

**2013 Third Professional Year Project**

**Power System for Tonga: Developing Demand and Consumption Forecasting Tool**

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## **Abstract**

This report delivers steps taken to develop Tonga electricity power demand and energy consumption forecasting analysis. Both quantitative and qualitative analysis is used to identify the factors that affect electricity consumption and demand of Tonga. Explanation is also given of the Tonga electricity market. The analysis of the factors is then used to project the future consumption and demand of the electricity for short, medium and long term.

# 1. Introduction

The Kingdom of Tonga consists of 176 islands scattered around the Pacific Ocean. The kingdom has four groups of islands; Tongatapu, Ha'apai, Vava'u and Niua. Tongatapu is the main island and it is located in the southernmost part of Tonga. Ha'apai is a group of islands that is located north of Tongatapu and south of Vava'u. The northernmost part of Tonga is called Niua. According to the Tongan department of statistics, 74% of Tongan population is located on the main island, Tongatapu [1]. The concentration of the population on Tongatapu Island increases the infrastructure and economic development of the island. To date, Tongatapu Island is the biggest consumer of electricity in Tonga with 14,650 customers [2]. Ha'apai and Vava'u each have a smaller population compared to Tongatapu. Thus, the consumption of electricity at those islands is smaller compared to the main island.

Tonga Power Limited (TPL) is the power company that is responsible for generating, transmitting, distributing and maintaining the power infrastructure in Tonga [2]. TPL manages four grid systems that are located in Tongatapu, Ha'apai, Vava'u and Eu'a Island. Each grid system is different in size depending on the population of the island. Tongatapu is the biggest consumer of energy as it has the largest population. It also has a more complex system compared to the other islands that have less population. Details about the power network for the four different grid systems are shown in Table 1:

Table 1: Tonga Power System [2]

Island	Tongatapu	Vava'u	Ha'apai	E'ua
Generation	12.68MW	1.27MW	372kW	372kW
Transmission Line	11kV	6.6kV	415V	415V
Customer	14650	3201	998	1062
Annual Consumption (By 2012)	38.38GWh	2.17GWh	1.23GWh	0.94GWh

This report presents a load forecast analysis for Kingdom of Tonga as a whole, as well as by region. It relates the patterns of energy consumption and power demand to other parameters, such as the economy, demography and price. Each analysis is heavily influenced by the quality of the data.

## 2. Background

Forecasting analysis is a common practice in the business world to predict and project the future condition and situation of a market. In the power industry, this practice helps a company to make important decisions in future investment. The analysis is not about producing an accurate result as future is unpredictable, it is merely about getting a perspective of the future trend of the electricity market. The practice involves data collection, data processing, and data analysis. The projection is then be made from the output of the data analysis. Figure below shows the basic steps of forecasting.



*Figure 1: Steps of Forecasting Analysis*

### 2.1 Data Collection

Analysing Tonga electricity demand and consumption is a challenging task. There are issues in getting data, how much past data is available and how reliable the data are. The data types that will be used to predict future consumption of electricity depend on the availability and the reliability of the data itself. Tonga does not have the same level of data recording and archiving as compared to developed countries. Thus, the first step in analysing the future demand and consumption of electricity in the Kingdom of Tonga is to identify the factors that can significantly affect the power demand and energy consumption.

#### 2.1.1 Key Driver

A Key driver is a factor that strongly influences the electricity demand and consumption. There are lots of parameters that can be used to compare with demand and consumption of electricity, however, the parameters must be sensible, useful and accessible. Transpower electricity demand forecast model report uses the following measures as the key drivers for New Zealand Electricity demand analysis [3]:

- Economy (measured by GDP)
- Demographics
- Electricity Price
- Embedded Generation
- Energy intensity

All the key drivers show a considerably high correlation with the electricity demand and consumption in developed and developing countries. In a small developing country such as Kingdom of Tonga, the dynamics of the electricity market are different compared as to these countries. However, there is a reasonable amount of data that is accessible for the Tonga electricity demand and consumption forecasting analysis using the key drivers used by Transpower, except embedded generation.

## 2.1.2 Data Availability

Each of the related institute records the data from the census that has been made. Different data sources provide different time scales of data. A short time scale for electricity consumption and demand data will increase the uncertainty for the forecast. Each type of data came from a difference source as shown in Table 2.

Table 2: Various Sources of Data and their type

Data Source	Data Type	Time scale
<b>Tonga Power Limited</b>	Electricity Consumption	2006 – 2013
	Power Demand (Tongatapu)	2007 – 2012
	Electricity Price	2002 – 2013
<b>National Reserve Bank of Tonga</b>	Gross Domestic Product (GDP)	2003 – 2011
<b>Tongan Department of Statistics</b>	Population (National and Regional)	1986 – 2011
<b>The World Bank [4]</b>	GDP and Population	1982 – 2011
<b>International Monetary Fund (IMF) [5]</b>	GDP and Population	1980 – 2011

## 2.1.3 Data Reliability

The reliability and the quality of the data is one of the issues when working with a developing country. The Kingdom of Tonga has its own unique issues regarding the reliability of the data.

- Lack of interest in a having data source is one of the main factors of that affects the quality of the data.
- The transition in the power utility management from the Shoreline Group to Tonga Power Limited in 2008 caused a loss of technical data such as power demand and electricity consumption [2].
- TPL is also facing a serious issue with meter tampering which affects the reading of the actual consumption
- GDP data also has a numberof versions and variations. There are a lot of big organizations that produce an estimation of the country GDP to assist foreign investors.

The poor quality of data affects the quality of the forecast. However, there are factors that can improve the quality of the data.

- Multiple sources of data will improve the quality of the analysis, as they verify each other
- TPL has an extensive program of meter upgrade and data monitoring to mitigate the meter tampering issue and indirectly improve their measurement and revenue.
- A longer time scale for each data set will offset the errors by providing a better trend analysis.

## 2.2 Data Analysis

There are two type of analysis that been undertaken for the forecasting; quantitative and qualitative analysis [6]. Both types of analysis compliment each other for a better perspective of the analyzed data. Quantitative analysis uses statistical tools to give a mathematical analysis of the model. Qualitative analysis interprets the result made by the quantitative analysis, giving reason to the mathematical and statistical models used. Both methods go hand in hand in the analysis.

### 2.2.1 Quantitative analysis

This component of the analysis quantifies the factors and trends of the demand and consumption of electricity. Two main statistical tool were used to quantify the behaviour of electricity demand and consumption; time series analysis and regression analysis. Both types of tool provide a better understanding of the power demand and consumption trends and factors.

#### 2.2.1.1 Time series analysis

The main type of analysis used to analyse the demand and consumption of energy of the Kingdom of Tonga is time series analysis. The tool examines the data pattern for a certain period of time. The historical data is then used to project the future demand and consumption depending on the mathematical model used to project the data [7].

