The United Nation's Climate Technology Centre and Network

Government of Tonga: Baseline and Benchmarking Study

National Renewable Energy Laboratory
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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, at a cost equivalent to around 10% of total gross domestic product and transportation consumes 25 million liters. Dependence on imported fuels places Tonga in a vulnerable position due to volatile fuel and electricity prices. This study provides background information in order to set an energy and emissions baseline and establish a business as usual projection. Such projections help Tonga plan, prioritize, and coordinate their efforts to reduce fuel use and emissions. The data collection methods and sources highlighted in this report will also help Tonga track energy use and emissions in the future.

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. The goal of the TERM is 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 join effort among the Government of Tonga, the electricity generator and distributor Tonga Power Limited (TPL) and other development partners. The TERM focuses on 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.[1]

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)[2]
    - 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)[3]
    - Established a Renewable Energy Authority, consisting of members appointed by the Monarch-in-Council and tasked with the development of renewable standards, conduct research, relay international obligations to the monarch, and enforce violations of renewable energy policy against offenders.

[1] "Tonga Energy Road Map 2010-2020" (Government of Tonga, June 2010), 8, https://sustainabledevelopment.un.org/content/documents/1330tongaEnergy%20Strategy.pdf.
[2] Government of Tonga, "Electricity Act" (2007), http://prdrse4all.spc.int/system/files/cap-32.12-electricity-act.pdf.
[3] Government of Tonga, "Renewable Energy Act" (2008), https://ago.gov.to/cms/images/LEGISLATION/PRINCIPAL/2008/2008-0010/RenewableEnergyAct2008_1.pdf.

- Joint National Action Plan on Climate Change Adaption and Disaster Risk Management (2010)[4]
  - 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)[5]
  - 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.

- Tonga Village Network Upgrade Project (2012)[6]
  - Reduced line losses from 18% to 12% in 20 villages, working to expand to more.

- Promoting Energy Efficiency in the Pacific (2014)[7]
  - 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 Strategic Development Framework II (2015-2025)[8]
  - Extends the deadline of the 50% renewable goal from 2012 to 2025; 2020 for rural communities.
  - Achieve 12% T&D losses by 2020.
  - Short-term goal to convert 75% diesel-based water pumping systems in Tongatapu to PV.
  - Goal of 80% of retail stores to sell reliable CFL bulbs at "same cost".
  - Banning import of inefficient electrical appliances.
  - All inefficient electrical appliance banned at border control.

- Outer Island Renewable Energy Project (2017)[9]
  - 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)[10]
  - 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

[4] "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.
[5] 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.
[6] "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.
[7] "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.
[8] "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.
[9] "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.
[10] "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.

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.

To implement the TERM and identify the most cost-effective solutions, the Government of Tonga requested technical support through the UN's program, CTCN. This document provides a summary of the research the National Renewable Energy Laboratory (NREL) has conducted to establish a baseline of Tonga's energy usage for the Ministry of Meteorology, Energy, Information, Disaster Management, Climate Change and Communications (MEIDCC).

1.2 About Tonga

To understand the energy and transport sectors within Tonga it is important to understand the geographic location, demographics and governance structure of the nation. Tonga is in the Pacific Ocean 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.[11] During the average El Nino year, 1.88 cyclones affect Tonga, 1.63 in La Nina years, and 1.67 during neutral years.[12] 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 geographic distribution and being a series of remote islands 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 outlines some goals to address the challenges created by relying on imported goods and fuels.

Until 2010, a majority of the legislative assembly (21/30) were appointed by the Monarch or nobility. Following sizeable pro-reform rioting in 2006, it was announced in 2008 that the Monarch would relinquish much of its executive power, and that a majority of the legislature would be elected democratically. 'Akilisi Pōhiva campaigned on the promise of democratic reform and was elected Prime Minister in 2014. In August 2017, the King dissolved parliament without providing an explanation, in an apparent struggle over executive privilege with the Prime Minster. Pōhiva's party won a subsequent snap election in November 2017, but he has been dealing with persistent medical issues since that time. The Monarch remains a significant power-broker in Tonga and is largely revered by the population—policy changes, related to energy or not, are subject to the consideration of both the King and Prime Minister.[13] Both the King and Prime Minister are supportive of reducing Tonga's climate impact and improving the nation's energy independence. In a move symbolic of "wider leadership," the Monarch of Tonga joined

[11] "Annual Report" (Tonga Power Limited, 2014), 5–6, http://www.tongapower.to/Portals/2/Docs/AnnualReports/TPL%202014%20Annual%20Report.pdf..
[12] "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..
[13] Steven Ratuva, "Tonga," *The Contemporary Pacific* 30, no. 1 (2018): 204–13.

the Solar Head of State program at COPP 23 in November 2017. The program will install a rooftop PV system on the residence of the King, the first Royal Palace in the world to do so.[14]

The Legislature established a National Statistics Department in 2015 tasked with conducting a census and compiling administrative records of government departments.[15] While the availability of information from government ministries has markedly improved since the passing of this act, a lack of consistency of statistics reported year-to-year, and a difficulty in obtaining this information persists. These problems are also true for state owned enterprises such as TPL.

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%). The baseline study was conducted to determine where savings could be made within each of the sectors to assist Tonga in achieving goals established in various legislation and policies.

2 Electricity

TPL is responsible for generation, transmission and distribution of power 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 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 improve energy efficiency, increase energy conservation, and reduce peak electricity demand. Rebates, incentives and utility investments that improve building envelope, the efficiency of heating and cooling 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 requires 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 or 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 where less energy is consumed through technological improvements. An example is switching out incandescent light bulbs with more efficient compact fluorescent lighting or light emitting diodes, which provide the same amount of light, but produce less heat – creating a more efficient light bulb.

[14] "Pacific Region Takes Spotlight at COP23," Fiji Times Online, accessed February 22, 2018, http://www.fijitimes.com/story.aspx?id=423172&.
[15] "Statistics Act," Act 7 § (2015), https://ago.gov.to/cms/images/LEGISLATION/PRINCIPAL/2015/2015-0007/StatisticsACT2015_1.pdf.

To understand the opportunities for efficiency and conservation the grid system and energy consumption within Tonga are discussed in this section.

