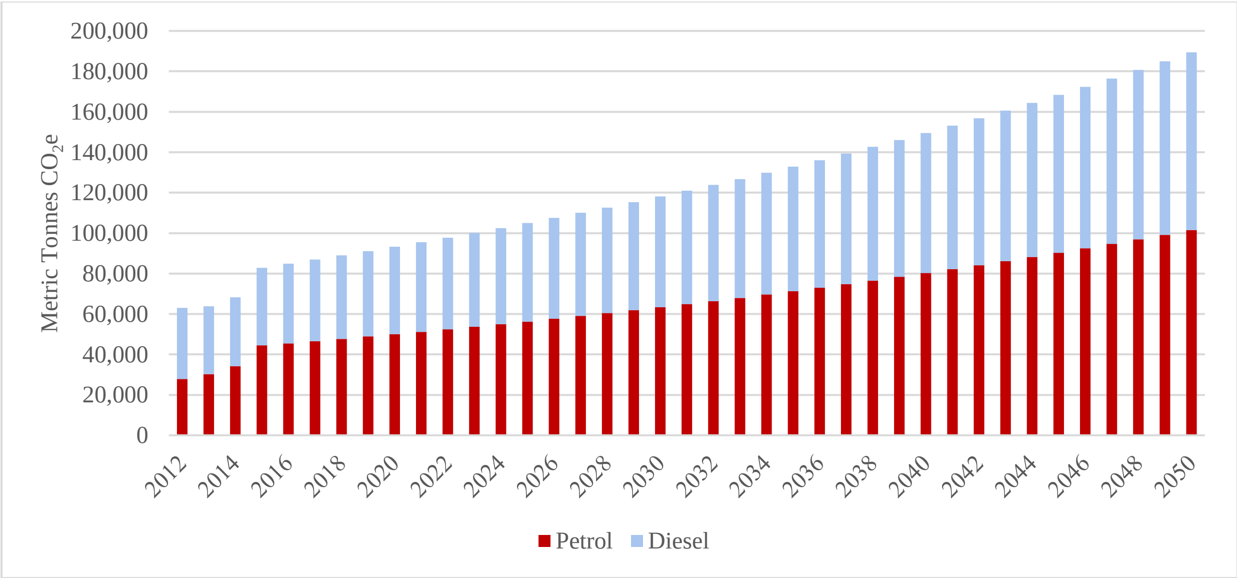


Figure 24 Tonga BAU Land Transportation GHG Emissions

3.2 Tonga Electricity Business-as-Usual Projection

Data from the TERM was compared to data received from TPL's annual reports in order to determine the best projection scenarios for all of Tonga, recognizing that the largest growth is predicted to occur on Tongatapu. The energy billed and peak demand for each of Tonga's four island groups is shown in Table 6. As more remote islands are electrified populations may shift on those islands as young adults may choose to move closer to family or new businesses may start in those remote island areas (e.g., tourism or resorts with access to power). Not knowing what the future holds for each of the islands a general projection was made based on total population growth. Historical data shows 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

	2010	2011	2012	2013	2014	2015
Tongatapu Grid						
Billed Energy, MWh	36,759.00	36,223.30	36,001.00	36,760.10	38,230.60	40,142.10
Peak Demand, MW	7.903	7.654	7.5	7.565	7.815	8.152
Vava'u Grid						
Billed Energy, MWh	4,037.00	3,978.10	3,953.70	4,037.10	4,198.60	4,408.50
Peak Demand, MW	1.021	0.989	0.97	0.981	1.013	1.058
Ha'apia Grid						
Billed Energy, MWh	1,236.50	1,240.00	1,255.40	1,294.20	1,346.00	1,413.30
Peak Demand, MW	0.3	0.3	0.304	0.313	0.325	0.341
'Eua Grid						
Billed Energy, MWh	882.1	884.6	895.6	923.3	960.2	1,008.20
Peak Demand, MW	0.229	0.227	0.225	0.228	0.235	0.245
Total, All Grids						
Billed Energy, MWh	42,914.50	42,326.00	42,105.60	43,014.70	44,735.30	46,972.10

Source: TERM

Table 7 Historical TPL 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
Total billed (MWh)	44,539	42,625	44,566	44,731	46,388	49,165	49,165	53,342	58,823
Total generated (MWh)	54,659	51,845	53,160	52,391	53,313	55,405	55,405	60,037	66,519
Customers	20,338	20,773	20,758	20,498	20,580	20,633	20,932	20,999	22,929
MWh billed per customer	2.19	2.05	2.15	2.18	2.25	2.38	2.35	2.54	2.57
Percent change		-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, this data was chosen to represent the total yearly generation in the BAU 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 a similar methodology to the transportation BAU, the electricity BAU was brought to the common metric of CO_2e emissions which is shown in Figure 26.

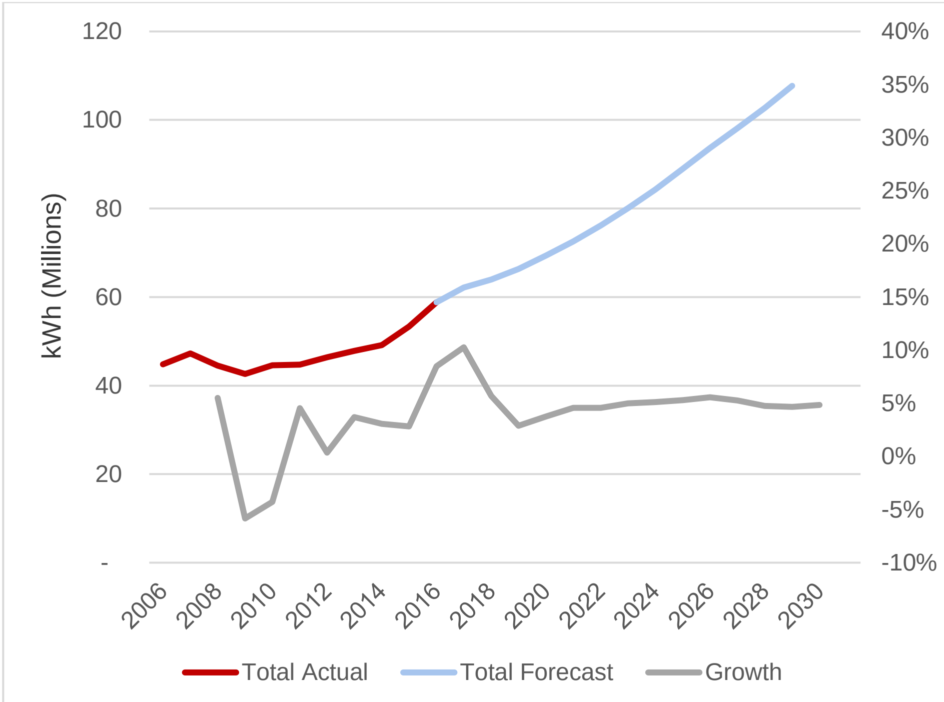


Figure 25 TPL Projected Load Growth (Source: TPL)

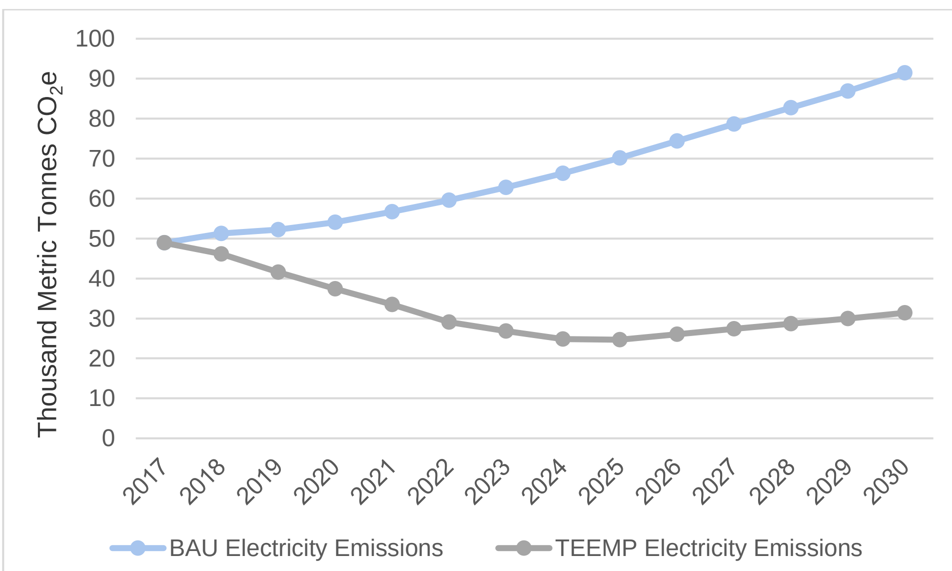


Figure 26 Projected Electricity Emissions Under BAU and with Policy Changes

4 Proposed Reduction Targets

Tonga's INDC calls for 50% renewable penetration in the electricity generation sector by 2020 and 70% by 2030 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 sub-components 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 that track the difference between BAU scenarios and the path to target achievement. It will then discuss policy and project options that enable achievement of these targets.

4.1 Transportation Wedge Analysis

GHG emissions from Tonga land transportation can be reduced through VKT reduction, vehicle efficiency improvement, idle reduction, and alternative fuels such as electricity or biodiesel. This section introduces each of these methods, proposes related goals, and assesses their contribution 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 sub-goals are a tangible way to check the feasibility of an overall GHG reduction target. Each sub-goal, 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 where traffic flow improvements lead to increased VKT[45].