In this part of the analysis, getting high quality archived data is important. A reliable source of data will improve the quality of the forecast that will be produced. Getting good and reliable archived data is a challenging task, nevertheless, it is a nature of working with a developing country. Reasonable amounts of archived data were collected from various resources. The collected data for time series analysis is shown in Table 2.

Every data set has a different available period of time recorded. The pattern and trend of the plotted data were fitted with a ‘Trendline’. A trendline is a line drawn through the data points that will explain the behaviour of the data through a period of time. The line generally linear or exponential. The line forms a mathematical representation of the data trend throughout the given time.

The Mean Absolute Percentage Error (MAPE) will then measure the level of fitness of the trendline to the data [8].

$$M = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right|,$$

where,

$A_t$  = actual value

$F_t$  = Forecast value

$n$  = number of fitted points

The formula shows how the data compares to the mathematical model. A high value of  $M$  indicates a high percentage error.

### 2.1.1.2 Regression Analysis

Regression analysis is a statistical approach to find the relationship between two variables. In this report, regression analysis was used to find the relationships between the Tonga electricity demand and consumption and the key drivers discussed in section 2.1.1. Table 3 shows the list of data used to correlate with electricity demand and consumption:

Table 3: Establishing the electricity consumption and demand with difference factors

Dependent	Independent
Electricity Consumption	Economy (GDP)
Electricity Consumption	Electricity Price
Electricity Consumption	Population
Power Demand	Economy (GDP)
Power Demand	Electricity Price
Power Demand	Population

Determining which factors that will affect the electricity demand and consumption is the main focus in regression analysis. Different types of regression analysis can be used to establish the relationship between two variables. In this report, two types of regression were used to quantify the relationship between the independent and dependent variables; linear and exponential regression.

i) Linear Regression [8]

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, \quad i = 1, \dots, n.$$

where,

- $y_i$  = dependent variable
- $x_i$  = independent variable
- $\beta_0$  and  $\beta_1$  = parameter
- $\varepsilon_i$  = error term
- $n$  = data point

ii) Exponential Regression [9]

$$y_i = \beta_0 e^{x_i}, \quad i = 1, \dots, n$$

where,

- $y_i$  = dependent variable
- $x_i$  = independent variable
- $\beta_0$  = parameter
- $n$  = data point

The variation between the regression line and the actual data is used to calculate the correlation coefficient,  $R^2$ . The correlation coefficient has a range value from zero to one. When  $R^2$  is equal to one, it indicates that the regression line perfectly fits the data, while zero  $R^2$  indicates that the two variable does not have any relationship. While  $R^2$  establishes a relationship, it does not establish causation [10]. To establish causation, underlying signs need to be observed.



### 2.2.2 Qualitative analysis

Qualitative analysis is an interpretation of the graph and mathematical model made in the quantitative analysis. In time series analysis, a history of the Tongan political situation can be reflected on the trend. News from the local media is used to relate any event with the changes in the power demand and consumption trends. From there, key drivers will be determined and compared to the electricity demand and consumption. The key drivers may or may not affect the demand and consumption. Relative comparison will be used to identify the contribution of any factor with the changes in demand and consumption trends.

### 2.3 Data Projection

Assuming that the past electricity demand and consumption trends hold true in the future, a projection of future data can be undertaken to predict future demand and consumption. Uncertainty of the projected data increases, the further the projection is made. Short, medium and long term forecasts will be determined from the data projection. The quality of the analysis will be considered before any projections are made.

## 3. Results and Discussion

Microsoft Excel data analysis package had been used to analyse the data. Each of analysis in this section is elaborated with explanation about the significant contribution and the reasoning behind the mathematical and statistical tools used.

### 3.1 Time series analysis

#### 3.1.1 Electricity consumption trend

The electricity consumption in this report includes both national and regional level of analysis. The past consumption data plot in time and a mathematical model is fitted to the curve to establish a relationship. The goodness of fit of the model is shown by the correlation coefficient,  $R^2$ . The model is then used to project the future electricity consumption of Tonga.

##### *i. National Analysis*

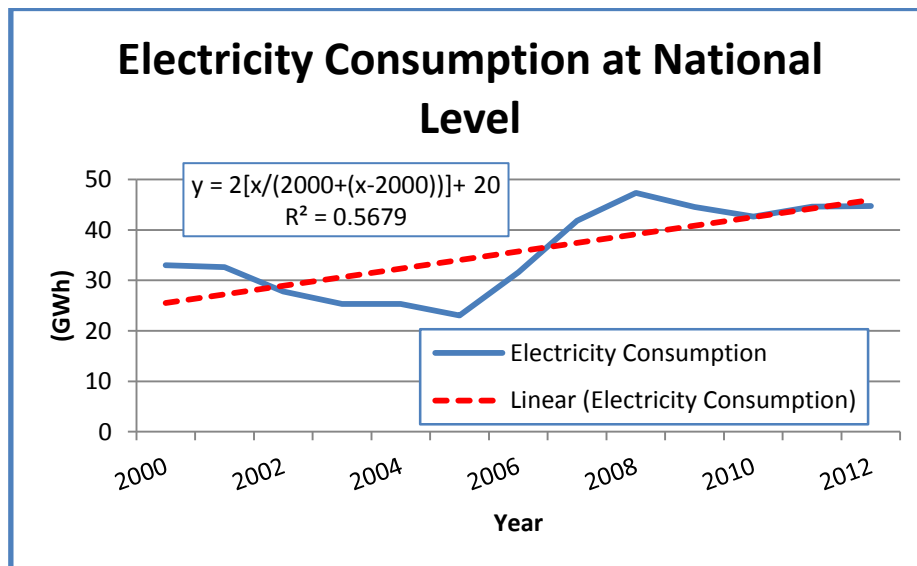


Figure 2: Electricity Consumption of Kingdom of Tonga

Figure 2 shows the electricity consumption trend from the year 2000 until 2012. The electricity consumption decreases steadily from 2000 until 2005. From 2006, the consumption increases significantly up to 47GWh. After that, the consumption is relatively unchanged after 2008. Across this total period of time, a linear correlation can be made of the consumption trend. There is a considerable goodness of the linear model to the data with correlation coefficient equal to 0.5679. The established linear relationship is then used to project the future consumption of electricity in the Kingdom of Tonga at national level.

