Energy xxx (2016) 1–12

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Grid electricity for Fiji islands: Future supply options and assessment of demand trends

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ARTICLE INFO

Article history:
Received 29 August 2016
Received in revised form
7 November 2016
Accepted 8 November 2016
Available online xxx

Keywords:
Electricity demand
Regression model
Forecast
Validation
Analytic hierarchy process

ABSTRACT

Electricity is a secondary energy source and one of the main drivers for economic development of a nation. Long-term planning for electricity demand is essential for strategic expansion of supply options which would require significant investment in terms of human resources and capital. This paper is focused on the past trends in annual grid-electricity demand for Fiji, from which forecast is done using statistically significant linear regression models. The regression models reveal that domestic grid-electricity demand variance is explained by population, GDP and electricity price. However, for non-domestic demand, the variance is explained by changes in population and GDP with electricity tariffs playing a small role. The absolute deviation of forecasts for total demand from 5 different regression models ranges from 1.2 to 32%. For domestic demand it ranges from 3.0 to 5.0% while non-domestic deviation ranges from 1.7 to 19%. Analytic hierarchy process was employed to choose the best model for demand forecast which then led the discussion on future supply options for grid-electricity expansion in Fiji. Biomass power plants, hydro and GCPV are seen to be the most promising supply.

1. Introduction

The most obvious way to carry out a preliminary forecast for electricity needs of a nation is by studying the current demand trends. However, it should be noted that relationships which drive the current electricity demand today may change in the future. Electricity demand is determined by economic conditions, prevailing weather conditions and consumer usage patterns and it varies by second, minute, hour, week, public holiday, month and season over every year into the future planning horizon [1,2]. Forecast of electricity demand is needed for government departments and the power utility (Fiji Electricity Authority-FEA) to plan for their grid expansion and finance planning. Better policy decisions can be made once the past energy usage trends and current energy usage patterns are analyzed [3] and studied to provide rigorous analysis of the determinants of electricity demand [4].

Forecasting per se, does not guarantee a successful strategy but it provides a credible and justifiable reason to base strategies for electricity generation expansion [5]. Without a reasonable forecast, the strategies would be baseless and would most likely be ineffective. The forecasting and strategic implementations are iterative processes and knowledge is gained in the process from past experience [5]. The main steps for successful electricity demand forecast can be:

1. Defining the electricity demand.
2. Division of the total electricity demand into its main components.
3. Analysis of drivers of the electricity demand which includes GDP and population. A forecasting model for these drivers is necessary to forecast energy demand.
4. Finally, some tools can be used to gauge the models which include sensitivity analysis and retrospective projections.

In general, forecasting techniques can be classified as judgmental (made by experts), univariate (considers one explanatory variable) and multivariate (considers two or more explanatory variables) [6]. The forecasting models can be explanatory model (where the predictor variable is explained by external factors (explanatory variables) or time series model such as ARIMA,

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http://dx.doi.org/10.1016/j.energy.2016.11.054
0360-5442/

exponential smoothing and structural models (here prediction of future is based on past values of a variable) or a model based on combination of explanatory variables and time variables [7]. A number of researchers have used times series or explanatory models to forecast electricity demand which are discussed below.

Foley et al. [1] reviewed the different electricity system modeling techniques and discussed a number of propriety electricity system models used in the USA and Europe. Bianco et al. [8] noted two main issues for reliable forecasts; (i) there has to be sufficient and necessary information available and (ii) even though complex models provide accurate forecasts, it is difficult to manage. Authors [8–11] have used cointegration, integrated fuzzy regression algorithm and trigonometric grey prediction model to forecast electricity consumption. Other authors [12–15] have used advanced models such as Auto Regressive Integrated Moving Average (ARIMA), Seasonal ARIMA and Multiplicative Seasonal ARIMA to forecast demand of electricity.

Underlying Energy Demand Trend (UEDT) and Structural Time Series Model (STSM) are used by authors [16,17] to forecast residential electricity demand. Hyndman and Fan [2] devised a methodology to forecast the probability distribution of annual and weekly peak electricity demand for South Australia since 2007. A multiple regression model was developed to forecast monthly electricity demand from 1996 to 2003 based on weather variables, gross domestic product and population growth [18].