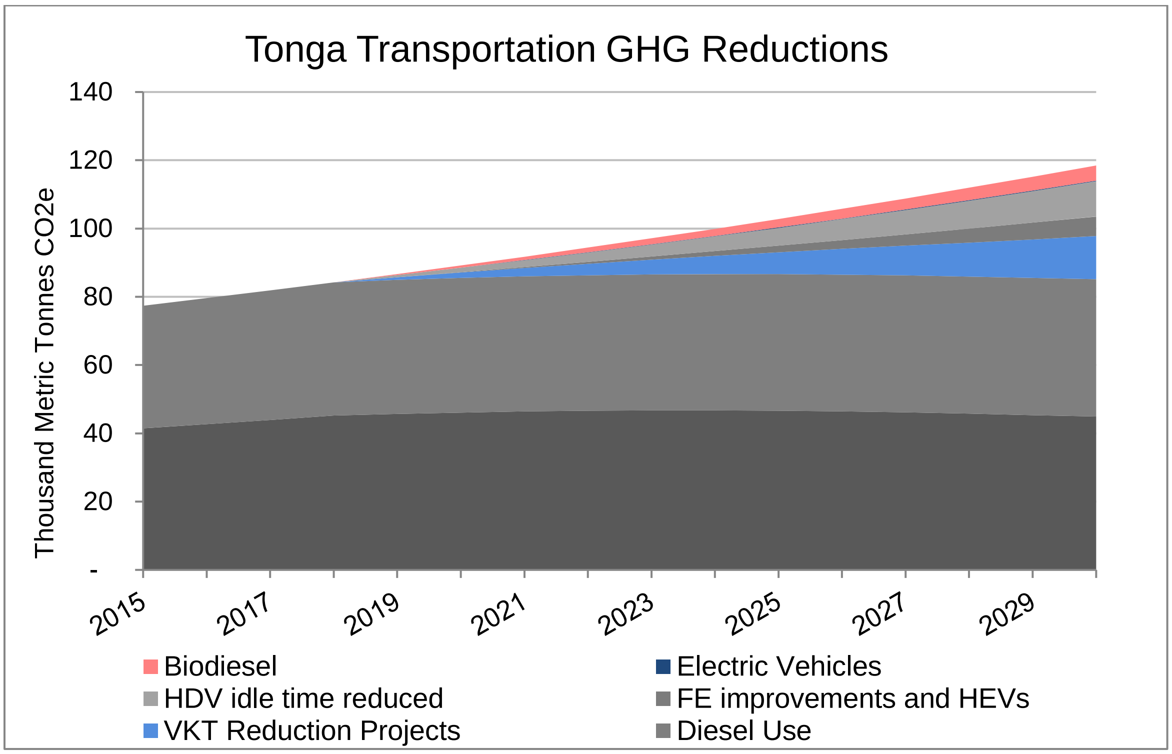


Figure 27 Transportation Wedge Analysis, thousand metric tonnes of CO_2e

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

1. 20% reduction in VKT of light-duty vehicles (LDVs) through walking, biking, transit, rideshare, telecommute. This sub-goal focuses on LDV's because these vehicles are responsible for the majority of emissions increases as a country develops. It should be noted that a 20% reduction from the 2030 BAU VMT is equivalent to a 15% reduction from the 2018 VMT.

2. 30% improvement in fuel economy for new LDVs through registration fees, import tariffs, or fuel economy standards. This would be an improvement from 10.1L/100km in 2016 to 7L/100km in 2030. This sub-goal is realistic because it is slightly less ambitious than what the U.S. achieved through its Corporate Average Fuel Economy program between 2010 and 2017 (34% improvement in 7 years, starting at 10L/100km[46]).

3. HDV idle time reduced by 1 hour per day. HDV's use about 3.5 liters of diesel per hour and LDV's about 1.5[47]. 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[48]. Tonga is at an advantage since it's warm temperatures enable easy diesel startup without concerns for gelling fuel. Numerous technologies can enable significant idle reduction, including automatic engine shut-off, storage cooling, axillary power units, electrified parking spaces, and batteries[49].

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 2030[50]) 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[51].

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 EVs, and these costs are dropping quickly[52]. 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 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, PHEVs, and EVs and the market can determine which is favored at any given time.

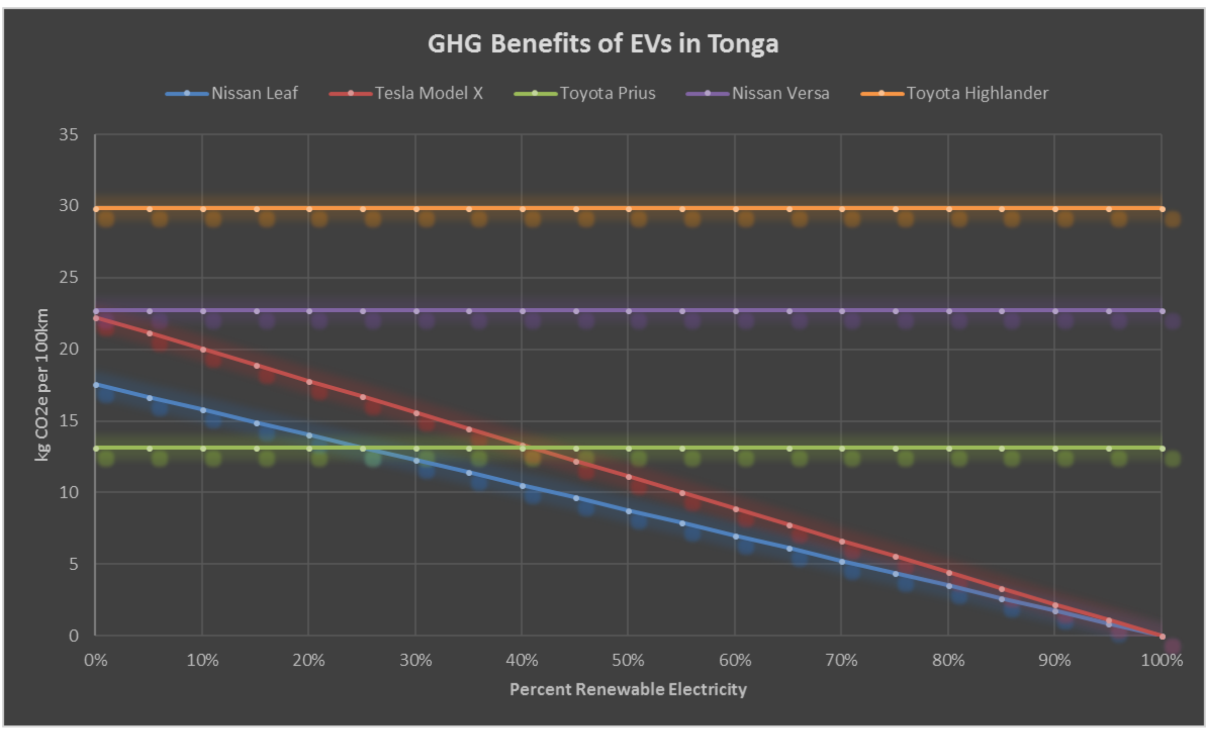


Figure 28 GHG Emissions Benefits of Electric Vehicles in Tonga

4.2 Electricity Wedge Analysis

Tonga's INDC includes a commitment to replace 50% of electricity with renewables by 2020 and 70% by 2030; Tonga's Strategic Development Framework (published the same year as the INDC) states the goal as 50% by 2025.

While the goals are ambitious, and significant effort is underway to design and construct renewable project in an effort to meet the 2020 target, indications are that the target would be met. To achieve the 2020 goal, a significant number of renewable energy developments are currently underway and planned, including the installtion of battery storage systems. To account for some potential slippage, the electricity model uses the 50% renewable by 2025 target, and then maintains that level of renewable penetration through 2030. Efforts to reach 50% renewable before 2025, or to exceed 50% renewable henceforth should be applauded, but using the 2025 target provides a more achievable target for the model.

Tonga's ambitious renewable plan will already significantly reduce the countries emissions from electricity. Pairing this plan with a suite of Energy Efficiency 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 2025 without any MEPS or policy options, Tonga would need the equivalent generation from approximately 120,213 solar panels; when the suggested Energy Efficiency 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 91.5 thousand metric tonnes CO_2e to 31.4 thousand metric tonnes CO_2e––is possible. This signifies a reduction of 60.1 thousand metric tonnes CO_2e, of which 49% is from increased renewable energy penetration, 16% is from stringent MEPS reductions, and 35% is from a suite of other policy options.