**ii. Tongatapu**

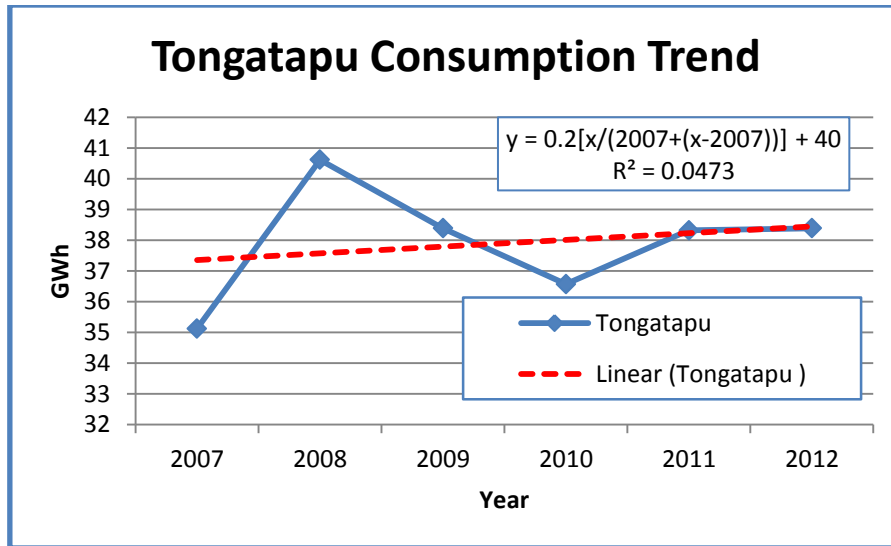


Figure 3: Electricity Consumption of Tongatapu

Compare to the analysis at the national level, the data available for Tongatapu electricity consumption only covers from year 2007 to 2012. The correlation coefficient of the linear trendline shows less correlation between the linear trendline and the data. The reduction of data size increases the uncertainty of the projected data. Nevertheless, the electricity consumption trend of Tongatapu Island is similar to the national level from 2007. The dominance of the island in electricity consumption is reflected by the number of the population and the economic activity that occurred in the island. Hence, a similar mathematical model can be used to forecast the electricity consumption for the Tongatapu Island as for the national level.

iii. *Vava'u*

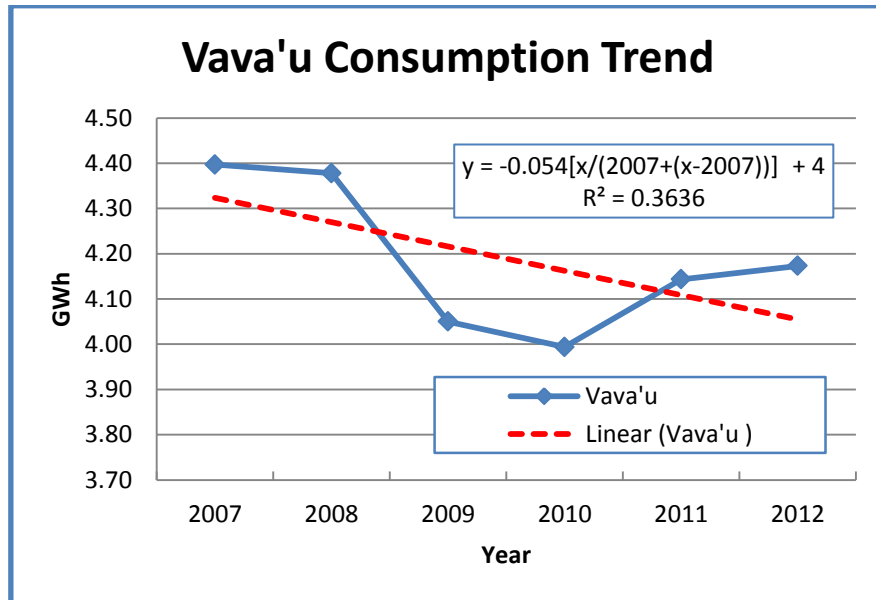


Figure 4: *Vava'u* electricity consumption

The Vava’u region shows a significant reduction in electricity consumption from 2007 until 2010. The consumption increases after 2010. Simple linear regression further clarifies the decline trend of electricity consumption in the future. Reduction of consumption at Vava’u is possible as the population of the island has steadily decreased since 2006 [1]. However, the increase of consumption from 2010 indicates the promising growth of consumption in the future. The electricity consumption of Vava’u will have a slower growth in the future.

iv. *Ha'apai*

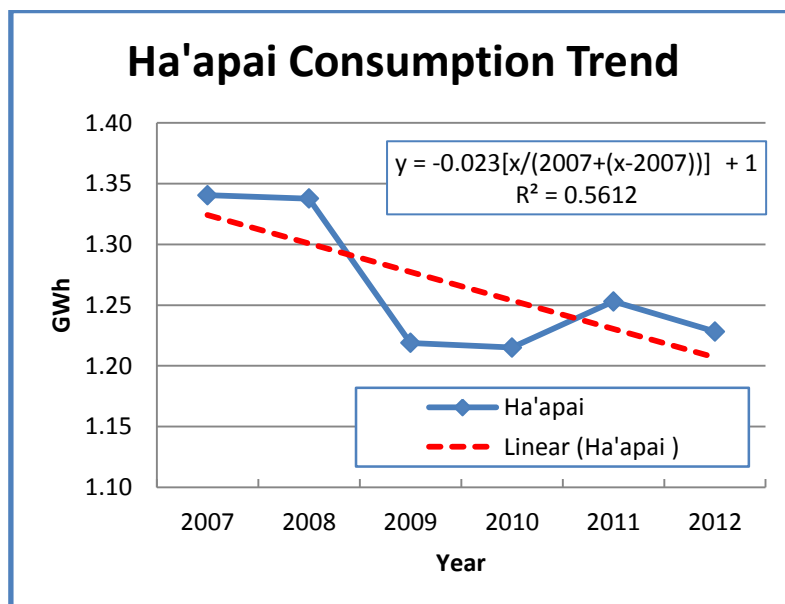


Figure 5: *Ha'apai* electricity consumption trend

The overall electricity consumption trend for the Ha’apai region shows a steady decrease. Even though there is an increase in consumption during 2011, it decreases in 2012. A simple linear regression shows negative correlation. The steady decrease of consumption can be explained by the steady decline of population of the region since 1986 [1].

v. 'Eua

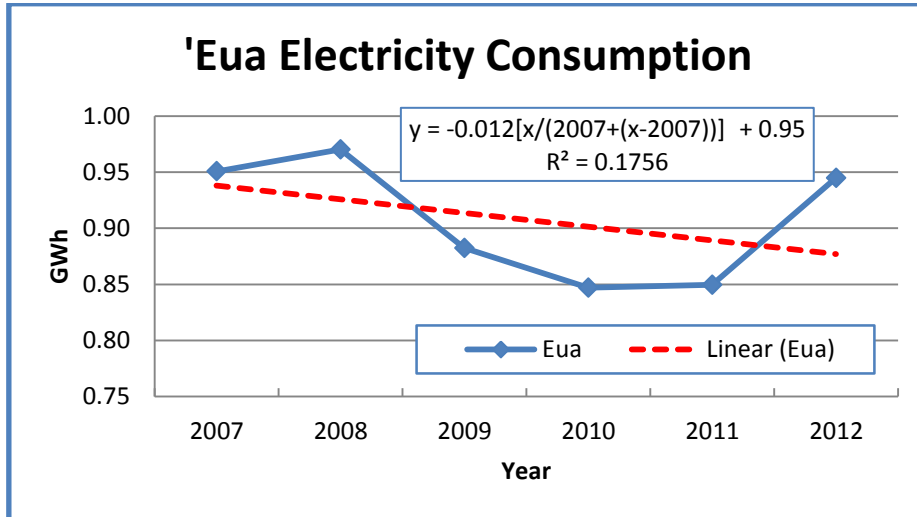


Figure 6: 'Eua electricity consumption trend

'Eua Island have similar consumption trend compare to the other outer island except in 2012. According to the local source, the increase of consumption was contributed by the construction of a resort. The construction skewed the overall trend of the island electricity consumption. Nevertheless, a slower growth of consumption is expected in the future.