The aim of this paper is to study the trend and forecast of total, domestic and non-domestic grid-electricity demand in Fiji and discuss the possible options to satisfy the increasing requirements. The first section of this paper presents a brief literature review followed by discussion on the electricity utility in Fiji and methodology used. Section 4 discusses past trends of total, domestic and non-domestic demand followed by construction of linear regression models for total, domestic and non-domestic demands. These models are then used to forecast demand till 2040 in section 6. Section 7 presents validation of models which then led to choosing the best model to forecast demand using multi-criteria decision analysis. Following this is a discussion on supply options for grid electricity in future. Finally, conclusions of this study are presented.

2. Methodology

The grid-electricity demand data was collected from Fiji Bureau of Statistics (FBoS) and FEA. Total, domestic and non-domestic demand data (1976–2014) was collected from FBoS Key Statistics Books [19] while historical electricity price data was obtained from FEA. Demographic and economic data (population and GDP) were also obtained from FBoS. The trends for these data were first studied and linear regression models (univariate and multivariate) were created using SPSS at 95% confidence. The dependent variable was taken to be grid-electricity demand. The explanatory variables used were population, GDP and electricity price. The data used for analysis was from 1976 to 2010 and the data from 2011 to 2014 was used to test the validity of the models created. These regression models were then used to forecast demand till 2040. For deciding the best model for demand forecast, AHP was used.

3. Electricity utility in Fiji

Being an island nation, with two major islands and approximately 300 other outer smaller islands, connection of grid electricity to all population in Fiji is not possible. FEA, the sole electricity utility, is responsible for generation, transmission and distribution of all grid-connected electricity in Fiji. Considering grid – electricity production and sales for FEA data (2006–2012) from FBoS, there is an average of 8.6% difference between them. Fiji Department of Energy is responsible for electrification of other smaller islands and rural areas. According to last census data (2007) 75% of the population is connected to grid electricity while 14% have access to electricity based on distributed generation (solar home systems and micro hydro) [20].

FEA supplies grid electricity in Viti Levu, Vanua Levu and Ovalau as shown in Fig. 1. The main source for electricity generation is hydro power stations and diesel generators. FEA's aim is to supply electricity with as much renewable based electricity as possible [21]. In 2014, the mix of electricity generation was 45% from hydro, 51% from diesel generators and 4% from independent power producers (using biomass energy). These percentages are variable over the years. Considering generation data from 1998 to 2014 [21], hydro power electricity generation ranges from 46 to 85%. This percentage mainly depends on the rainfall and peak demand. Table 1 shows the peak demand for grid electricity, installed capacity and available capacity of generation for the 3 islands. There is no interconnection of grids between the islands. The number of customer account increased by 2.95% from December 2014 to December 2015, bringing the total number of customer account to 171939 [22]. From the total number of customers, 90% are domestic customers, with 9.6% commercial customers and only 0.06% industrial customers.

4. Trends for grid-electricity demand

4.1. Total grid-electricity demand trend

Electricity demand data from 1976 to 2014 was obtained from Fiji Bureau of Statistics and this was analyzed. The demand has been increasing with an overall 368% increase in the last 38 years (from 1976 to 2014), Fig. 2. The average annual increase in grid electricity demand is 4.3%.

An interesting key point to note is that: there are “3 steps” in the grid-electricity demand (i) prior to 1983, (ii) between 1984 and 2000 and (iii) from 2001 to date, Table 2. From 1983 to 1984, there was 24% increase in demand while from 2000 to 2001 as earlier discussed there was 25% increase. The jump in 1983–1984 was due to new 80 MW Monasavu hydro power scheme coming online while 2000 to 2001 jump was because more people were being connected to the grid and increase in economic activity despite the political unrest in 2000. A few dips in electricity demand trend were observed, 1987, 2000, 2006 and 2010. This first three dips (1987, 2000 and 2006) could be contributed to political unrest in Fiji. The 2010 dip was because the tariff charged to customers (electricity price) increased and this led to customers consuming less.

4.2. Sectorial grid-electricity demand trend

The objective of this section is to consider three main sectors (residential, commercial and industrial) for their grid electricity demands. It should be noted at this point that commercial and industrial customer definition used by FEA is [24]:

(i) Domestic – these are residential customers who pay FJD0.3310/kWh consumed. If their consumption is less than or equal to 85 kWh/month then domestic customers only pay FJD0.1720/kWh. The rest (FJD0.1590/kWh) is subsidized by government.

(ii) Commercial - these are both commercial and industrial customers whose maximum demand is less than 75 kW. The tariff charged to them is FJD0.3990/kWh for consumption up to 14999 kWh per month. If their consumption exceeds 14999 kWh/month then they pay FJD0.4180/kWh.