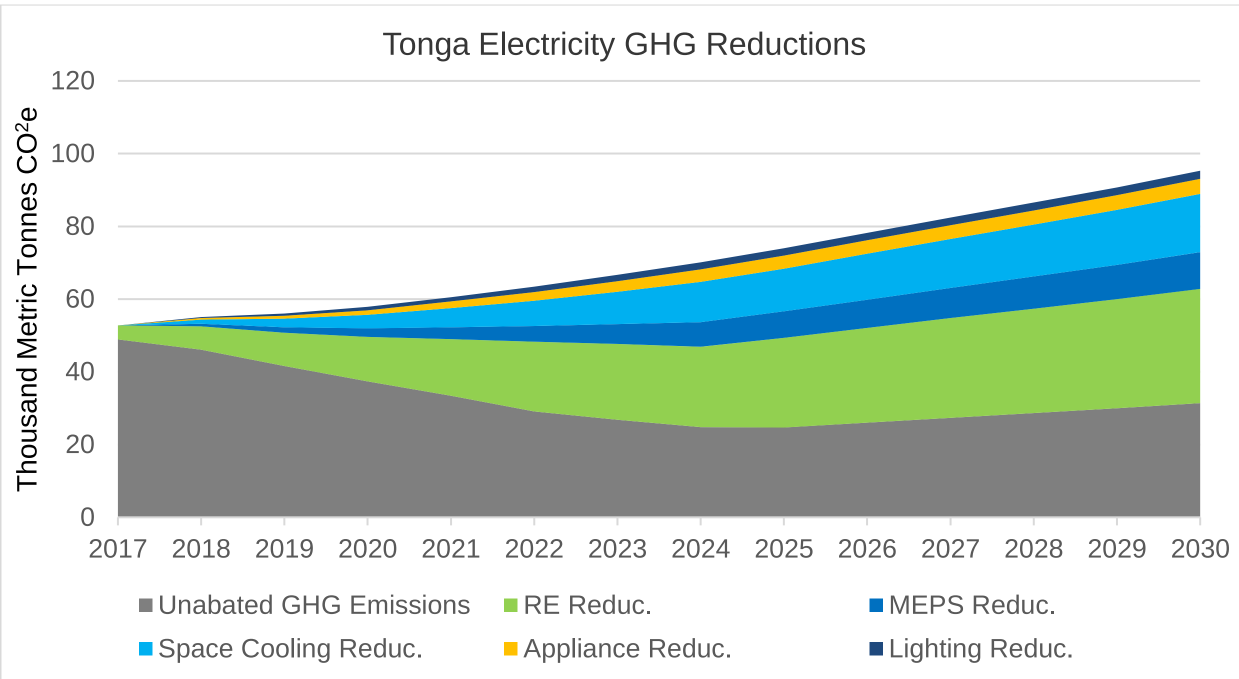


Figure 29 Electricity Wedge Analysis

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

1. One hundred percent adoption of MEPS by 2022 (based on 7 year phase in of policies); extend MEPS to AU/NZ standards for all fridge/freezers, ACs, water heaters, TVs, computers, clothes washing machines/dryers, cooking appliances, and curtail importation of non-LED bulbs. Implement 100% labelling of appliance efficiency too.
2. Fifty percent renewable energy penetration by 2025. Incentivize adoption of TPL's existing net-metering program, especially for high use customers. By generating electricity on site, additional benefit can be realized by avoiding line losses.
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 whenever 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. Institute an Integrated Resource Planning process with TPL to identify how EE and renewable 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 50% reduction of CO_2e a year by 2030. This represents a reduction from the BAU emissions of 210,000 metric tonnes of CO_2e, using 2020 as the refence year. 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

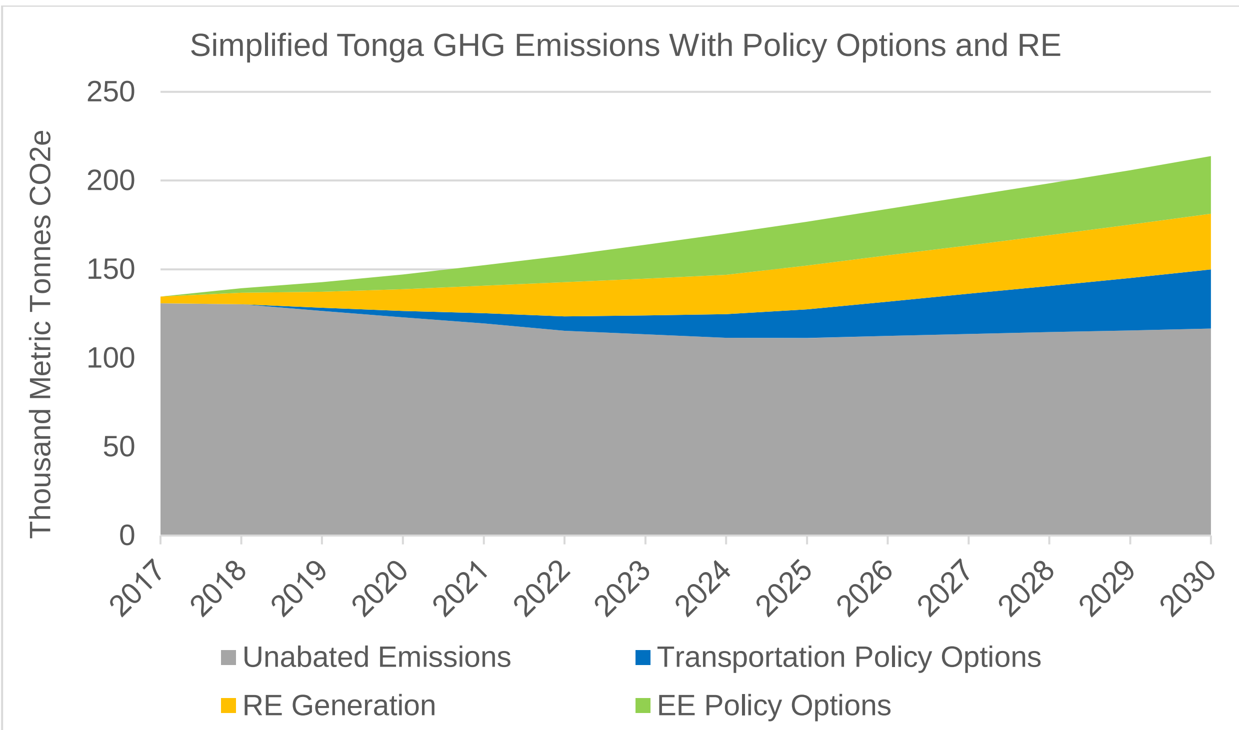


Figure 30 Simplified Combined Wedge Analysis

4.4 Energy Flow Diagrams of 2017 Baseline and 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 are only a portion of the energy used, and GHG's emitted, in Tonga. Therefore, the breakdown of sectoral fuel use does not compare directly, when looking at percentages, to Tonga's INDC.

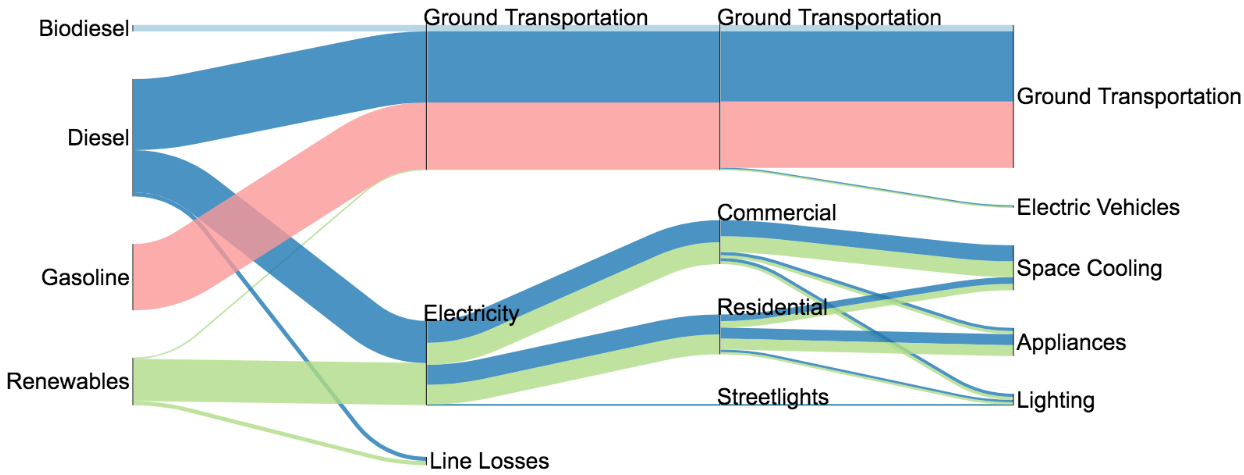


Figure 31 Tonga 2030 Energy Flows with Goals Achieved in the Electricity and Ground Transportation Sectors

The major changes between the two diagrams are the addition of large quantities of renewable energy that go largely to the commercial and residential sectors, and the associated reduction in diesel use. While 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; while 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. While 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 load they serve, and thus less likely to be susceptible to substantial line losses.

4.5 Energy Intensity with TEEMP Policy Changes

While the energy intensity of Tonga is projected to rise at a linear rate under the BAU, 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. Energy efficiency measures like those detailed in the TEEMP reduce Tonga's vulnerability to volatility in fuel markets or supply chain issues.