### 3.1.2 Power demand trend

The only available data for power demand analysis is collected from Popua power station, generation station for Tongatapu Island. Since Tongatapu Island is the biggest consumer of electricity, the power demand trend for the national level can be approximated from the power demand of Tongatapu Island. The collected data is then plotted and shown in figure 7.

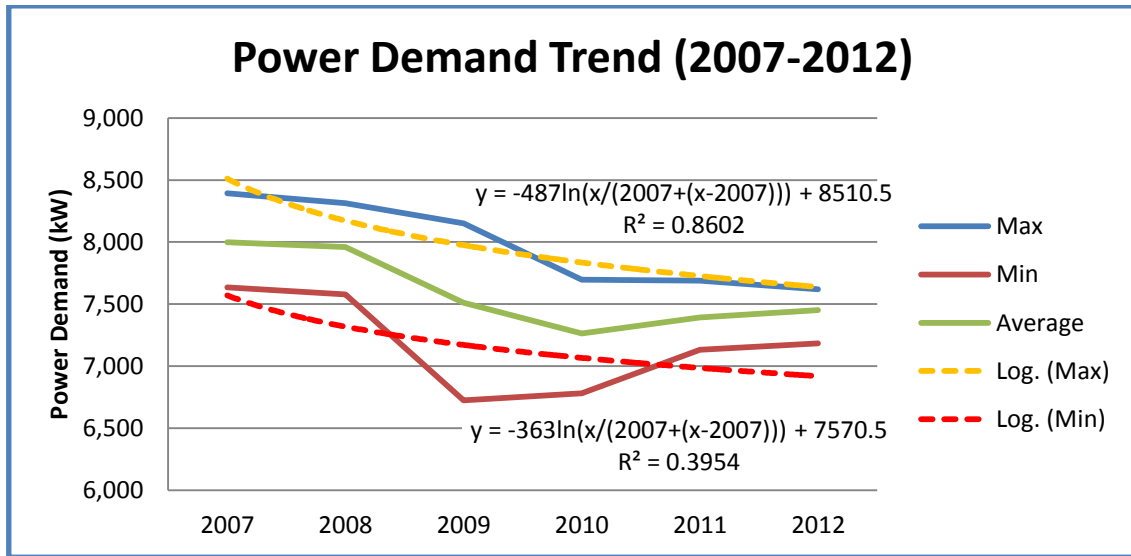


Figure 7: Tongatapu Power Demand Trend

The overall power demand trend is decreasing for the past five years. Statistically, the trendline clarify the qualitative observation as the trendline equation show declining pattern. The declination of the trend can be explained by the effort of the TPL to reduce power demand by improving the efficiency of the appliance and upgrading the cooling and ventilation system of the government office [2].

### 3.2.3 Energy Intensity

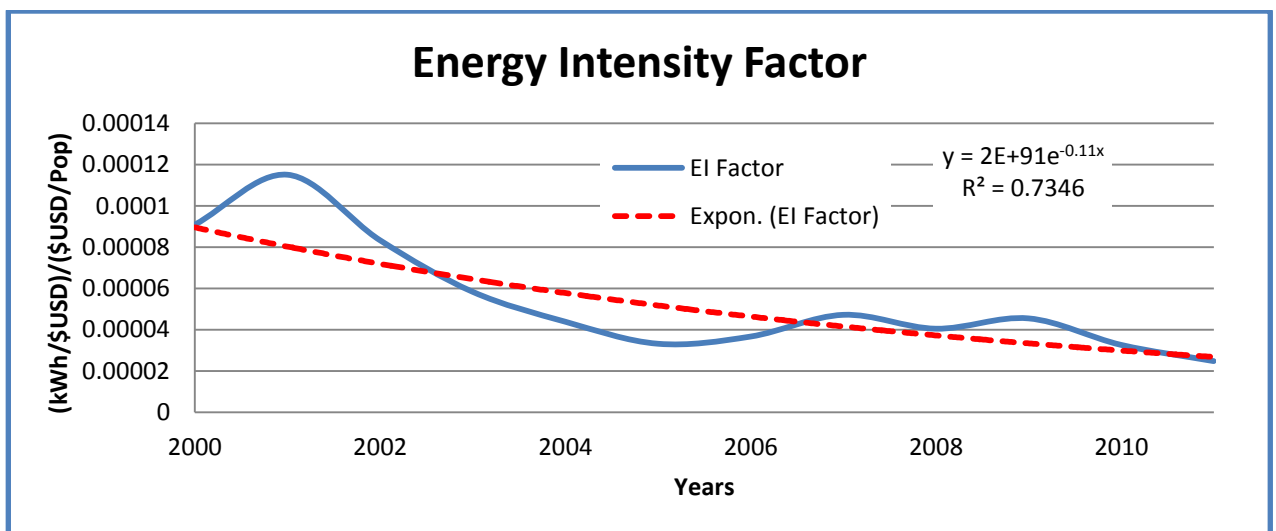


Figure 8: Energy Intensity Factor

Energy intensity is type of analysis that shows the efficiency of the energy use to produce GDP [11]. The trend is decreasing by the time goes by. Figure 14 indicates that Tonga electricity consumption become more efficient by the time goes. If the trend continues in the future, a slower growth of electricity consumption will be observed in the future.

## 3.2 Regression Analysis

### 3.2.1 Electricity consumption

#### i. Economy

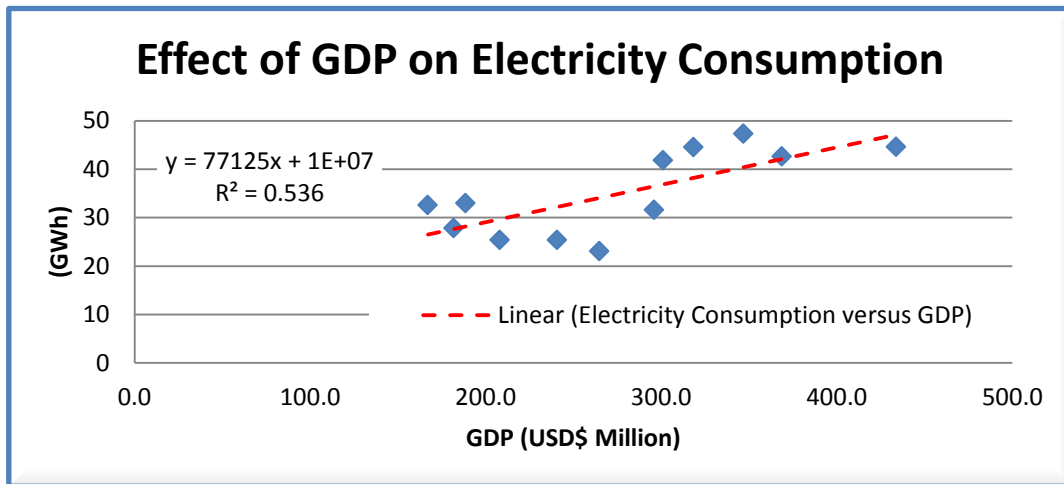


Figure 9: Analysing the effect of the GDP on electricity consumption [12]