2.1 Generation, Transmission and Distribution

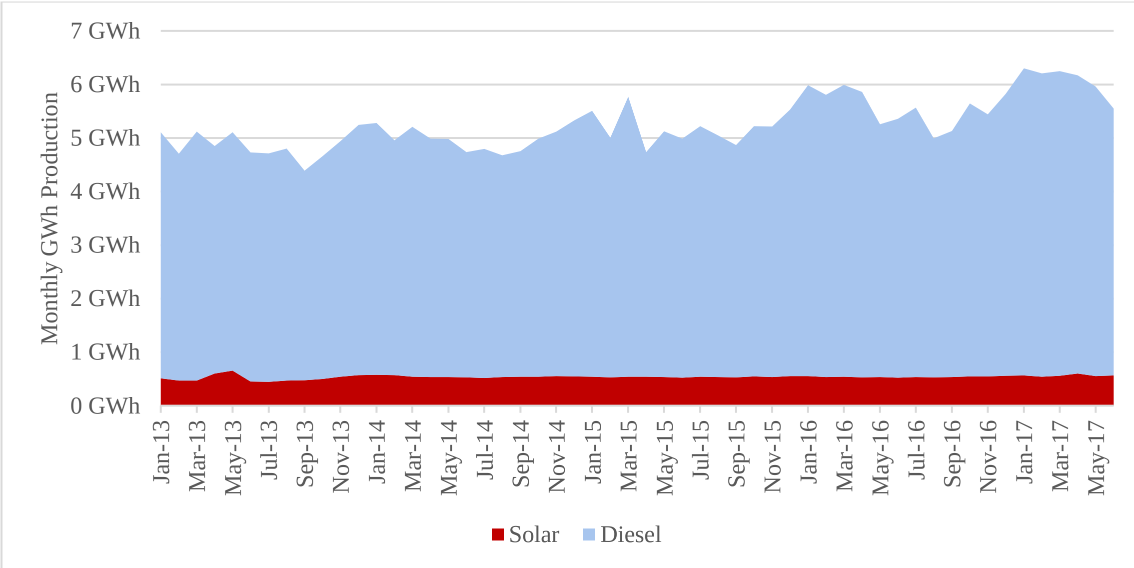
The 2017 installed capacity of the four grid systems is shown in the following table, by source, and grid type. Tongatapu's system represents the majority of the installed capacity, predominantly supplied by diesel fuel. As of June 2017, the total installed capacity on Tongatapu is 17.8MW, with 14 MW 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 ownership of electrical appliances. Two additional renewable projects are currently under construction: a 1.3 MW wind farm funded by the Japanese International Cooperation Agency (JICA), and a 2 MW PV project developed by Chinese investors through PPAs with TPL.

Table 1 2017 Installed Generation Sources

Location	Grid Status	Conventional Capacity	RE Capacity (MW)	BESS Capacity (MW)
Tongatapu	TPL Grid (11kV)	14.00 MW	2.80 MW	1.00 MW
Eua	TPL Grid (Medium Voltage)	0.37 MW	0.20 MW	
Vava'u	TPL Grid (Medium Voltage)	1.87 MW	0.42 MW	0.20 MW
Nomuka (Ha'apai)	Non TPL Grid (6.6kV)	0.09 MW	0.07 MW	
Ha'afeva (Ha'apai)	Non TPL Grid (6.6kV)	0.06 MW	0.07 MW	
Ha'ano (Ha'apai)	Non TPL Grid (6.6kV)	0.06 MW	0.07 MW	
Uiha (Ha'apai)	Non TPL Grid (6.6kV)	0.09 MW	0.07 MW	
Household Generators (Tongatapu)	Off grid		0.05 MW	
Household Generators (Ha'apai)	Off grid		0.06 MW	
Household Generators islands (Vava'u)	Off grid		0.13 MW	
Household Generators (Niuas)	Off Grid		0.04 MW	
TOTAL		**16.55 MW**	**3.98 MW**	**1.20 MW**
Source: TPL Existing Installed Capacity (June 2017)				

Figure 1 below demonstrates 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 1 Energy Generation Mix for Tonga (Monthly kWh)



Source: TPL Monthly Generation Data (June 2017)

Voltages vary between the four grid systems and transmission and distribution losses vary, as well. Voltages for each island are as follows:

> Tongatapu: 11kV for primary distribution; three phase: 415V; single phase: 240V
> Vava'u, Ha'apai, and 'Eua: 6.6kV for primary distribution; three phase: 415V; single phase: 240V

Most of the primary distribution network on all islands is aerial lines supported by wooden poles from trees harvested on the island of 'Eua. The exposure of these wooden poles 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.

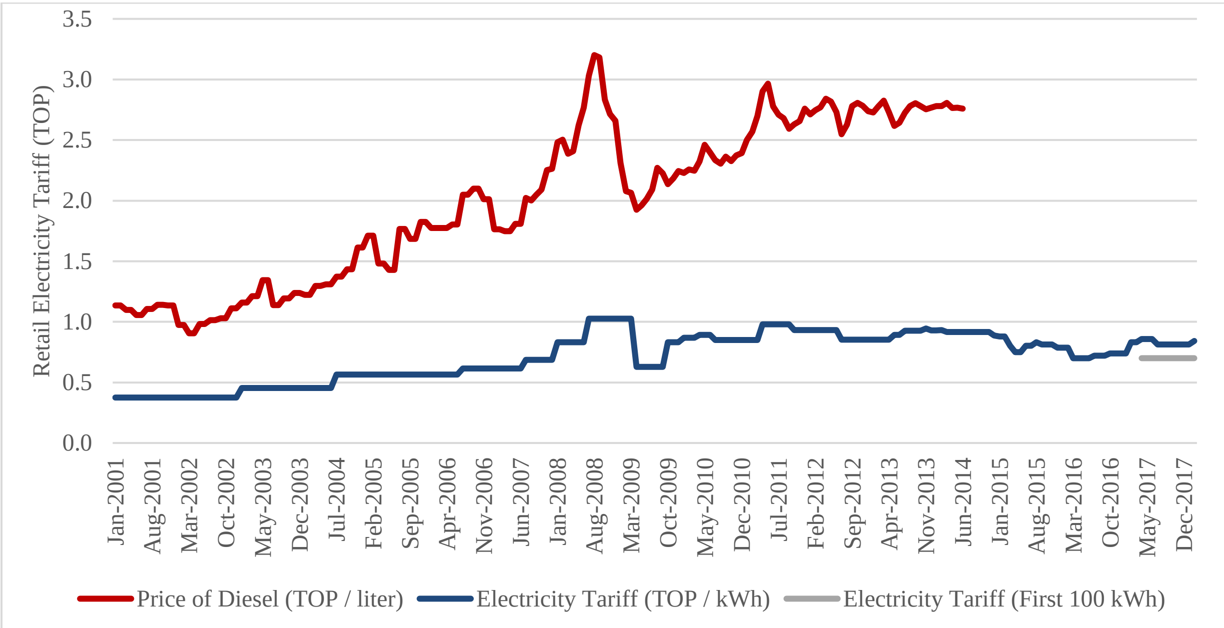
Table 2 Transmission and Distribution Losses

	TPL (Total)			Tongatapu			Vavau			Haapai			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 electricity vary due to dependence on imported diesel fuel, however in 2009 TPL changed the structure across the four islands to create a more uniform pricing structure, 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). In a 2017 survey of Tongans by the Pacific Community, only 13.2% of respondents were aware what the approximate tariff rate was.[16] Figure 2 below 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 stymie the impact of increasing rates on consumers, the government introduced a Line Tariff, with a fixed rate at 0.7 TOP for the first 100 kWh of monthly consumption, applicable to all customers.

Figure 2 Electricity Tariff and the 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 without having the meter replaced or disconnection fees 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 sent out to the customers (i.e., the difference between the power generated and the power consumed by the end-user).[17]

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[16] Tebbutt Research, "Survey of Consumer Awareness and Use of Energy Rating Labels in PICs: TONGA COUNTRY REPORT" (The Pacific Community (SPC)), 23, accessed February 22, 2018, http://prdrse4all.spc.int/sites/default/files/09_pearl_-_tonga_country_report_d9.pdf.

[17] "Tongatapu Monthly Usage," accessed March 13, 2018, http://www.tongapower.to/Customers/MonthlyUsuage/TongatapuMonthlyUsage.aspx.