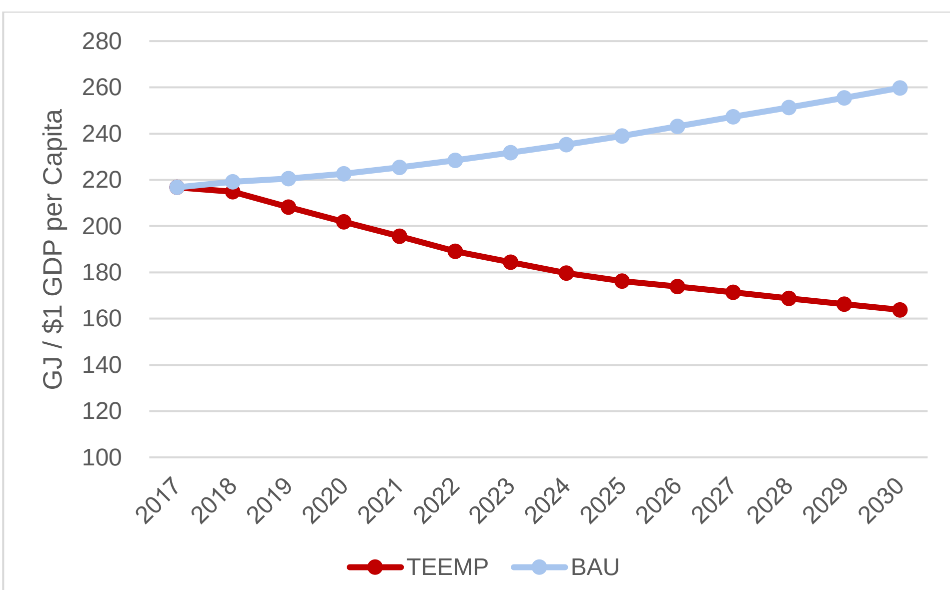


Figure 32 Energy Intensity of Tonga Following TEEMP Policy Implementation

5 Projects and Policies to Reduce GHG Emissions

The next step in the path towards achieving the goals laid out in Section 5, and to further verify the feasibility of these goals, is to propose policies and projects that would achieve them, package them as a programme in a logframe matrix, prioritise them and give an estimate to their costs.

It should be noted that the scope of this study is only the transportation and electricity sector, a large portion of Tonga's total emissions are from industrial processes, the agricultural sector, and other non-energy 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 INDC.[53]

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. These policies and projects are presented with key considerations regarding their implementation. They are presented with preliminary assessments of the size of potential GHG reduction, upfront cost (many of their lifecycle costs are negative), time to implement, ancillary benefits (which frequently translate to popularity or political feasibility), and available support. Assessments are generalized as green for good, yellow for average, and red for bad. In the event of a tie for number of positive scores, priority is given to the ranking on the left. The top ten options are elaborated in text below. It is however worth mentioning three key developments which would affect fuel use, efficiency, GHG emissions and other significant positive impacts on the Tonga economy. These are the:

- The switch to 10 ppm diesel fuel since 2018
- The current very high priority the current govetment gives to improving the roads throughout Tonga since it came to power in September 2019, and
- The constrution in 2021 of the bridge across the lagoon linking the capital and Folaha village

Table 8 Policies and Projects to Reduce GHG Emissions from Ground Transportation

Wedge	Policy Options / Projects	GHG Reduction	Upfront Cost	Time to Implement	Ancillary Benefits	Support Availible
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 laguna** (and some associated dredging)	High	Med	Med	High	Med
VKT Reduction	Build a **strategic parking lot and bus stop** at intersection of Taufa'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 laguna, 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

1. Use a platform such as NextBus to **coordinate busses**:
   - 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. Reduced stress and lost time associated with riding the bus, encouraging more ridership. Census data indicates 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
   - *Resource:* Urban Bus Services in Developing Countries and Countries in Transition

   Consideration: Tonga's bus industry is fairly uncoordinated though they have an association. NextBus is better suited to a developed industry with better developed infrastructure such as roads, bus stops, etc. Perhaps begin with something like Fiji's where buses are registered based on a certain route and a timetable so as to deliver safe and reliable service to the public. There is an opportunity to look at establishing a national bus company prior to adopting NextBus based on the appropriateness of the transport infrastructure and consumer awareness.

2. Enact a **safe bicycle passing law** for drivers passing cyclists or pedestrians:
   - 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, while violations were plentiful, enforcement was rare.[54]
   - *Resource:* League of American Bicyclists--Model Safe Passing Law
   - *Resource:* Public Policies for Pedestrian and Bicyclist Safety and Mobility

   Consideration: Existing legislations provide for the safety of every users of the road, including pedestrians. Current width of roads would not permit allocating a particular lane for bicycles, buses etc other than the footpaths for pedestrians.

3. **Send a mechanic to HEV/EV maintenance training** in Japan or New Zealand:

- 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.
- *Resource:* Toyota Tajimi Service Center
- *Resource:* MITO Automotive Electrical Engineering Program

Consideration: Given a small market with high staff turnover and loss of trained people due to migration, consider working with the local industry, e.g Toyota, to conduct local training so as to benefit more local mechanics and for the training to be based on accredited trainers and courses. Training in NZ and Japan should be on specialized areas targeting sponsored participants with years of experiences in the industry.

4. Provide pedestrians (particularly school children) and cyclists with **safety reflectors and lights**:

- VKT will increase so long as pedestrians feel safer in cars than on foot. Travelling on foot at night is a particular concern as seventy-five percent of US accidents resulting in a pedestrian casualty occurred in the dark.[55] Various pilot programs to distribute reflectors or lights to school children have proven effective at mitigating accidents. Studies identify that reflector vests are the most effective option for increasing the visibility of cyclists to drivers.[56]
- *Resource:* A Road Safety Manual for Decision-Makers and Practitioners (Pages 78-81)

Consideration: Safety of children and pedestrians is a very high priority of the Ministry of Police in enforcing the relevant legislations. Pedestrian casualty at night due to absence of reflectors and lights are at a minimal. More and more footpaths are constructed in the town areas and are heavily used by people doing evening and early morning exercises.

5. Install **rumble strips** and painted lines demarcating lane boundaries to increase pedestrian and biker safety:

- As most countries develop, they initiate a negative feedback loop. Cars are prioritized, VKT increases, pedestrian and biker safety decreases, which incentives 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
- *Resource:* A Road Safety Manual For Decision-Makers and Practitioners (Page 28*)*

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

Photo Sources: Caley Johnson and Kevin Collington

Consideration: As in #4 above, **s**afety of children and pedestrians is a very high priority of the Ministry of Police in enforcing the relevant legislations. Footpaths are the priority for pedestrians and are currently constructed in the town areas and are extending to villages now. Dedicated lanes need to be considered in light of the competing demands for parking spaces as well as the practicality of enforcing and monitoring given current capacity and technology.

6. **Limit Idle Time with the help of fleet partners and idle reduction technologies**
   - 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 since children are particularly susceptible to air pollution. In addition, many states and municipalities around the world successfully restrict idling due to air and noise concerns[57]. Numerous technologies are available that allow vehicles to reduce their idle time while performing tasks required of the idling vehicle.
   - *Resource*: SmartWay Verified List of Idling Reduction Technologies
   - *Resource*: Idle Reduction for Long-Haul Trucks
   - Case Studies: Clean Cities Fleets Using Idle Reduction Technologies

Consideration: Traffic during peak hours for the drop off and pick up of students are getting longer and longer. Village school buses are currently being used and the use of buses would assist too.

7. Set **Vehicle Registration fee and/or import tariff according to fuel consumption**:
   - People are most responsive to up-front costs when purchasing vehicles rather than lifecycle 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 CO_2 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[1]. 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 are much more politically feasible.
   - *Resource*: Vehicle Registration Fees Implemented by Countries
   - *Resource:* Fuel Economy State of the World 2016
   - *Tool:* New Zealand Fuel Economy Rating Database

Consideration: Government services fees and tariffs are usually submitted by the government of the day together with its annual budget to be approved by Parliament. Regulations are subsequently amended to facilitate the implmentation of the changes.

8. **Blend 10% biodiesel into all diesel fuel**
   - As described in section 5.1, by 2030 this quantity of biodiesel would be supplied by a majority waste grease supplemented by about 25% waste grease. 10% biodiesel is compatible with nearly all diesel vehicles in a warm climate and provides lubricity and cetane benefits[58]. To take full advantage of it's waste grease resources, Tonga would need to build biodiesel production facilities with a total of about 1million 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[59].
   - *Resource*: Economics of Small-Scale Biodiesel Production
   - *Recource*: European Biodiesel Board
   - *Resource*: National Biodiesel Board
   - *Resource*: Philippines Shell Foundation Inc. Project COCONUT (they are working with farmers in the Philippines to improve coconut productivity for biodiesel).

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

Consideration: Baseline study did not provide some firm estimates on waste grease nor of sources such as copra oil. While the technology may have worked in Europe and the Philippines, there is a need for some detailed studies of the proposal to provide clearer guidance to the way forward.

9. **Water taxi in the Laguna** (and some associated dredging):
   - 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[60]. Furthermore, the distance from Nuku'alofa to various towns lining the laguna is much shorter travelling across the laguna instead of 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
   - Resource: Forget Flying Cars: We Need Floating Ones

Consideration: The proposed ADB-funded bridge across the lagoon linking the capital to Folaha village is linked to this proposal. Construction of the bridge is planned to begin in 2021.

10. **Build a strategic parking lot and bus stop at intersection of Taufa'ahau Rd. and Loto Rd**.
    - 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. 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 facilitates carpooling and mass transit

Consideration: Personal convenience and one's own independence would be a challenge to this proposal. The proposed change would need time to perfect itself and public education would be needed to support public acceptance and participation.

11. Introduce **Fuel economy and fuel cost labeling requirements**:
    - Economics provides 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[2].
    - *Example:* Fuel Economy Labeling, Focus on non-EU Countries
    - *Review*: Evaluation of Vehicle Fuel Efficiency Labeling and Consumer Information Programs

Consideration: This is regarded as a low hanging fruit that would be easy to implement and monitor. A lot of Tongans who have visited NZ and Australia are quite familiar with this vehicle labelling.