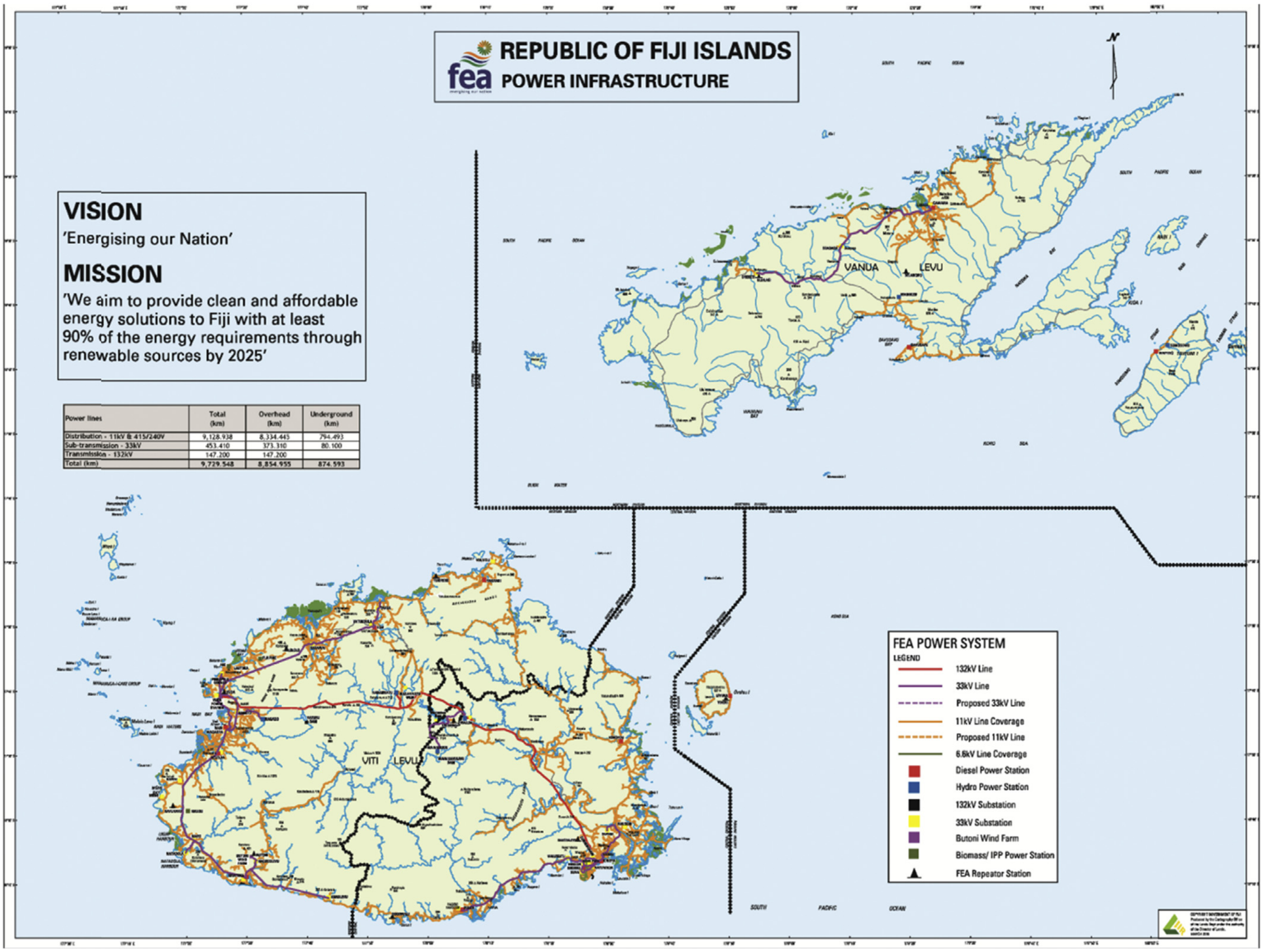

Fig. 1. Power infrastructure of FEA. Source: [23].

Table 1
Peak demand, installed capacity and available capacity of grid-electricity [22].