2.2 Consumption

Census figures indicate the population in Tonga is 100,651, as of 2016. 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 92.3% of the population had access to electricity.[18] 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 9.2% growth in new customer accounts between 2016 and 2017. TPL does not report electricity consumption by sector, but they do report that 4,750 (21%) of their customers are commercial.[19] There are two peak demands during the week with a peak in the mornings and another later in the afternoon and evening. 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. Wet and dry seasons show a shift in demand due to higher temperatures, as well.

The buildings sector is one of the main energy consumers in the world, contributing around 40% of the total energy consumption, with heating, ventilation and air conditioning systems (HVAC) systems being the biggest contributors. In tropical areas such as Tonga, cooling in buildings has become critical where the buildings are sealed and not open, especially in offices, supermarkets, banks, etc. The use of mechanical HVAC systems are 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 the 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 three areas that are commonly associated with the highest energy consumption: appliances, building design, and street lighting.

2.2.1 *Appliances*

In order to understand energy profiles, ownership of appliance data from Census data was analyzed. The 2016 Population Census indicates there are 18,005 private households in Tonga with Tongatapu having the largest population of 12,953 private households. As mentioned previously, 92.3% of the households are electrified. The majority of appliances used in households are refrigerators, freezers, air conditioning units, televisions, lighting and washing machines. Most cooking is done using propane gas, therefore is not included in the electric appliances breakdown. Households with electric appliances and the types of goods are summarized in Table 3.

Table 3 Households with Electric Appliances

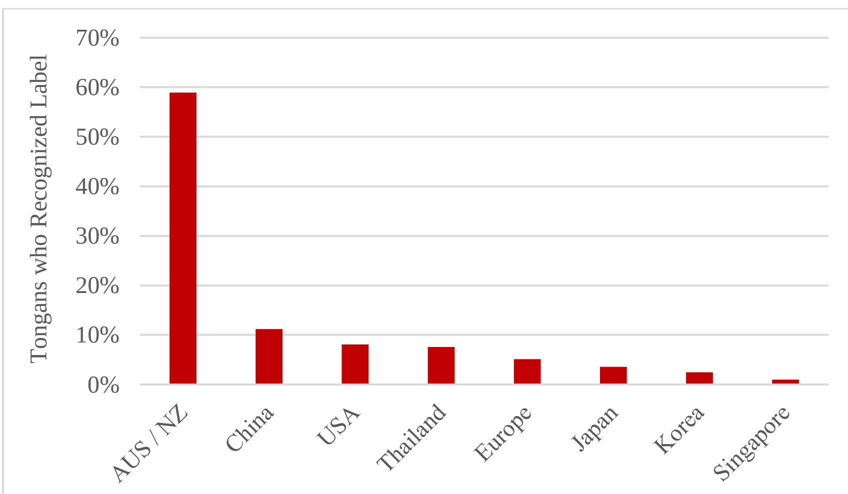
Appliance	Number of Households with Good	Total Number of Goods	Percent of Households with Good
Cell Phones	15929	41082	88%
Washing Machine	13947	14374	77%
TV	13147	14858	73%
CD/DVD Player	10414	11400	58%
Fridges	8959	9502	50%
Freezer	7144	7620	40%
Laptops	6791	8887	38%
Land Line Phones	4720	4720	26%

[18] "Progress Toward Sustainable Energy Global Tracking Framework 2015 (GTF 2015)," accessed March 13, 2018, /data/progress-toward-sustainable-energy-global-tracking-framework-2015-gtf-2015.
[19] "Annual Report" (Tonga Power Limited, 2017), 24, http://www.tongapower.to/Portals/2/Docs/Final%20AR_201617.pdf.

Tablets	3204	4314	18%
Sewing Machine	3110	3337	17%
Desktop Computer	1576	1822	9%
Generator	946	1002	5%
Solar Panel	755	896	4%
Air Condition	329	481	2%
Source: 2016 Census			

Due to the remote location of Tonga appliances are imported from Australia and New Zealand or from Fiji, China and Singapore. The Minimum Energy Performance Standards 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 the products may be less expensive if they're imported from Asia or through Fiji, which means the number of appliances being brought in with less stringent energy standards is higher – thus contributing to the overall energy load with appliances and electronics. In a 2017 Pacific Community (SPC) survey of Tongans, 58.9% 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 TV advertisement. Figure 3 below shows the percent of respondents who recognized an energy performance label by source country when prompted with an example.

Figure 3 Energy Performance Labels by Tongan Recognition



Source: Tebbutt Research, 2017 (page 18-20)[20]

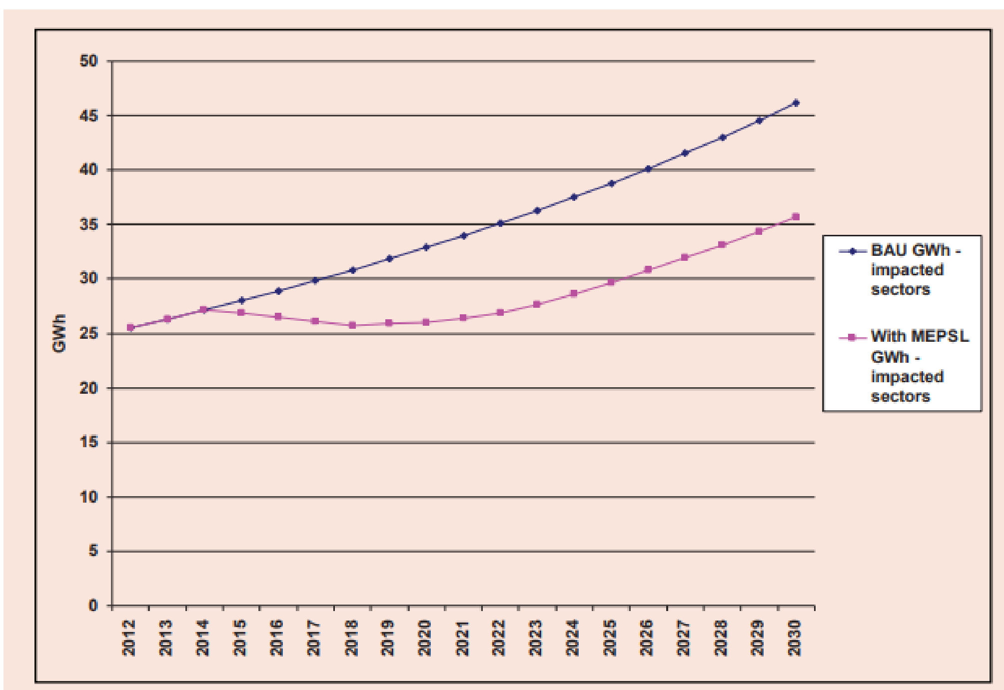
[20] Tebbutt Research, "Survey of Consumer Awareness and Use of Energy Rating Labels in PICs: TONGA COUNTRY REPORT."