5.2 Electricity Energy Efficiency Policies and Projects

Table 9 details preliminary least-cost policy options to achieve EE targets in more detail. Policy options are grouped into three categories: "Low Hanging Fruit" which are inexpensive relative to the results they would deliver, "Energy Transformation Projects" which could require lengthy or expensive implementation processes, and "Incremental Improvements" which are policies that would influence the development of infrastructure over a longer time period.

[2] https://www.nrel.gov/transportation/drive.html

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:

1. Implement **building standards** for resilience and energy efficiency (e.g. passive ventilation and daylighting with appropriate external shading):
    - As GDP per capita increases, an increasing amount of power is used to supply load that could be better satisfied by mindful construction practices; such as orientating 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.
    - *Ongoing Project:* Review, Strengthening & Updating Of the Tonga Building Code
    - *Example:* Guidelines for Cyclone Resistant Construction of Buildings in Gujarat (India)
    - *Resource:* Mainstreaming Building Energy Efficiency Codes in Developing Countries

    Consideration: This is a policy option that the Ministry of Infrastructure is currently working on, for instance, the review of the current Building Code.

2. Implement a **public awareness campaign** on energy efficiency and conservation:
    - Creating an energy-efficiency public awareness campaign focusing on both the environmental, and personal economic benefits to rate-payers who reduce their consumption. The introduction of a MEP Sprogram goes

hand in hand with this; while 80% of Tongans said appliance running costs are important to them, only 34% plan on looking for an AUS/NZ MEPs label next time they are purchasing an appliance.[61] Introducing a program that is easy to understand and educating customers as part of a broader energy efficiency 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
- *Resource:* Creating an Awareness Campaign

Consideration: The Pacific Appliance Labelling and Standards (PALS) programme have been successfully implemented throughout the Pacific Islands and in Tonga too. The proposed legislation regarding MEPS is incorporated into the draft Tonga Energy Act. Energy stakeholders such as the MEIDECC, TPL and the MTED all have public awareness programmes that need support to become more targeted and more effective too.

3. Establish a demand-side management **revolving loan or rebate program** to aid in financing more efficient equipment (residential, commercial and industrial):
   - 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.
   - *Example:* The Thai Energy Efficiency Revolving Fund
   - *Resource:* Exploring the Case for Revolving Funds for Domestic Energy Efficiency Programs

   Consideration: There are existing experiences such as a revolving loan with the Tonga Development Bank, supported by the IUCN. There are also government funds within TDB for targeted policy initiaves of government such as supporting agricultural exports, increasing tourism earnings, etc.

4. Work with TPL to create an **integrated resource plan** to incorporate RE, EE, and more efficient reciprocating engines that can be dual fuel:
   - While TPL is eagerly working towards Tonga's renewable energy goals, the company publishes little long-term planning detailing how these goals will be achieved. An integrated resource plan provides an opportunity for the company to lay out a long-term, realistic framework outlining how goals will be met in a scope not 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
   - *Resource:* Greening the Grid—Grid Integration Studies
   - *Resource:* Best Practices in Electric Utility Integrated Resource Planning

   Consideration: There are existing effort to review Tonga's NDC and to derive a NDC Investment Plan from it. All of these would provide inputs to the development of a TPL IRP.

5. Perform **energy audits** of buildings to create baselines and implement energy conservation measures:
   - 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.[62] Strengthening energy efficient building standards and performing audits on the largest consumers—including government buildings--can have a large role in reducing overall demand.
   - *Example:* Caribbean Hotel Energy Efficiency Action Program
   - *Resource:* A Guide to Energy Audits

   Consideration: This is an area where close collaborations between the MEIDECC and the TPL will be required.

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

- Work with TPL, the Bureau of Statistics, the MOI, and the Public Service Commission to 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
- *Resource:* Energy Analytics for Development

Consideration: There are various data collection effort going on. At the regional level is the Pacific Regional Data Repository. Tonga has been a beneficiary of ESCAP's Evidence-based policies for the Sustainable Use of Energy Resources in Asia and the Pacific" and there are current collection effort by TPL and Statistics too. The draft Energy Act has clauses to support a more effective and coordinated energy data collection and sharing among the energy stakeholders.

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 energy efficiency 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 to avoid presenting a risk of damaging buildings or other infrastructure; 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, as is currently being undertaken by the NZ-funded Tonga Village Network Upgrade Project . Prioritizing areas that are frequently disrupted may help with strategic planning. Installing microgrids with onsite renewable energy 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. **Fuel Diversification.** 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 unable to be accessed. 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 (RNG) from farms, landfills, and sewage treatment facilities are another option that wasn't proposed in this plan due to budget considerations but could be favorable if Tonga places 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 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 Consderations

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 persue 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. Tecnicians, 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 expendenture. 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 Millenium 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 Monitoring the TEEMP

The TEEMP should be viewed as a national programme that tends to coordinate Tonga's EE effort, beginning with the electricity and transport sectors, but which other sectors such as agriculture and waste can be added once developed and studied.

The general objective of the programme should be consistent to the TERM's as *Reduce Tonga's Vulnerability to Oil Price Shocks and Achieve an Increase in Quality Access to, and use of, Modern Energy Services in an Environmentally Sustainable Manner.*

The purpose of the TEEMP is to reduce GHG emissions from both transportation and electricity by 50% from the BAU by 2030.

For the monitoring of the TEEMP, there are four suggested Results from the TEEMP being:

Result 1: Improved institutional, policy, legislative and governance frameworks for coordinating and managing the implementation of the TEEMP
Result 2: Improved awareness and funding support and strengthened local technical capacity to plan, implement and monitor low carbon projects in the transportation and electricity sectors
Result 3: Reduced greenhouse gas emissions in the transportation sector
Result 4: Reduced greenhouse gas emissions in the electricity sector

Figure 10 is a complete logframe matrix for the TEEMP

Given that the TEEMP is part and parcel of Tonga's TERM, and hence the adoption of the TERM objective to be used for the TEEMP, the management and M & E of the TERM is to be conducted by the same institutional structure as the TERM, with the inclusion of the Ministry of Agriculture and the Waste Authority.

Draft Logical Framework for the Tonga Energy Efficiency Master Plan: (2020 – 2030)

	Intervention logic	Objectively verifiable indicators of achievement	Sources and means of verification	Assumptions
General objective	**The general objective is** to ***Reduce Tonga's Vulnerability to Oil Price Shocks and Achieve an Increase in Quality Access to, and use of, Modern Energy Services in an Environmentally Sustainable Manner***	• % growth rate of Tonga's dependence on fossil fuel is reduced by 2030 • % improvement / increase in Tonga's energy intensity by 2030 • 70% of the electricity generation is from RE by 2030	• Annual Report of MEIDECC • Annual Report of TPL • Progress reports of the TERM Plus & NDC	• Current and subsequent govts are committed to the Paris Agreement
Project purpose	**The purpose of the TEEMP is to reduce GHG emissions from both transportation and electricity by 50%**	• A reduction of at least 106,000 metric tonnes of CO2 equivalent per year by 2030 in both transport and buildings	• Annual Report of MEIDECC • Progress report on the NDC	• Current and subsequent govts are committed to the TEEMP

	Intervention logic	Objectively verifiable indicators of achievement	Sources and means of verification	Assumptions
	from the BAU by 2030.			
Results	**Result 1: Improved institutional, policy, legislative and governance frameworks for coordinating and managing the implementation of the TEEMP**	• The Tonga Energy Efficiency Regulation on MEPSL becomes a part of the Energy Act by 2025	• Report of the Attorney General's Office & minutes of Cabinet meetings	• Current and subsequent govts are committed to the reform of the energy sector
		• The Building Code is reviewed to incorporate EE and resilience by 2023	• MoI annual report	• MoI support
		• The TERM institutional structure is activated in 2020 to coordinate and manage the implementation, monitoring and reporting of the TEEMP	• Cabinet Decision	• MEIDECC support
	Result 2: Improved awareness and funding support and strengthened local technical capacity to plan, implement and monitor low carbon projects in the transportation and electricity sectors	• At least 1 international and 1 local launch of the TEEMP by end of 2021	• MEIDECC launch reports	• Covid-19 travel restrictions are lifted.
		• 50% of the TEEMP budget gets confirmed funding by 2025	• MEIDECC launch reports • Ministry of Finance Budget Reports	• TEEMP is featured in Tonga LEDS, GCF Country Programme, NDC Investment Plan, etc.
		• 20% of the TEEMP budget comes from the National Budget by 2025	• MEIDECC budget • Ministry of Finance Budget Reports	• Cabinet support
		• TEEMP gets promoted in at least 5 investment forums by 2024	• Annual reports of the MEIDECC	• MEIDECC support

	Intervention logic	Objectively verifiable indicators of achievement	Sources and means of verification	Assumptions
		• 200 people trained on scholarships and on accredited energy auditing courses in transportation and electricity by 2025	• Annual reports of the MEIDECCC and Ministry of Education and Training	• TNQAB support
		• EE is incorporated in the primary, secondary and TVET school syllabus by 2025	• Annual reports of the MEIDECC and Ministry of Education and Training	• MET support
		• An accredited national qualification on EE is adopted by the TNQAB by 2025	• Annual reports of the MEIDECC and Ministry of Education and Training	• TNQAB support
		• No. of trade fairs completed & No. of public appearances	• MEIDECC reports	• MEIDECC support
	Result 3: Reduced greenhouse gas emissions in the transportation sector	• 20% reduction in VKT of light duty vehicles through walking, biking, public transit, ridesharing and telecommuting by 2023	• Tonga National Communication & reports on the progress with its NDC implementation.	• MoI support
		• HDV idle time reduced by 1 hr per day by 2030	• MoI vehicle registration	• MoI support
		• All road transportation diesel contains 10% biodiesel by 2030	• MoI vehicle registration	• Biodiesel production is economically feasible
		• 10% of new LDVs are hybrid and electric by 2030	• MoI vehicle registration	• Adopted tax incentives on e-vehicles
		• 20 GPS fish locator and VMS deployed in fishing by 2024	• Ministry of Fisheries reports	• MoF support