#### ii. Population

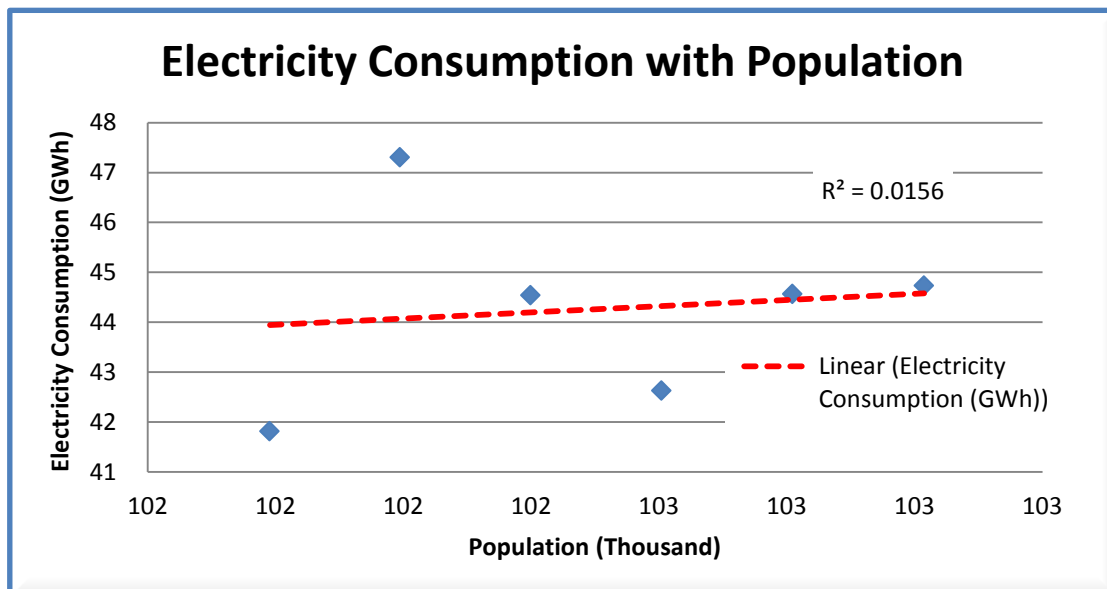


Figure 10: Relationship between population sizes with electricity consumption

iii. Price

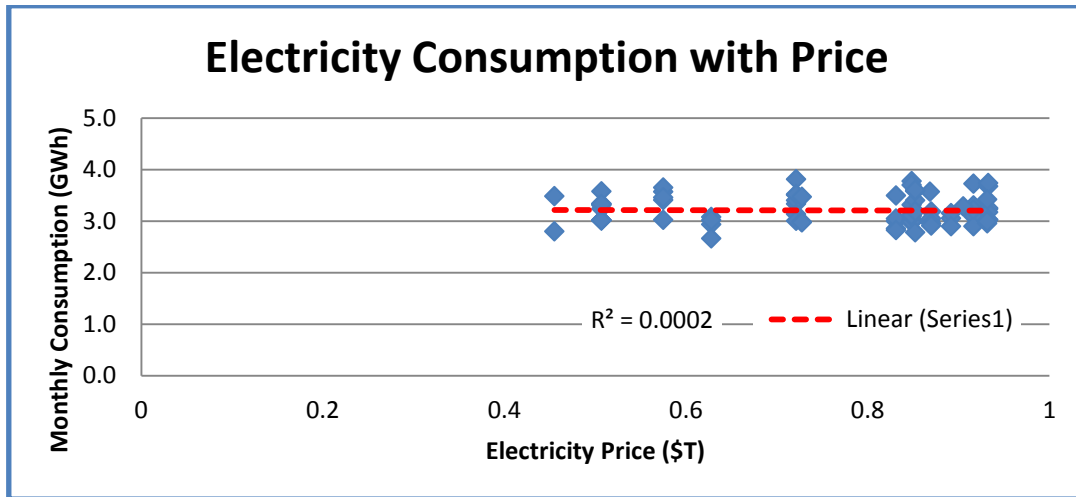


Figure 11: Effect on price on electricity consumption

Regression analysis shows that there is a better relation between electricity consumption with GDP compare to population and price factor. However, GDP data does not indicate census from every regional. So GDP is only good to predict the future consumption of electricity at the national level. The future consumption of electricity at regional level is better explained by the population size as the Tongan Department of Statistics provide a detail distribution of the population at regional and national level. The electricity price did not show any significant relationship with the electricity consumption. It is explained in the relatively low score of correlation coefficient compare to the other factor.