Figure 4 Various Energy Efficiency Labels

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

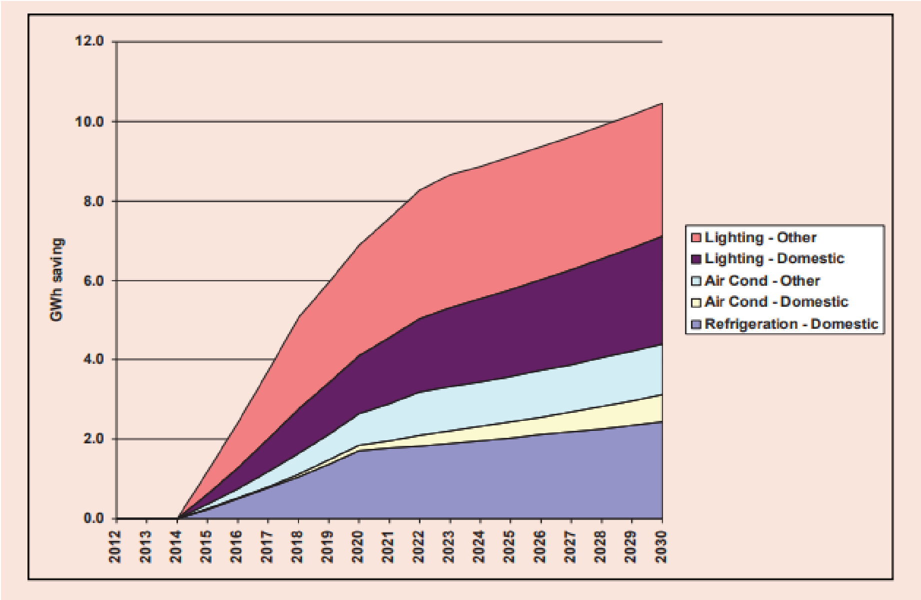
In an assessment funded by Australian Aid, scenarios were formulated around the business as usual (BAU) activities in Tonga and implementing minimum performance standards for lights and appliances. Scenarios were used to compare the energy savings in GWh consumed through 2030. Implementing MEPs early on will achieve a 10GWh savings by 2030, as shown in Figure 5.[21]

Figure 5 BAU and MEP Scenario for Tonga through 2030



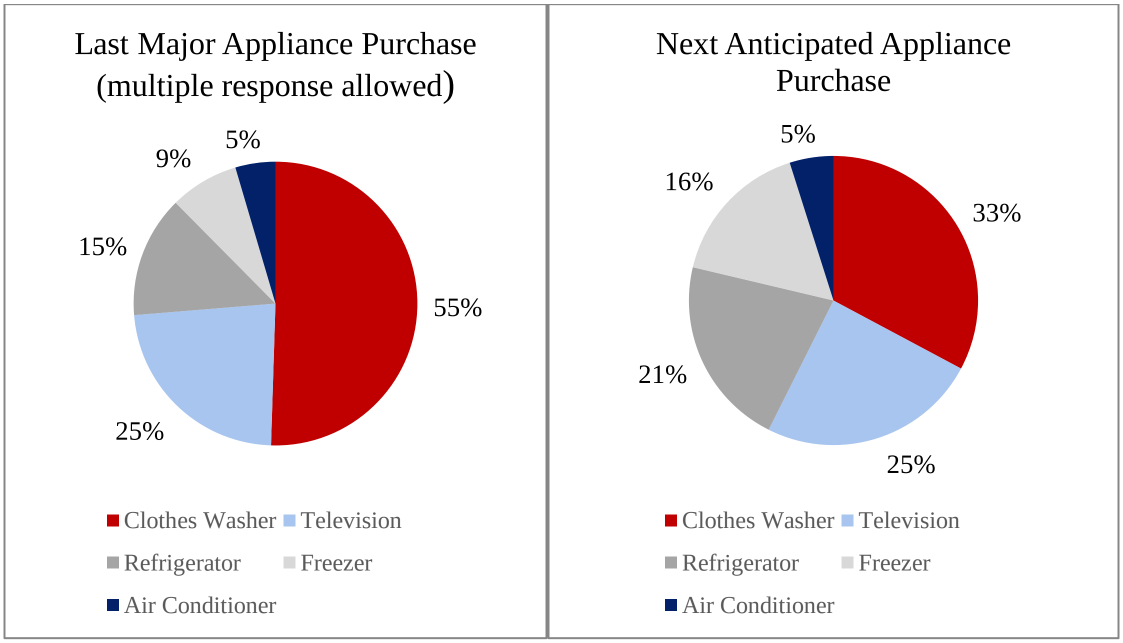
In the same analysis, the energy savings were calculated for each appliance and lighting type, as shown in Figure 6. Based on baseline conditions in the 2016 published report, the greatest energy savings achieved through MEPs is related to lighting, air conditioning and refrigeration.

Figure 6 Energy Savings by End-Use associated with MEPs in Tonga



This analysis, coupled with information on the next major appliances expected to be purchased can lead to further anticipation of MEPs savings. Clothes washers, televisions, refrigerators and freezers make up the majority of 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 7 and Table 4 give an indication of the current appliances installed and anticipated appliances to be purchased.

Figure 7 Tongans Reported Last Major Appliance Purchase (left) and Next Anticipated Appliance Purchase (right)



Source: Tebbutt Research

Table 4 Appliances Imported by Country of Origin

Item	Country of Origin	Number Imported (2009-2017)	Percent of Imports
Air Conditioner	New Zealand / Australia	325	0%
	Singapore	15	29%
	China / HK / Taiwan	985	60%
	Other	2025	24%
Fan	New Zealand / Australia	6137	2%
	Singapore	510	32%
	China / HK / Taiwan	8455	42%
	Other	10941	28%
Freezer	New Zealand / Australia	3423	7%
	Singapore	825	38%
	China / HK / Taiwan	4641	26%
	Other	3172	53%
Fridge	New Zealand / Australia	3281	14%
	Singapore	853	7%
	China / HK / Taiwan	433	26%
	Other	1594	11%
Stove or Oven	New Zealand / Australia	209	6%
	Singapore	116	34%
	China / HK / Taiwan	673	50%
	Other	990	10%
Solar Components	New Zealand / Australia	1555	0%
	Singapore	57	34%
	China / HK / Taiwan	5132	56%
	Other	8447	40%
Water Heater	New Zealand / Australia	325	2%
	Singapore	16	26%
	China / HK / Taiwan	206	32%
	Other	256	0%
Source: Import statistics 2009-2017, Tonga Ministry/Department of Statistics			

Goods were observed to be labeled in retail spaces in October 2017, indicating the amount of energy that might be consumed, which is a good practice.

Figure 8 Refrigerators with AUS/NZ (left) and Singaporean (right) Energy Labels in Tonga

Source: EE-Pacific PEEP2

2.2.2 *Building Design*

Typical energy consumption in each sector 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. TPL's largest customer is a single Church of Latter-day Saints complex built in 2007, which uses an average of 116,000 kWh / month, or 3 – 3.5% of the total billed consumption on Tongatapu.[22] This level of consumption indicates a different architectural design (e.g., closed windows and doors) with higher 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. Offices 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.

Energy efficiency improvements in new and existing buildings require skills to identify, evaluate, design and ultimately to implement energy efficiency measures in buildings. Different types of buildings require different skills, with residential buildings being fairly straightforward and uniform, whereas commercial and industrial buildings have more complexity and are varied. There are typically more retrofit opportunities than new construction opportunities because the building stock "turns over" very slowly; with perhaps 10 times as many retrofit opportunities as new construction. Energy auditing and improved construction codes can lead to improvements in the energy consumption of buildings. Training can help prepare energy auditors, but there is no substitute for experience and the best auditors have a long background in system installation or operation and maintenance. An auditor identifies, measures and evaluates them in terms of technical feasibility and cost-effectiveness.