	Intervention logic	Objectively verifiable indicators of achievement	Sources and means of verification	Assumptions
	Result 4: Reduced greenhouse gas emissions in the electricity sector	• At least 10 major electricity consumers are audited and recommendations are implemented by 2026.	• AMREC and contract reports	• TPL and MEIDECC support to the AMREC
		• 3 additional appliances are included in the MEPSL regulation by 2026	• Regulations and government gazette	• MEPSL continues to be implemented
		• At least a 5% decrease in line losses and a 5% increase in underground cables by 2030	• TPl reports	• Continuation of the Tonga Village Network Upgrade project
		• At least 6 MW of RE mini-grids plus battery storage are installed by 2030	• TPL & MEIDECCC reports	• Favourable investment climate
		• 100% of all street lights and government premises are on LED lights by 2030	• AMREC & MoI reports	• Government's support
		• 100% of the tourism accommodation premises comply with the hotel guide by 2030	• Ministry of Tourism reports	• MoT support
		• At least USD 5 M is secured for a EE revolving fund / rebate by 2030	• Energy sector reports	• Donor support
		• A very effective public awareness programme reach out to 90% of the population by 2027	• Media reports	• MEIDECC and TPL have dedicated Comms staff
		• At least USD 2 M is secure to kick start a cool roof programme by 2027	• Energy sector reports	• Donor support

	Intervention logic	Objectively verifiable indicators of achievement	Sources and means of verification	Assumptions
		• An IRP for TPL and a data base programme for the energy sector is adopted by 2025	• TPL and Statistics reports	• TPL Board's support.

7 Financing the TEEMP

It is estimated that the financing of the TEEMP would require about USD 27 million with 7% or USD 1.97 million to implement low hanging activities within its first 3 years. The bulk of the financing (87% or USD 23 million) would be needed for the more difficult and longer term activites in years 4-7 while 6% or USD 1.5 million will be required for the implementation of least urgent activities in year 8 – 10.

Activities have been grouped based on a preliminary assessment of the ease by which they can be implemented and financed given the very crude nature of of the GHG emission estimates.

Tonga's GCF Country Programme includes Reducing emission from the land transportation (energy efficiency) with the JNAP 2, NDC and the TERM as sources of strategic priority. There is an estimate of USD 12 million for this priority activity which would be more than sufficient to cover the estimated costs under Transport in the TEEMP. Tonga's other multilateral and bi-lateral partners are potential sources of financing for the TEEMP.

The Tonga government can also contribute to the TEEMP through its funding of the MEIDECC staff and their operational costs. Through the necessary promotion and incentives the private sector could find it attractive to invest in the activities of the TEEMP.

There are parallel activities that are related to the financing of the TEEMP. Together with the GGGI, Tonga is developing its Low Emission Development Strategies (LEDS) and with the GGGI and the Pacific NDC Hub it is reviewing its NDC and developing a NDC Invesment Plan. These initiatives will be complementary to the TEEMP and vice versa.

Figure 11 is a draft of the key activities under each results areas of the TEEMP together with a rough estimate of the costs and a grouping of the activities according to how easy they can be funded and fully implemented.

ACTIVITIES:	MEANS:	COSTS (IN USD):	RESPONSIBLE LEAD AGENCIES:	Modelled GHG Impacts (annual CO2e reduction by 2030)	Year 1 - 3	Year 4 - 7	Year 8 -10
					High	Medium	Low
Result 1: 1.1 Draft and conduct consultations on a MEPL Regulation	Consultancy, workshops and meetings, training and awareness, etc	300,000	MEIDECC		300,000		

ACTIVITIES:	MEANS:	COSTS (IN USD):	RESPONSIBLE LEAD AGENCIES:	Modelled GHG Impacts (annual CO2e reduction by 2030)	Year 1 - 3	Year 4 - 7	Year 8 -10
					High	Medium	Low
to be added to the Energy Bill							
1.2 Review the Building Code to incorporate EE by 2023, seek Cabinet approval and support its associated awareness and enforcement activities	Consultancy, workshops and meetings, training and awareness, etc	200,000	MoI			200,000	
1.3 Reactivate the TERM institutional structure in 2020 to coordinate and manage the implementation, monitoring and reporting of the TEEMP	Cabinet submission and consultation meetings	5,000 Sub-total: 505,000	MEIDECCC		5,000		
Result 2: 2.1 Launch of the TEEMP locally and at COP 26 on 9-19 November 2020, in Glasgow, UK	Travel, publication, promotional materials, venue, catering & equipments	100,000	MEIDECCC		100,000		
2.2 Conduc t annual energy investment forums and other relevant forums to promote the TERM+, TEEMP, etc	Travel, publications, promotional materials, venue, catering & equipments	500,000	MEIDECCC			500,000	
2.3 Offer scholarships and Conduct accredited energy auditing course in transportation and electricity and implement the findings	Scholarships, Trainers, training materials, tools & equipment, venue, catering	250,000	AMREC supported by MEIDECCC & TPL			250,000	
2.4 Incorporate EE in the primary, secondary and TVET school syllabus	Consultancy, workshops, training of trainers, teaching materials and equipments	300,000	MET			300,000	
2.5 Develop a national and accredited qualifications on EE and an energy literacy programme for all sectors	Consultancy, workshops, training of trainers, teaching materials and equipments	300,000	MET			300,000	
2.6 Promote local funding for the TEEMP during the budget preparation process	Promotional materials, meetings, displays and site visits	10,000 Sub-total: 1,460,000	MEIDECCC		10,000		

ACTIVITIES:	MEANS:	COSTS (IN USD):	RESPONSIBLE LEAD AGENCIES:	Modelled GHG Impacts (annual CO2e reduction by 2030)	Year 1 - 3	Year 4 - 7	Year 8 -10
					High	Medium	Low
Result 3: 3.1 Implement a programme (including physical structures) to promote the safety and health benefits of walking and cycling	Consultancy, equipments, trainings and workshops a. Enact safe bicycle passing law b. Distribute safety reflectors and lights c. Install rumble strips	400,000	MoI & MET	a. 12,700 b. 12,700 c. 12,700		400,000	
3.2 Implement a programme to improve efficiency of buses and limit vehicle idle time	a. Consultancy, equipments, trainings and workshops b. Study and Establish national bus company c. Increase number of school buses d. Use platform for coordinating buses e. Build strategic parking lot and bus stops at bottlenecks f. Introduce technologies to reduce idle time	500,000	Chamber of Commerce, MoI & School PTAs	a. x b. x c. 12,700 d. 12,700 e. 10,300			500,000
3.3 Introduce water taxi in the Fanga'uta lagoon	Consultancy, Dredging, testing & promotion	250,000	MoI	12,700			250,000
3.5 Adopt appropriate fiscal and financial incentives to promote HEVs, EVs and fuel economic vehicles, tuks-tuks, etc	Consultancy, workshops, training and demonstration	200,000	MEIDECCC & Finance and National Planning			200,000	
3.6 Promote biodiesel & e-mobility	a. Consultancy, testing 10% biodiesel, demonstration, equipments and training b. Training of trainers on e-mobility	350,000	MoI & Agriculture	a. 4,500 b. 300		350,000	
3.7 Set vehicle registration and import tariff according to fuel consumption engine size and improve customer awareness	a. Consultancy, consultation meetings and workshops b. Introduce fuel economy labels, consultancy, training and consultation workshops	250,000 Sub-total 1,950,000		a. 5,700 b. 5,700 Total for Transport 102,700	250,000		
Result 4: **Activities** 4.1 Implement building standards (see 1.2).	Consultancy, workshops, training, equipments, demonstration, etc	300,000	MoI	1,100	300,000		
4.2 Conduct energy audits and implement the recommendations	Consultancy, workshops, training of trainers, equipments, demonstration, etc	500,000	AMREC supported by TPL and MEIDECC	700		500,000	