3.2.2 Power Demand

i. Economy

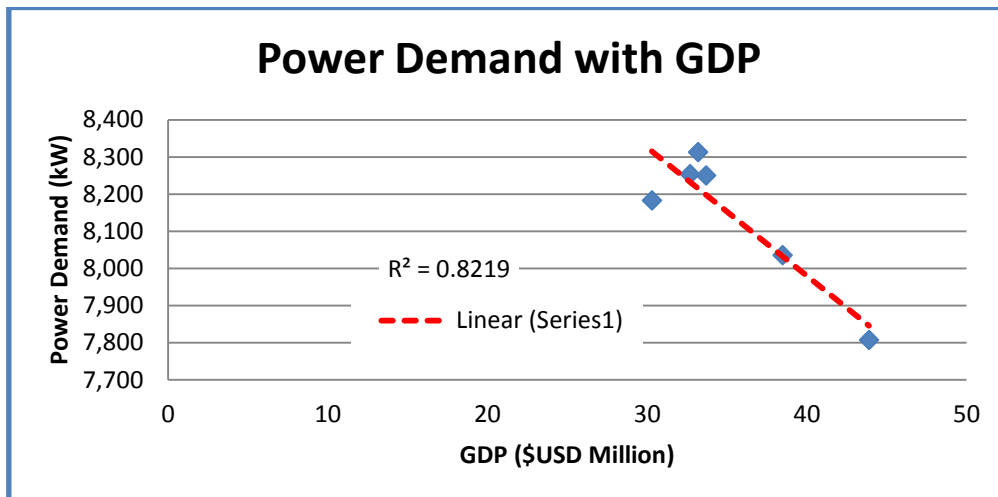


Figure 12: Effect of GDP on power demand

**ii. Population**

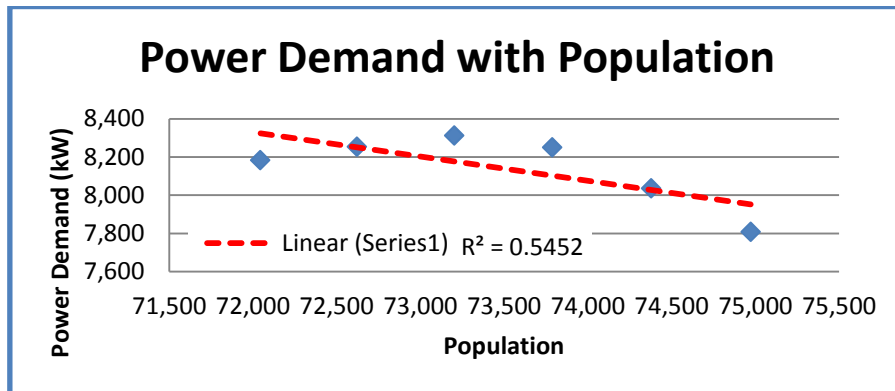


Figure 13: Effect of population on power demand

**iii. Price**

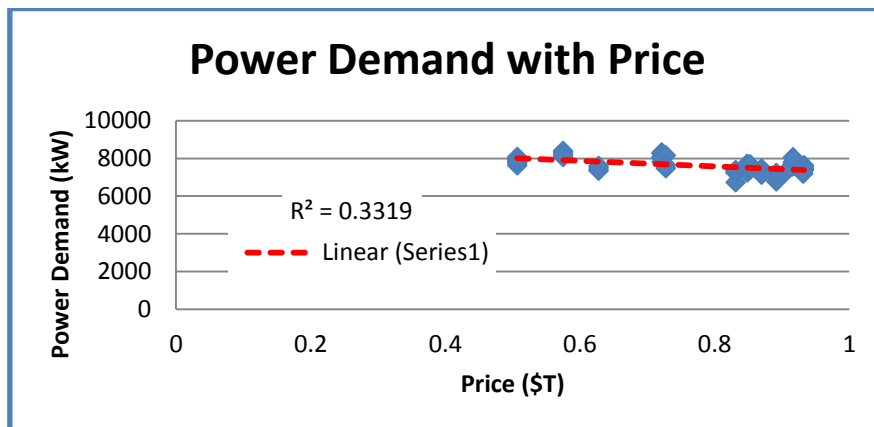


Figure 14: Effect of electricity on power demand

The overall decreasing trend of power demand and the small number of data does not show a good representation of the future power demand. The regression analysis shows that there is negative correlation between every analysed factor with power demand. Further analysis and investigation is needed to study the underlying sign of the relationship.

### 3.3 Data Projection

According to the time series and regression analysis done in the previous section, it is known that some of the key driver used in New Zealand is not obviously applied in Kingdom of Tonga. GDP and population show some relationship with the electricity consumption and demand. The electricity price however did not show a convincing relation as it has the lowest correlation coefficient.

#### 3.3.1 Electricity Consumption Forecast

Assuming that the trend continues in the future, the future consumption at the national level and regional level are show in figure 15.



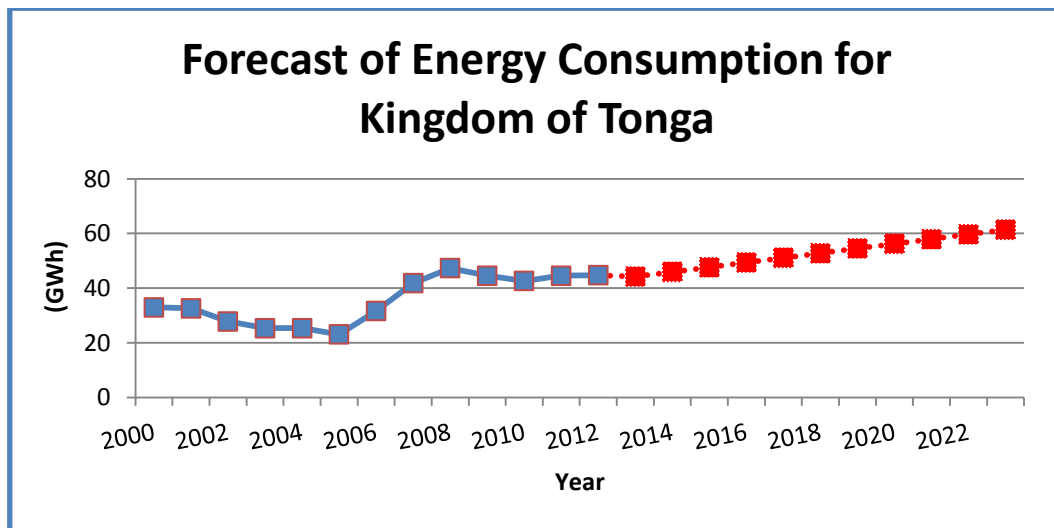


Figure 15: Electricity consumption forecast for Kingdom of Tonga

### 3.3.2 Power Demand Forecast

The forecasting analysis for the power demand is the most challenging part of the assignment. None of the key drivers analysed contribute to the positive growth of the power demand. There is two component of the issue: statistical issue and actual behaviour of the power demand of the country. Statistical component of the issue is related to the number of samples taken. GDP data is produced annually, while population data is produced once in a five years. Small number of sample data increases the uncertainty of the projection.

The trend can also reflect an actual situation of the power demand. The increase in private solar generation may reduce the overall power demand. The technology improvement in energy efficient appliance can also contribute to the reduction in power demand. This is part of the energy intensity factor theory. Nevertheless, it is non-conservative to predict that the future power demand of the country is decreasing. However, it is better to assume that there will be slower growth of power demand in the near future.