Once an auditor identifies measures, a designer can be engaged to specify the size and type of replacement components and detail how the measure will be implemented in construction drawings and specifications. The design is often let for bid and the project implemented by building trades such as electrical, mechanical, lighting, refrigeration/air conditioning/ and control system contractors. A commissioning agent may be engaged to ensure that the retrofit system is operating according to the

[22] "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.

intent of the design. Due to the fact that opportunities are distributed within buildings, and varied and detailed in nature, it requires a lot of labor to deliver benefits compared to central renewable energy plants, but the benefits are robust and permanent. The best kWh is a kWh not used, and efficiency is recognized as a prerequisite to sizing renewable energy systems. Renewable energy and the appropriate controls and system designs within buildings may also be needed to meet supply-side management and resilience goals.

Building codes were implemented in Tonga in 2007. The Building Control Division (BCD) 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 general public and its related clients are to be updated of 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." One way in which the goals can be met is through updating building codes to include energy efficiency.

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. 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, etc.). It is recommended that climate change considerations be incorporated into building codes along with energy efficiency requirements, which will also help with sustainable development and lower poverty levels associated with energy bills and recovering from severe climate-related events.

Some considerations for Tonga are to create setback zone guidelines in a coastal setbacks policy to protect buildings from sea level rise and increasing storm surges, elevated structures may be needed in certain areas to protect from the same threats, and requiring installation of attached features, such as roofing materials or solar PV panels to 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 also 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, no more than two stories tall, etc.)
- Passive survivability techniques to reduce energy consumption and allow the building to be occupied without power (e.g., natural daylighting, natural ventilation, rainwater collection, etc.)
- 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, etc.)

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.

2.2.3 *Street Lighting*

The last major sector of energy in Tonga is street lighting. Tonga does not use traffic lights, opting for energy efficient roundabouts, which is a great practice. The street lighting installed is typically near town or village centers and along major junctions or intersections. A program exists to switch older, less efficient street lights have been converted to higher efficiency LED lamps to save energy. According to various reports, Tonga replaced the following number of street lights 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

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

3 Transportation

The analysis in this section focuses on land transportation because that is the most clearly allocated to Tonga, it is the most under Tongan control, and it is growing at a much faster rate than aviation fuels (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.

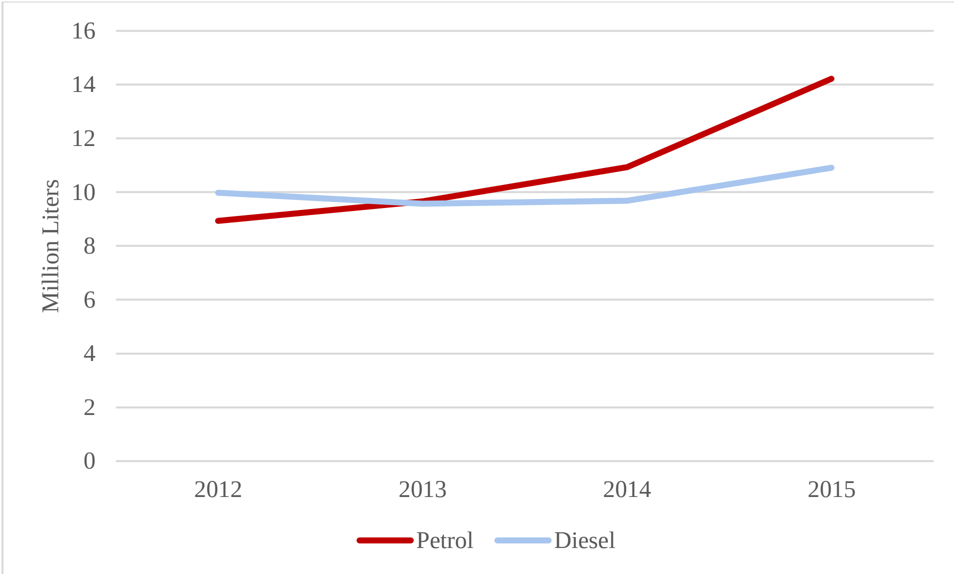
3.1 Tonga Transportation Fuel Baseline

The baseline for Tonga's transportation activities and fuel consumption are summarized in this section.

3.1.1 *Land Transportation Fuel Usage*

Fuel usage has been tracked and compiled by the Ministry of Commerce, Consumer, Trade, Innovation, and Labour (MCCTIL). Starting in 2012, they divided their petroleum into petrol, diesel, Jet A1, and Kerosene and they divided their 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.

Figure 9 Land Transportation Fuel Usage in Tonga



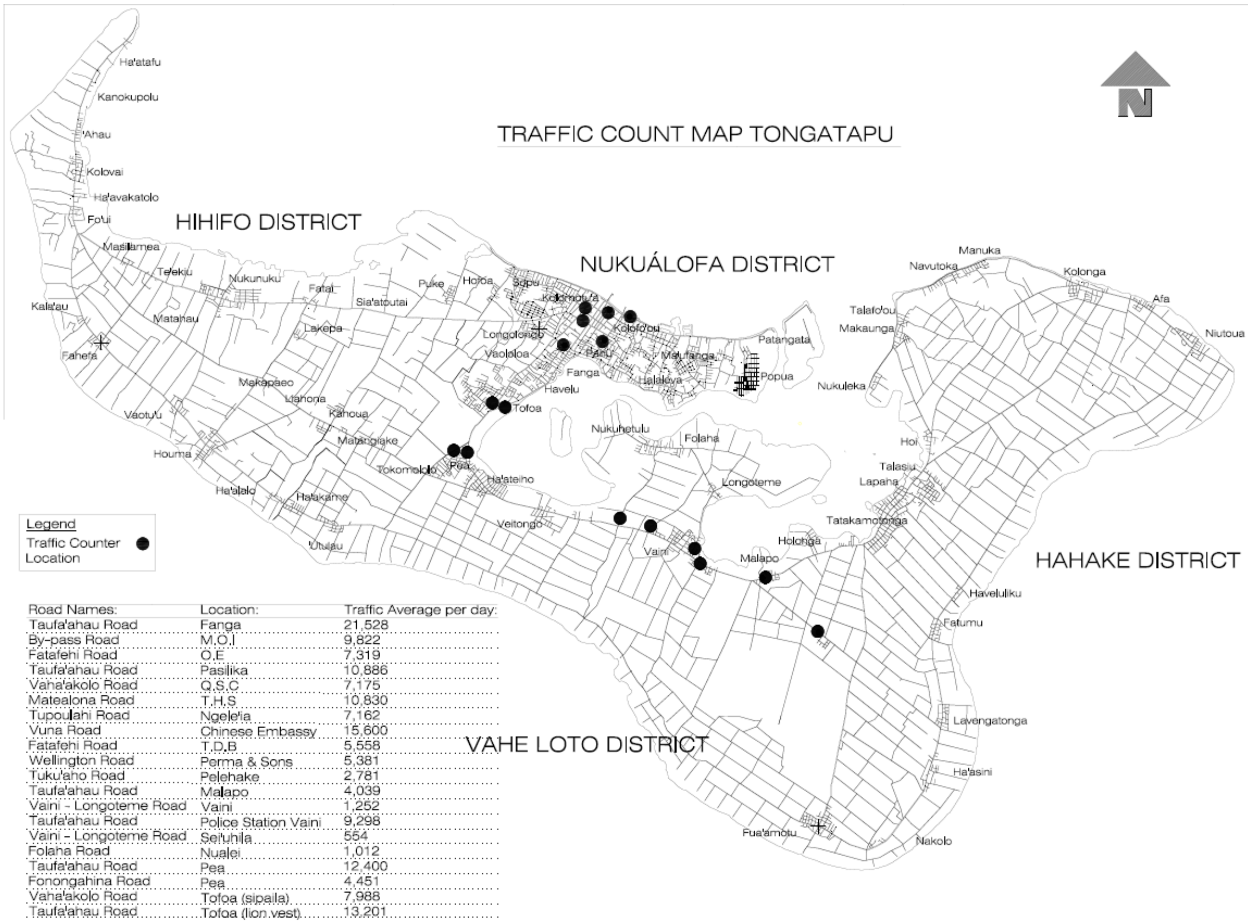
Source: MCCTIL Fuel Volume 2012-2015 Report