ACTIVITIES:	MEANS:	COSTS (IN USD):	RESPONSIBLE LEAD AGENCIES:	Modelled GHG Impacts (annual CO2e reduction by 2030)	Year 1 - 3	Year 4 - 7	Year 8 -10
					High	Medium	Low
4.3 Extend the PALS programme to include other appliances and promote use of solar water heaters	Consultancy, workshops, training, equipments, demonstration, etc	250,000	MEIDECCC, Chamber of Commerce, Consumer Division MTED	10,100	250,000		
4.4 Reduce TPL line losses to the identified optimum level, implement grid hardening measures & extend the Village Network and the underground cabling works	Consultancy, workshops, training, equipments, demonstration, etc	10,000,000	TPL			10,000,000	
4.5 EE Public awareness campaigns	Promotional materials, publicity and visibility events and promotions, transport, etc	250,000	MEIDECCC, TPL, NGOs	600	250,000		
4.6 Install mini-grid projects and RE systems with storage	Consultancy, equipments, trainings, meetings and workshops, awareness and promotion	10,000,000	TPL & MEIDECCC			10,000,000	
4.7 Change all streetlights and light at government premises to LED	Equipments, training, demonstration, awareness and visibility, etc	500,000	AMREC		500,000		
4.8 Implement a certification process for sustainable / green hotels by year 7	Consultancy, equipments, trainings, meetings and workshops, awareness and promotion	200,000	Ministry of Tourism			200,000	
4.9 Implement a cool roof programme	Consultancy, equipments, trainings, meetings and workshops, awareness and promotion	250,000	MoI				250,000
4.10 Establish a DSM revolving loan or rebate programme by 2030	Consultancy, trainings, meetings and workshops, awareness and promotion	500,000	Banks				500,000
4.11 Strengthen the planning and data collection and analysis capacity in the energy sector	Consultancy to draw up a IRP for TPL, workshops, equipments, training	250,000 Sub-total 23,000,000 **GRAND TOTAL 26,915,000**	TPL & MEIDECCC	Total for electricity 12,500 **TOTAL 115,200**	1,965,000	250,000 23,450,000	1,500,000

8 Conclusion

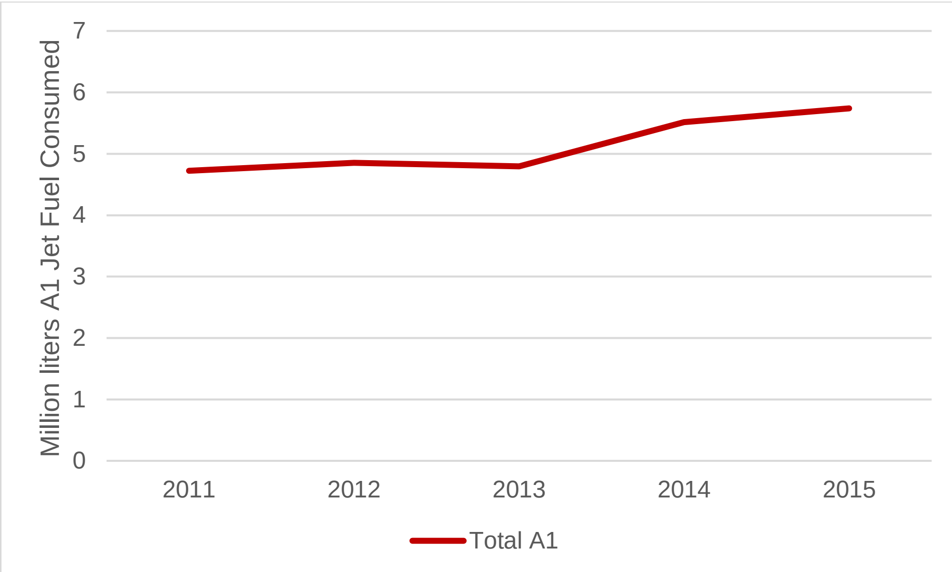
Through the outlined suite of policy options, a reduction of 50% a year by 2030 is possible using 2020 as the reference year. That represents a reduction from the BAU emissions of 210,000 metric tonnes of CO_2e. Action taken in the ground transportation field is responsible for 30.4% of the projected 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 polices 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 an institutional set up, similar to the TERM's, headed by MEIDECC, and members should include MOI, TPL, MCCTIL, PCREEE, Agriculture and Waste, 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 and also promote private sector investments in the TEEMP. The 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.