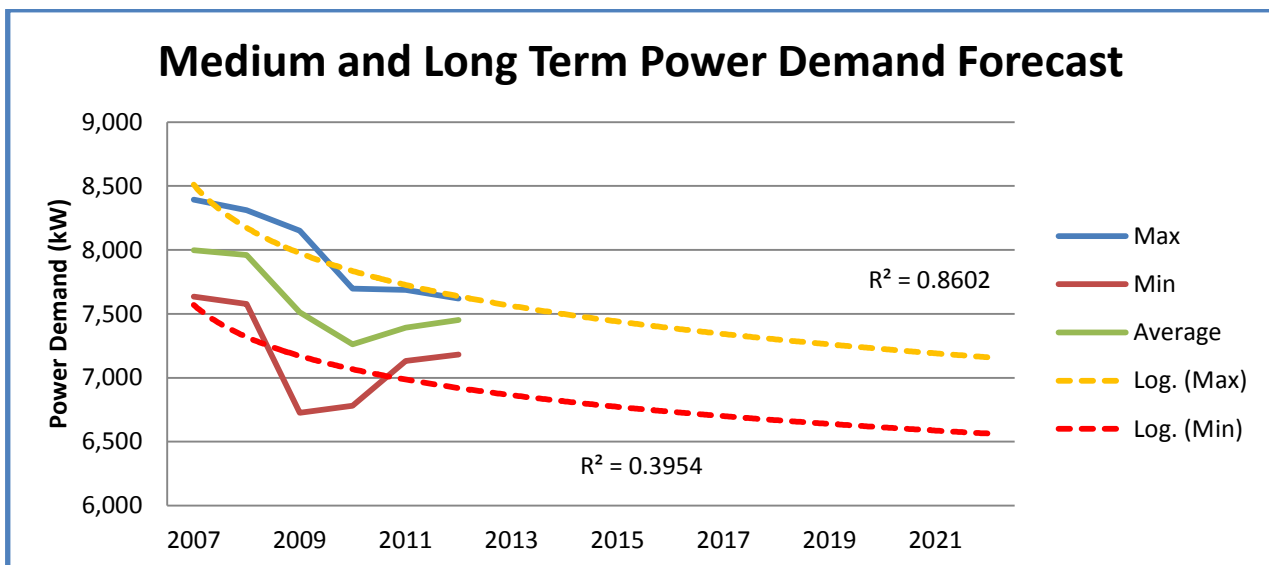


Figure 16: Forecasted Power Demand based on projection of time series analysis

## **4. Conclusions**

The analysis shows that there is a steady growth for electricity consumption in the future. While, GDP and population can give significant effect to the electricity consumption pattern as they show a reasonable correlation with the electricity consumption data. GDP have higher correlation coefficient with the electricity consumption compare to the population. However, the availability of the population data at regional level made the forecasting electricity consumption at every grid possible. For power demand, there is a steady decline trend in the sample data. The quality of the data is somehow argued as there is big construction project occurred at Tongatapu after the riot in 2006 caused damage to the central business district. Any major consumption in Tonga could skew the data and bias the quantitative analysis.

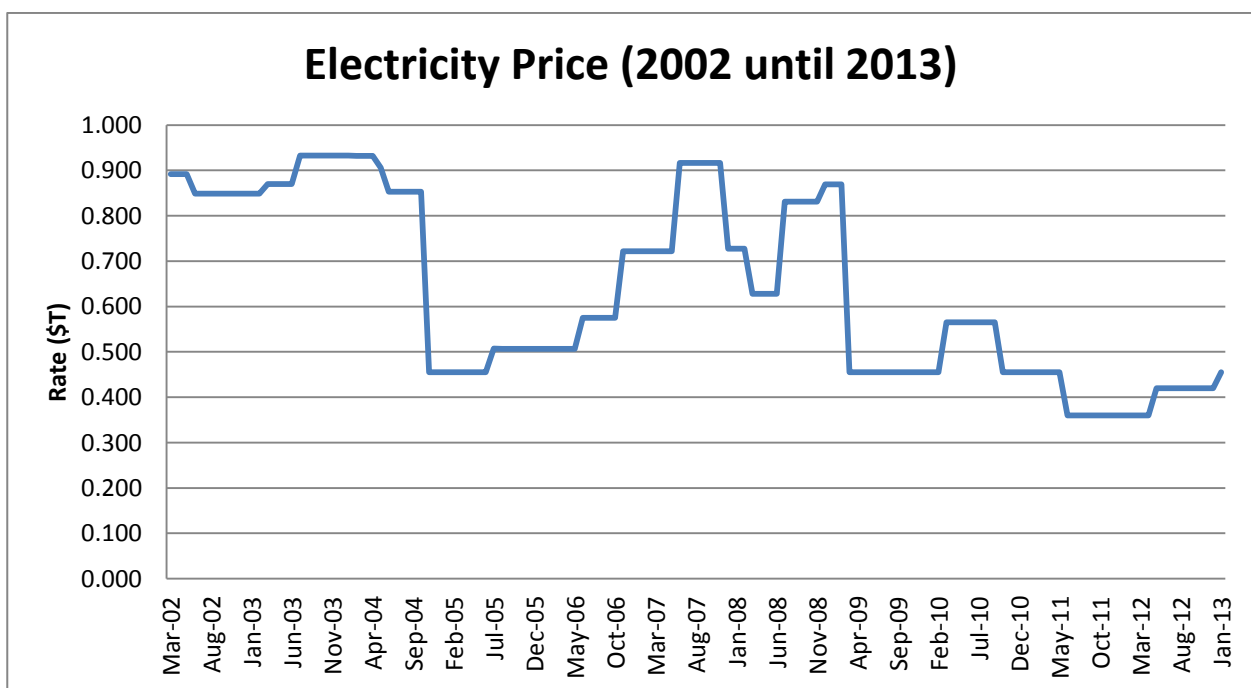
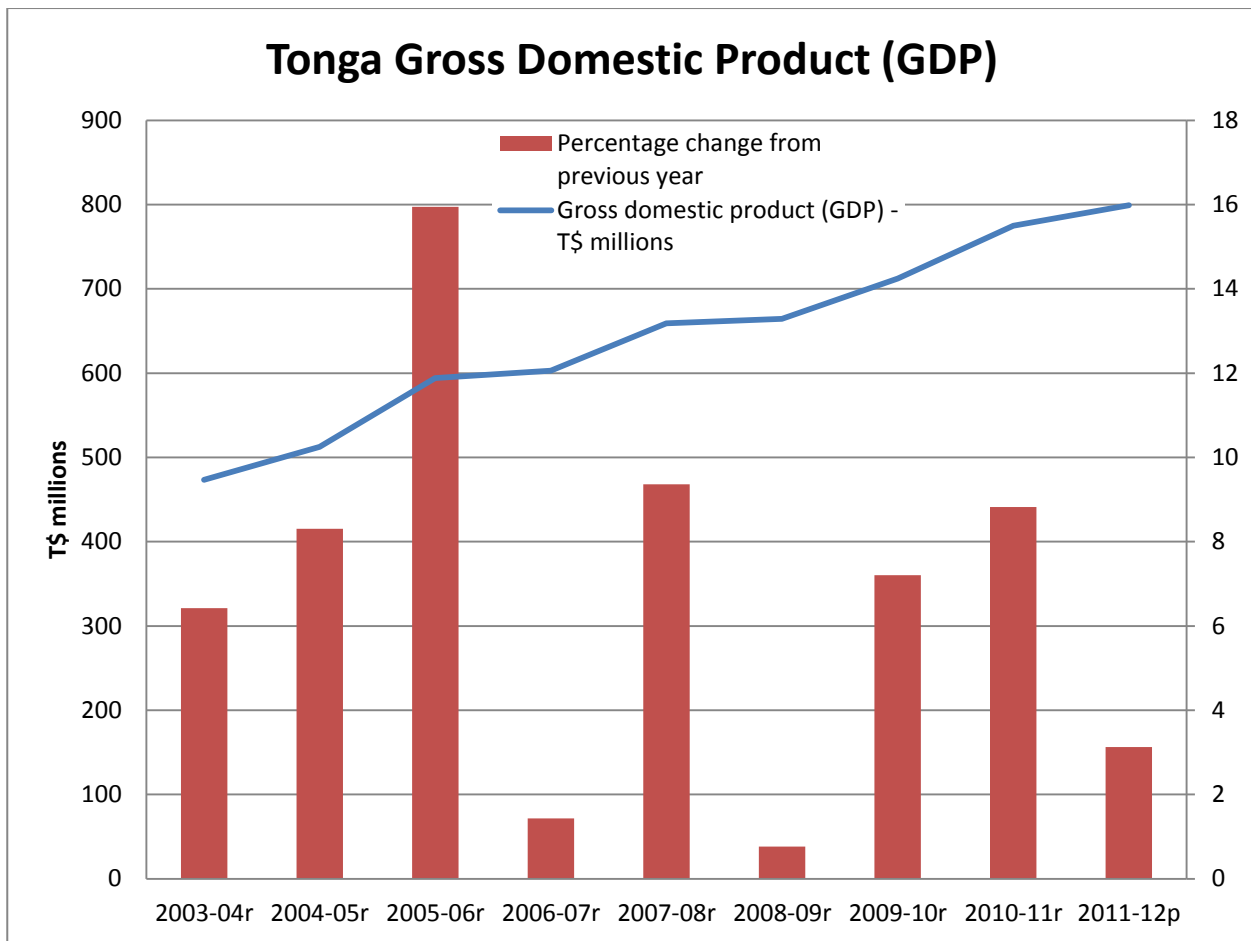
## **5. Further Improvement**