3.1.2 *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 below.

Figure 10 Traffic Count Map of Tongatapu



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

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 5 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 5 Traffic Counts, Traffic Destinations and Daily VKT on Tongatapu

Road	Counter Location	VEH's/day	Destination A	Km's 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 Faloha on to Vietongo and Coast
** There were no counters in the Hihifo or Hahake districts. See text for how the vehicle numbers were estimated.

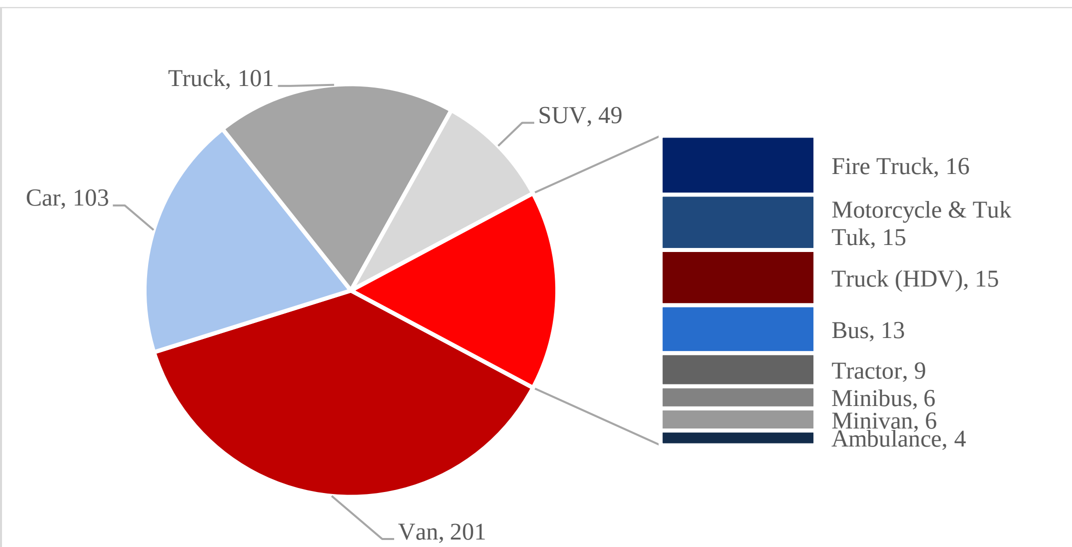
The results of Table 5 are that Tongatapu sees 545,531 VMK every day. Assuming that they see this flow 6 days per week, this aggregates to nearly 171 million VKT every year. In order to extrapolate from Tongatapu to all of Tonga, a linkage was made between VKT to fuel use. 15% of land transportation 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 GDP and other parameters.[23] Furthermore, when one divides the fuel used in Tonga by this VKT, you see that the average vehicle sees a fuel consumption rate of 12.5 L/100km—a figure that is quite realistic for the vehicle population.

3.1.3 *Vehicles*

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

1. Census data of household goods (2011 and 2016). 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 and government vehicles. Furthermore, it's vehicle types aren't 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.[24] 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 11.

Figure 11 Government Vehicle Inventory by Type



Source: Ministry of Infrastructure 2016/17 Government Vehicle Inventory

[23] Liisa Ecola et al., "The Future of Driving in Developing Countries," *RAND Corporation*, n.d., 138.
[24] National Reserve Bank of Tonga, "Vehicle Registrations," accessed March 19, 2018, http://reservebank.to/index.php/economic/vehicle-registrations.html.

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.[25]
5. The "government vehicles" category was replaced by the better data we have on government vehicles, and these vehicles were allocated to their weight-based categories.

Table 6 Tally of Vehicles in Tonga by Type

Vehicle Type	# 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 as if we had based the calculations 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.

3.1.4 *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.

[25] Ministry of Merchandise and Trade Statistics, "Foreign Trade Reports," 2016 2008.

The Ministry of Infrastructure has provided yearly data on the number of domestic vessels 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.

4 Business-as-Usual Projections

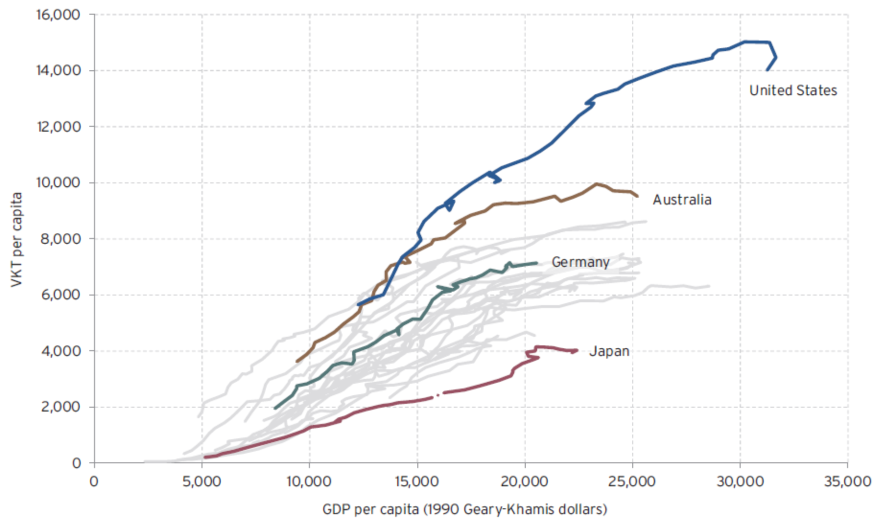
In order to identify areas of reduction and effectiveness of various conservation scenarios it is important to create business as usual (BAU) projections. Where data was available the information was used to create historic trend lines to help with projections. Where data was not available for both the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

4.1 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[26]) is between $5,000 and $20,000 USD.[27] In other words, this is the range where VKT growth is on the steep part of the S-curve (see Figure 5 below). Tonga's per-capita GDP crossed into that zone in 2015 (see figure 6). 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.