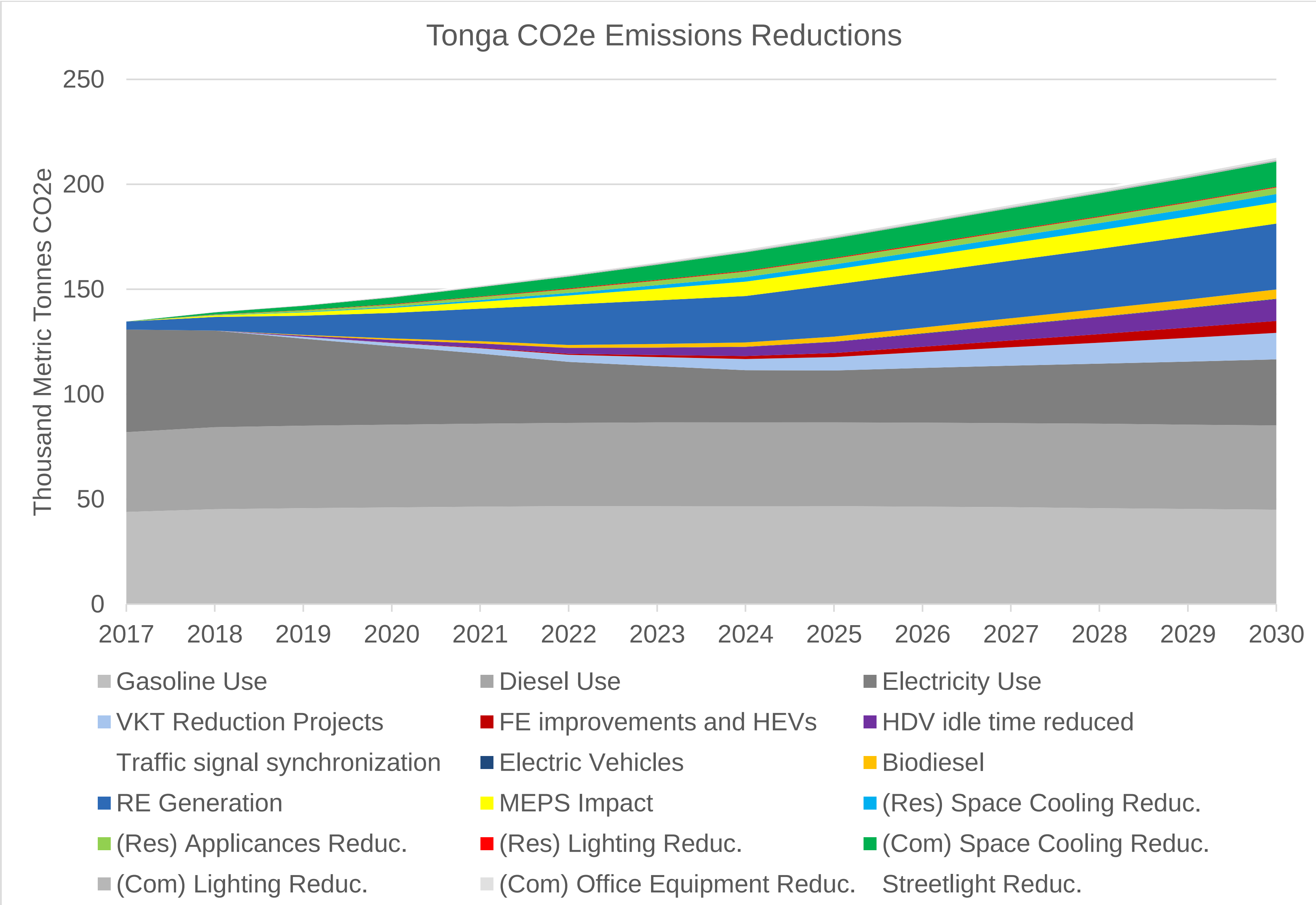
Appendix A. Supporting Documentation

Appendix Figure 1: Yearly A1 Jet Fuel Consumed in Tonga



Source: MTED Fuel Volume 2012-2015 Report

Appendix Figure 2: Tonga CO_2E Emissions Reductions with Sectoral Breakdown



Endnotes

[1] "Tonga Energy Road Map 2010-2020" (Government of Tonga, June 2010), 3, https://sustainabledevelopment.un.org/content/documents/1330tongaEnergy%20Strategy.pdf.
[2] Ibid.
[3]Ibid, 8.
[4] Government of Tonga, "Electricity Act" (2007), http://prdrse4all.spc.int/system/files/cap-32.12-electricity-act.pdf.
[5] Government of Tonga, "Renewable Energy Act" (2008), https://ago.gov.to/cms/images/LEGISLATION/PRINCIPAL/2008/2008-0010/RenewableEnergyAct2008_1.pdf.
[6] "Joint National Action Plan on Climate Change Adaption and Disaster Risk Management 2010-2015" (Ministry of Environment and Climate Change and National Emergency Management Office, July 2010), http://www.sprep.org/att/IRC/eCOPIES/Countries/Tonga/66.pdf.
[7] Government of Tonga, "Ozone Layer Protection (Amendment) Act of 2014," Pub. L. No. Act 2, accessed March 12, 2018, http://macbio-pacific.info/wp-content/uploads/2017/08/21A-OzoneLayerProtectionAmendmentAct2014.pdf.
[8] "Tonga Village Network Upgrade Project – Reduces Line Loss and Elevates Power Distribution," Tonga Power Limited, accessed March 12, 2018, http://www.tongapower.to/NewsRoom/tvnup_update_dec2012.aspx.
[9] "Tonga, Phase 2 Presentation" (Promoting Energy Efficiency in the Pacific, International Institute for Energy Conservation), accessed February 6, 2018, http://prdrse4all.spc.int/system/files/peep2_-_country_presentation_tonga.pdf.
[10] "Tonga Strategic Development Framework 2015-2025" (Government of Tonga, May 2015), http://www.finance.gov.to/sites/default/files/TSDF%20II_English_printed%20to%20LA%20on%2019May2015_0.pdf.
[11] "OIREP Invitation for Bids," Outer Island Renewable Energy Project, February 23, 2017, http://www.gov.to/wp-content/uploads/2017/03/1S1E-ICB-TPL-Vav-06-Invitation-for-Bids.pdf.
[12] "Tonga Renewable Energy Project (TREP), under the Pacific Islands Renewable Energy Investment Program" (Asian Development Bank, March 17, 2017), https://www.greenclimate.fund/documents/20182/893456/16450_-_ADB_-_Tonga_Renewable_Energy_Project__TREP___under_the_Pacific_Islands_Renewable_Energy_Investment_Program.pdf/76c24e30-4a86-4369-b9a8-7f699d77cf2c.
[13] University of Texas, available online at https://legacy.lib.utexas.edu/maps/islands_oceans_poles/tonga.jpg.
[14] "Annual Report" (Tonga Power Limited, 2014), 5–6, http://www.tongapower.to/Portals/2/Docs/AnnualReports/TPL%202014%20Annual%20Report.pdf..
[15] "TPL Tongatapu & 'Eua Distribution Network Restoration Plan" (Tonga Power Limited, 2018).
[16] "2017–2018 Tropical Cyclone Season Outlook for Tonga," ReliefWeb, October 25, 2017, https://reliefweb.int/report/tonga/2017-2018-tropical-cyclone-season-outlook-tonga-0..
[17] "Pacific Region Takes Spotlight at COP23," Fiji Times Online, accessed February 22, 2018, http://www.fijitimes.com/story.aspx?id=423172&.
[18] "Tonga 2016 Census of Population and Housing" (Tonga Statistics Department, October 2017), https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/07/07f43535eac99827825b1da8e2ee750c.pdf?sv=2015-12-11&sr=b&sig=dUQz%2FuwGZff6%2F763deG2siKIWj0xFKsnoOG9ijCV%2FvQ%3D&se=2018-12-17T02%3A48%3A42Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22Tonga_2016_Census_Report_Vol_1.pdf%22
[19] "Progress Toward Sustainable Energy Global Tracking Framework 2015" (PRDRSE4All, July 2016). http://prdrse4all.spc.int/data/progress-toward-sustainable-energy-global-tracking-framework-2015-gtf-2015
[20] Calculated from 2016 and 2017 TPL Annual Reports.
[21] Argonne National Laboratory. 2017. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model.
[22] "GREET Emissions Database," (Argonne National Laboratory, 2017) https://greet.es.anl.gov/
[23] "Tonga Country Energy Security Indicator Profile 2009," (Secretariat of the Pacific Community, Euei) https://issuu.com/jale-s/docs/tonga_country_profile
[24] "Tongatapu Monthly Usage," accessed March 13, 2018, http://www.tongapower.to/Customers/MonthlyUsuage/TongatapuMonthlyUsage.aspx.
[25] "Kingdom of Tonga: Electric Supply System Load Forecast" (Asia Sustainable and Alternative Energy Program, March 2010), 19, https://www.astae.net/sites/astae/files/publication/Tonga-Electric-Supply-System-Forecasts%5B1%5D.pdf.
[26] "Building and Service Control Division Website" (Tonga Ministry of Infrastructure) http://infrastructure.gov.to/building-control/
[27] "National Institute For Building Sciences Releases New Report," (NIBS) https://www.nibs.org/news/381874/National-Institute-of-Building-Sciences-Issues-New-Report-on-the-Value-of-Mitigation.htm
[28] "Deltec's Hurricane Proof Homes Weather the Storm," (Ecogen Pulse) http://www.ecobuildingpulse.com/projects/deltics-hurricane-proof-homes_o
[29] "Electrical Appliance Energy Labelling and Minimum Energy Performance Standards for Pacific Island Nations" (George Wilkenfeld and Associates, December 1996), https://s3.amazonaws.com/clasp-siteattachments/1996-12_PacificIslandLabelsMEPS.pdf
[30] "Energy Labelling and Minimum Energy Performance Standards for Appliances and Lighting: Impacts in Cook Islands, Fiji, Kiribati, Samoa, Tonga and Vanuatu" (Austalian Aid, 2016), http://prdrse4all.spc.int/sites/default/files/energy_labelling_and_minimum_energy_performance_standards_for_appliances_and_lighting-impacts_in_ci.fj_.ki_.sa_.to_.va_.pdf
[31] Tebbutt Research, "Survey of Consumer Awareness and Use of Energy Rating Labels in PICs: Tonga Country Report" (The Pacific Commuity)

[33] Lucas Davis and Paul Getler. "Contribution of air conditioning adoption to future energy use under global warming," PNAS. December, 2014. http://www.pnas.org/content/pnas/early/2015/04/22/1423558112.full.pdf
[34] "Electrical Appliance Energy Labelling and Minimum Energy Performance Standards for Pacific Island Nations" (George Wilkenfeld and Associates, December 1996), https://s3.amazonaws.com/clasp-siteattachments/1996-12_PacificIslandLabelsMEPS.pdf

[35] U.S. Department of Energy software, eQUEST. Available online at http://www.doe2.com/eQUEST/
[36] Yarmouth, Massachusetts lighting project information available at https://www.yarmouth.ma.us/1247/LED-Streetlight-Project
[37] Liisa Ecola et al., "The Future of Driving in Developing Countries," *RAND Corporation*, n.d., 138.
[38] National Reserve Bank of Tonga, "Vehicle Registrations," accessed March 19, 2018, http://reservebank.to/index.php/economic/vehicle-registrations.html.
[39] Ministry of Merchandise and Trade Statistics, "Foreign Trade Reports," 2008-2016.
[40] International dollars, also known as Geary-Khamis dollars, are based on purchasing power parity.
[41] Ecola et al., "The Future of Driving in Developing Countries."
[42] Ecola et al., "The Future of Driving in Developing Countries."
[43] Knoema, "Tonga GDP per Capita, 1980-2017," accessed March 19, 2018, https://knoema.com//atlas/Tonga/GDP-per-capita.
[44] New Zealand Ministry of Transport, "Transport Volume : Vehicle Travel," accessed March 19, 2018, http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv002/.
[45] Include citation "Generated Traffic and Induced Travel: Implications for Transport Planning," (Todd Litman, Victoria Transport Policy Institute, April 2018) www.vtpi.org/gentraf.pdf
[46] "Vehicle Fuel Efficiency (CAFE) Requirements by Year" (U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy), www.afdc.energy.gov/data/10562
[47] "Idling Reduction Savings Calculator, Backgroud Data". Argonne National Laboratory www.anl.gov/sites/anl.gov/files/idling_worksheet.pdf
[48] Argonne National Laboratory, Idele Base. http://cleancities.energy.gov/idlebase
[49] "Idling Reduction for Long-Haul Trucks: An Economic Comparison of On-Board and Wayside Technologies," (Argonne National Laboratory, September 2016) https://anl.app.box.com/s/ordxowhhcqrp7fe3yd3oy2fqpwt3fpiw
[50] Assuming that each person produces approximately 22 lbs. of waste grease per year. www.nrel.gov/docs/fy99osti/26141.pdf
[51] Winfried Scheewe, "Coconut Farm Diversification," Group of Advocates for Sustainable Agriculture Inc. 2003. https://c.ymcdn.com/sites/echocommunity.site-ym.com/resource/collection/f6ffa3bf-02ef-4fe3-b180-f391c063e31a/coconut_farm_diversification_gasa__engl2.pdf
[52] "Overview of the DOE VTO Advanced Battery R&D Program," (U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy, June 2016). https://energy.gov/sites/prod/files/2016/06/f32/es000_howell_2016_o_web.pdf
[53] "CAIT Country Greenhouse Gas Emissions: Sources & Methods" (World Resources Institute, June 2015) http://cait2.wri.org/docs/CAIT2.0_CountryGHG_Methods.pdf
[54] David C. Love et al., "Is the Three-Foot Bicycle Passing Law Working in Baltimore, Maryland?," *Accident Analysis & Prevention* 48 (September 2012): 451–56, https://doi.org/10.1016/j.aap.2012.03.002.
[55] "2016 Pedestrian Saftey Data," (NHTSA, February 2018) https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812493.
[56] Joanne M. Wood et al., "Using Reflective Clothing to Enhance the Conspicuity of Bicyclists at Night," *Accident Analysis & Prevention* 45 (March 2012): 726–30, https://doi.org/10.1016/j.aap.2011.09.038.
[57] "Compilation of State, County, and Local Anti-Idling Regulations" (Environmental Protection Agency, April, 2006) www.epa.gov/sites/production/files/documents/CompilationofStateIdlingRegulations.pdf
[58] "Biodiesel Benefits and Considerations" (U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy) https://www.afdc.energy.gov/fuels/biodiesel_benefits.html
[59] Cooperative Extension System. "Extension Economics of Small-Scale Biodiesel Production," March 2012. http://articles.extension.org/pages/30024/economics-of-small-scale-biodiesel-production
[60] Hanna Kalenoja, "Energy Consumption and Environmental Effects of Passenger Transport Modes—A Life Cycle Study on Passenger Transport Modes," Tampere University of Technology. 1996. Page 15.
[61] Tebbutt Research, "Survey of Consumer Awareness and Use of Energy Rating Labels in PICs: Tonga Country Report" (The Pacific Commuity)
[62] "Kingdom of Tonga: Electric Supply System Load Forecast" (Asia Sustainable and Alternative Energy Program, March 2010), 19, https://www.astae.net/sites/astae/files/publication/Tonga-Electric-Supply-System-Forecasts%5B1%5D.pdf.