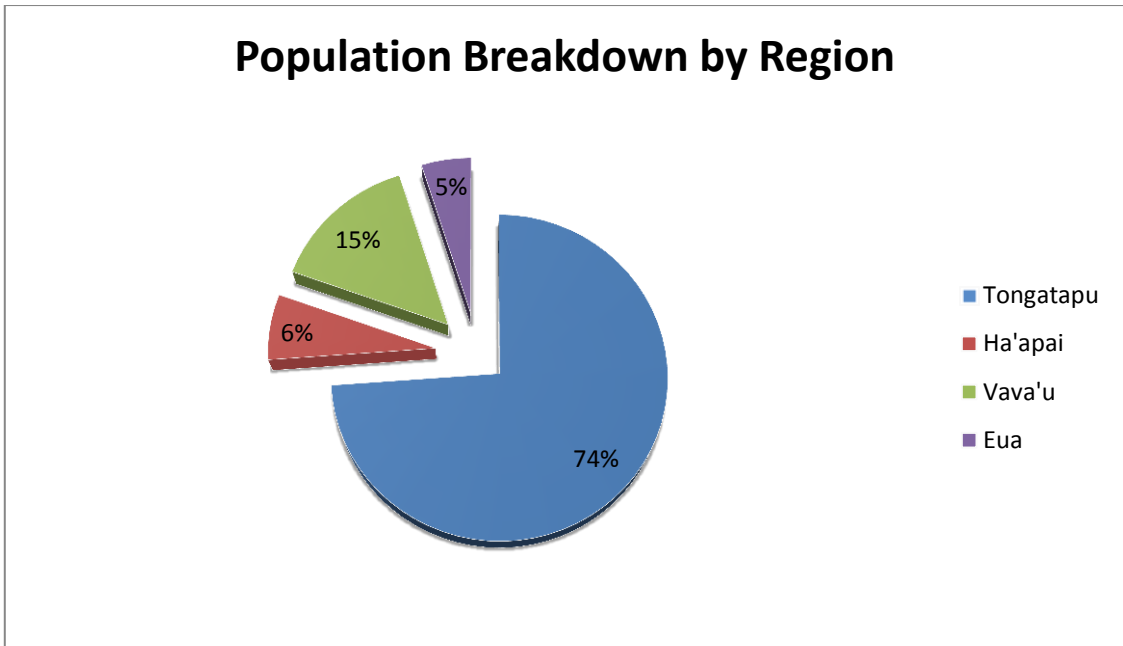
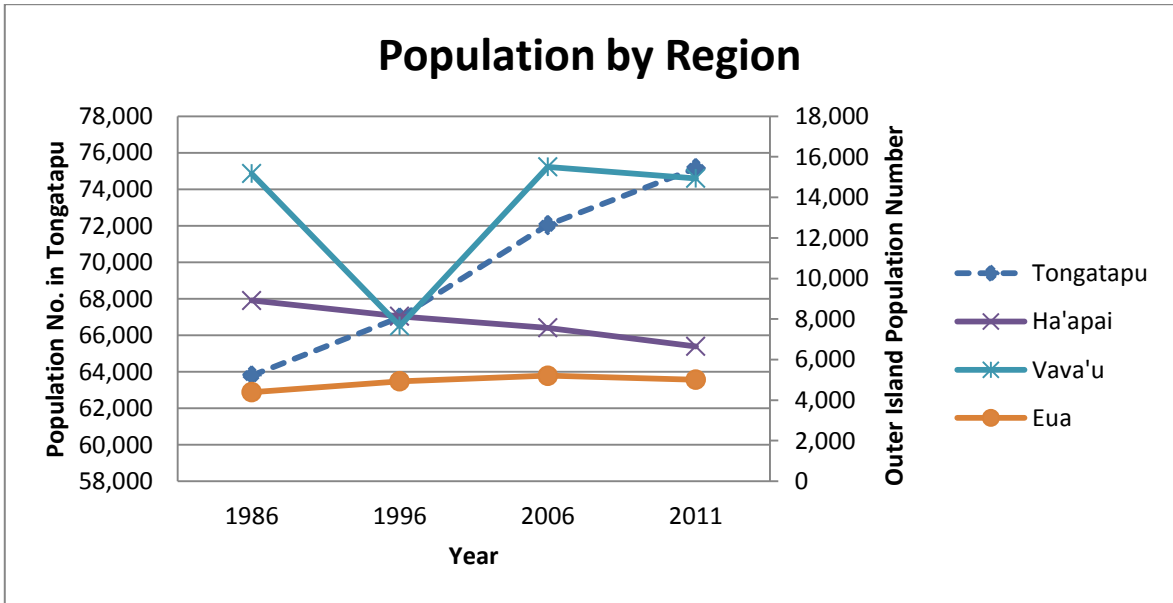
The quality of the forecast can be further improved by having more data. Statistically, an increase in number of data will reduce the error in analysis. The regression analysis can also be further improved by relating more external factors to the electricity consumption and demand. Other factor such as weather and seasonal condition of the country could improve the understanding of the electricity demand and consumption pattern for the Kingdom of Tonga.

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## 7. Appendices





## Regional Electricity Consumption with the population