[26] International dollars, also known as Geary-Khamis dollars, are based on purchasing power parity.
[27] Ecola et al., "The Future of Driving in Developing Countries."

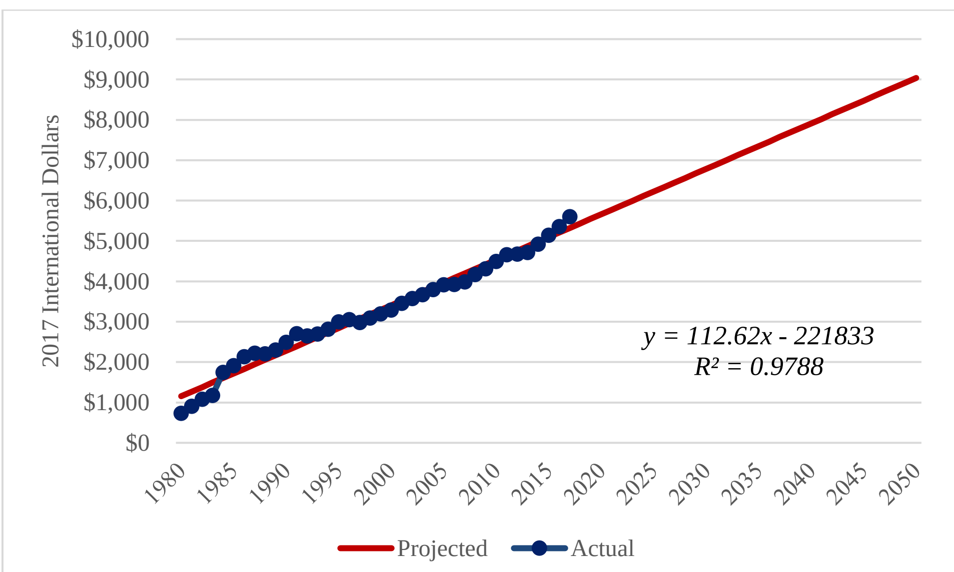
Figure 12 VKT of Motorized Passenger Travel and per-capita GDP for 22 Developed Countries



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 (Rand 2014), 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 13 (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 13 Tonga per-capita GDP with Purchasing-Power Parity



Data Source: Knoema Tonga GDP per-capita[28]

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

[28] Knoema, "Tonga GDP per Capita, 1980-2017," Knoema, accessed March 19, 2018, https://knoema.com//atlas/Tonga/GDP-per-capita.

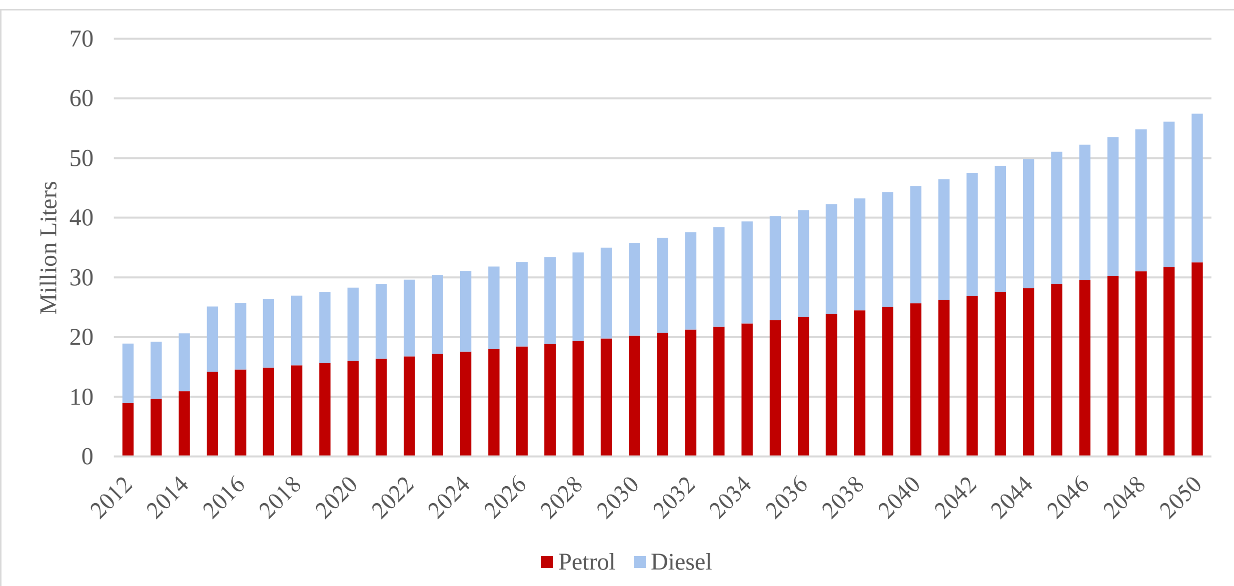
includes passenger travel. In the New Zealand, 23.6% of the total VKT are freight, so it is assumed that this ratio is the same for Tonga.[29] Subtracting 23.6% from the total VKT of Tonga leaves 1,750 VKT of motorized passenger travel per year.

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 12). 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, when Tonga has 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 5 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 12 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 23.6% 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 14. 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% gasoline and 43% diesel.
4. Tonga's growth in VKT, and its growth in fuel use, grows at 2.4% per year, compounded annually.

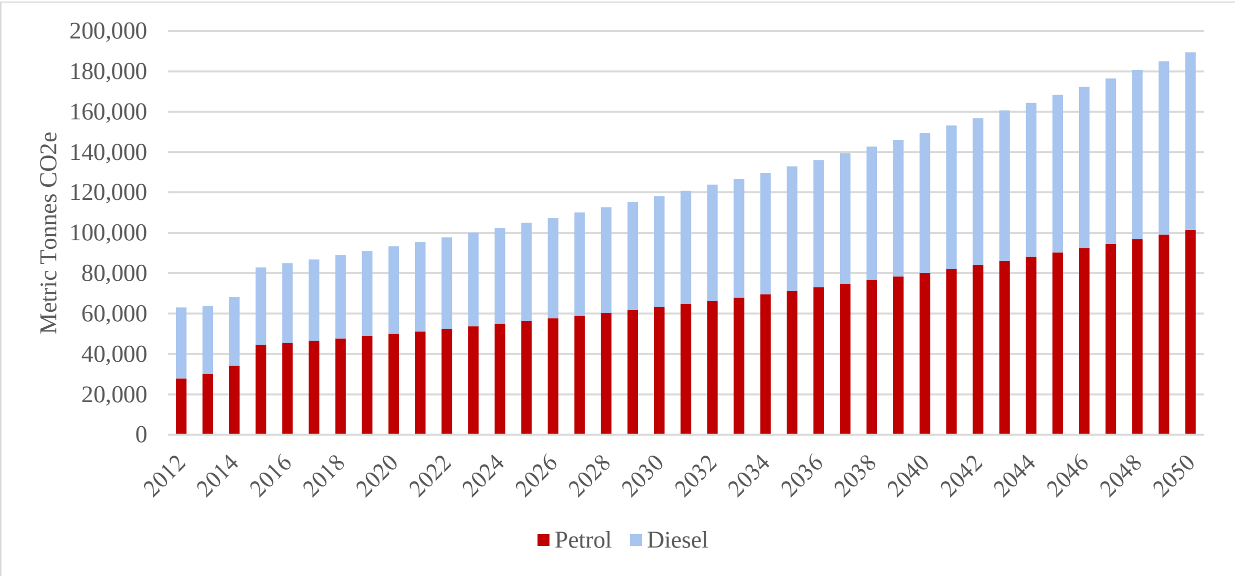
Figure 14 Tonga BAU Transportation Fuel Usage



[29] New Zealand Ministry of Transport, "Transport Volume : Vehicle Travel," accessed March 19, 2018, http://www.transport.govt.nz/ourwork/tmif/transport-volume/tv002/.

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 15.

Figure 15 Tonga BAU Land Transportation GHG Emissions



4.2 Tonga Energy Business-as-Usual Projection

Using a similar methodology to the one in followed for the transportation BAU, an energy BAU projection was created. Rather than using purchasing power parity (PPP), the energy BAU is based on kWh consumption and generation by population then brought to the common metric of CO_2e emissions. While PPP is useful for transportation related purchases it is more challenging to quantify for energy purchases when the market is controlled by imports and vary from island to island. As electrification rates increase in rural areas in all of the island chains the population served may be a more accurate representation of anticipated energy growth.

Using historic data provided by TPL, as well as the Tongan Ministry of Statistics, and projected data from the United Nations (shown in Table 7 below), an average kWh per person metric was determined.

Table 7 Projected Population Growth in Tonga

Year	Population	Growth Rate
2020	111,037	0.00%
2025	115,793	0.84%
2030	121,055	0.89%
2035	126,596	0.90%

Year	Population	Growth Rate
2040	131,906	0.83%
2045	136,387	0.67%
2050	139,926	0.51%

Source: World Population Prospects (2017 Revision)

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 8. 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 9. Projections in the TERM indicate an estimate of projected growth by 2020 of 28% from 2010 consumption levels. Due to the volatility in fuel prices, consumption and generation levels may vary. As a result, a realistic BAU is difficult to ascertain for the purposes of projecting energy consumption and energy needs. For the purposes of estimating a BAU a MWh billed per customer metric was established using TPL data from annual reports and extrapolated to overlay the metric on projected population growth.

Table 8. 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
Population (millions)	0.103	0.103	0.103	0.104	0.104	0.104

Source: TERM

Table 9. 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%

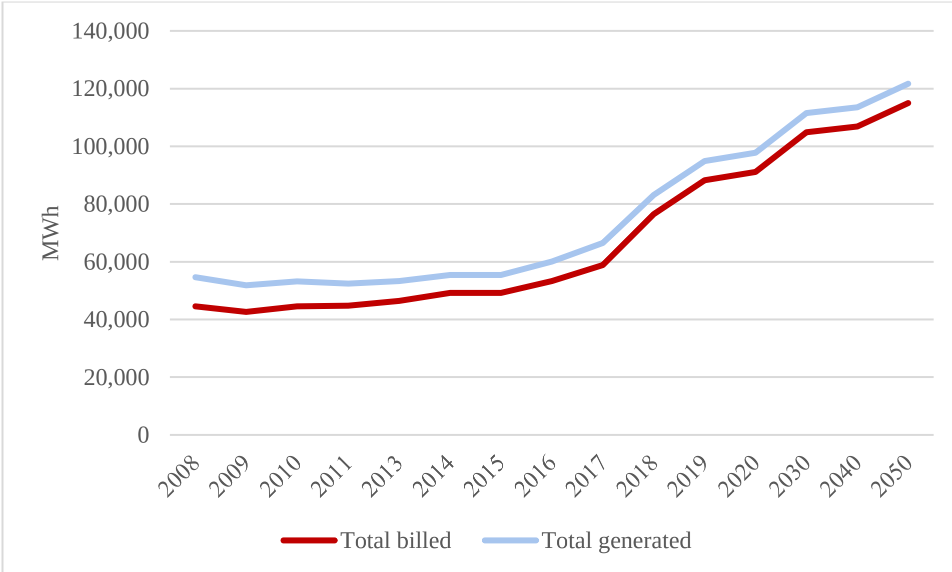
Based on projected population growth of ~2,000 people every decade, the customers served was estimated with a slight increase year on year due to an increase in electrification rates and a decrease in line losses. The projections of total customers served is shown in Table 10. The historic data for 2010 is shown in white cells and the projections are shown, based on assumptions listed, in the gray cells for 2020 through 2050.

Table 10 Projected Generation and Consumption (MWh) by Decade

	2010	2020	2030	2040	2050
Total billed (MWh)	44,566.23	91,140.00	104,860.00	106,820.00	114,996.00
Total generated (MWh)	53,159.57	97,835.29	111,555.29	113,515.29	121,691.29
Customers	20,758.00	29,400.00	29,960.00	30,520.00	31,080.00
MWh billed per customer	2.15	3.10	3.50	3.50	3.70

Figure 16 shows the projected growth in energy consumption with a “do nothing” approach or business as usual for Tonga as a whole. This is not shown by island grouping.

Figure 16 Projected Changes in Electricity Consumption in Tonga

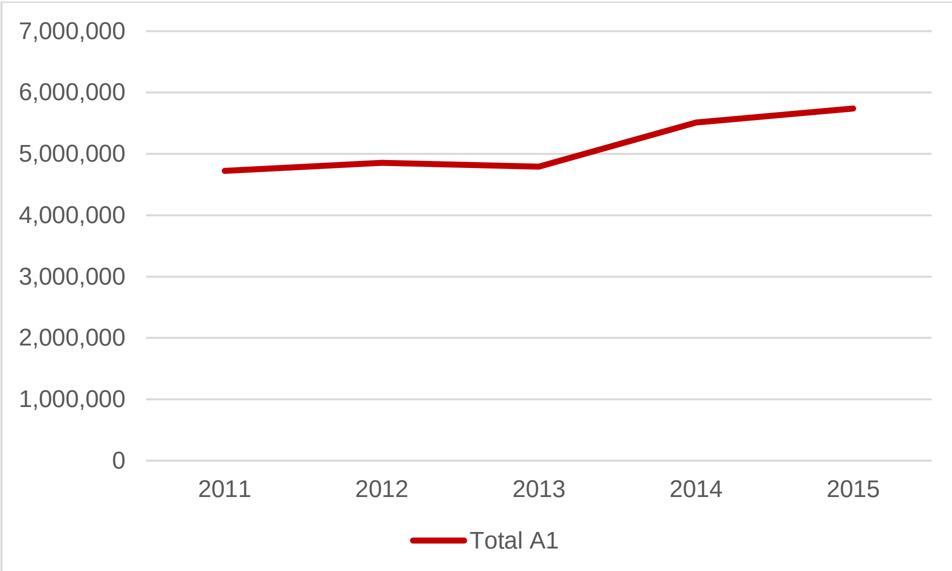


Acronyms

BAU	Business as Usual
GHG	Greenhouse Gas
GOT	Government of Tonga
INDC	Intended Nationally Determined Contribution
NREL	U.S. Department of Energy National Renewable Energy Laboratory
TPL	Tonga Power Limited
VKT	Vehicle Kilometers Traveled

Appendix A. Supporting Documentation

Appendix Figure 1: Yearly A1 Jet Fuel Used in Tonga



Source: MCCTIL Fuel Volume 2012-2015 Report