		Viti Levu	Vanua Levu	Ovalau	Total
	Peak demand (MW)	170.64	7.4	1.82	**179.86**
Thermal capacity	Installed (MW)	154.58	19.3	2.8	176.68
	Available (MW)	127.65	15.7	2.3	145.65
Renewable capacity	Installed (MW)	146.05	0.8	0	146.85
	Available (MW)	124	0.8	0	124.8
Total available generation capacity (MW)		251.65	16.5	2.3	**270.45**

(iii) Industrial – these are maximum demand customers (they use heavy machinery) who pay for their demand charge in FJD/kW and also they are charged less energy tariff. For example, for demands over 1000 kW, customers are charged FJD38.19/kW and their energy charge is FJD0.3183/kWh consumed.

Because of the above definitions where industrial and commercial customers are added together for determining the electricity demand, only two sectors are considered; domestic (residential) and non-domestic (commercial and industrial combined with institutions and streetlights). It is seen that even though the commercial and industrial customers for FEA comprise only around 10% they account for majority of the grid electricity demand. The average annual percentage increase in domestic and non-domestic demand over the past years is 4.7 and 4.2 respectively. For the past 38 years, non-domestic customers account for on average 75% of the total annual grid electricity demand while the rest (25%) is by residential customers. Hence, for applying policy on energy efficiency and conservation, it is recommended that non-domestic customers are focused on rather than residential.

Again, the "3 steps" is seen in non-domestic grid-electricity demand but not in domestic, Fig. 2. Therefore, total grid-electricity demand in Fiji is heavily dependent on the non-domestic demand.

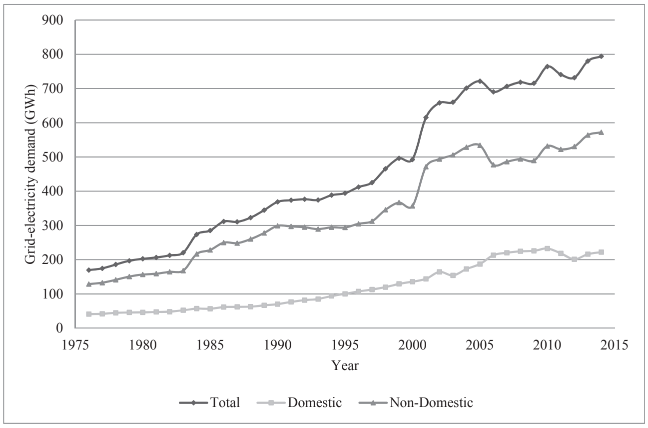

Fig. 2. Grid-electricity demand. Data source: FBoS [19].

a correlation between the variables. Next was the *adjusted coefficient of determination* ([1]adjusted R^2) which determines how well (in %) the independent variables in the model explain the variance in grid-electricity demand. The *F-test* from ANOVA table determines the overall significance of the model. In this F-test, p-values were considered. If the p-value was <0.05, then the null hypothesis (independent variable does not reliably predict the dependent variable) was rejected, which means that the model is reliable and can be trusted. The last statistic was the *t-test* which is used for testing the significance of coefficients of independent variables and constant term in the created model. Once more, the p-value is looked at as before.

The Pearson correlation between dependent variable and explanatory variables is shown in Tables 3–5. Very good and positive relationships were seen between the variables. Only electricity price correlation factor is relatively low, ranging from 0.7 to 0.8.

Table 2
Structural change in total grid-electricity demand.

Period	Total % increase	Average annual % increase	Structure % increase
1976–1983	68	3.82	
1984–2000	58	3.79	1983–1984 = 24
2001–2014	29	2.04	2000–2001 = 25

5. Explanatory linear regression models of grid-electricity demand

Linear regression is an attempt to model the relationship between two or more explanatory (independent) variable and dependent variable. In this section, the dependent variable is grid-electricity demand which will be estimated. The independent (or explanatory) variables considered for linear regression analyses are population (000's), GDP at current factor cost (FJD million), electricity tariff charged to customers, (Fig. 3).

In order to carry out linear regression and create models to estimate grid-electricity demand SPSS software (IBM SPSS Statistics V22) was used. For each demand (total, domestic and non-domestic), the three independent variables were first taken separately and a simple linear regression model was created and then, all the 3 variables were simultaneously considered to create a multiple linear regression model.

The multiple linear regression models would be in the form

$$E = \beta_0 + \beta_1 GDP + \beta_2 Pop + \beta_3 P + \varepsilon \quad (1)$$

where

E – is the estimated grid-electricity demand (GWh)
GDP – is the gross domestic product at current factor cost (FJD million)
Pop - is the population (thousands)
P – is the electricity price (FEA tariff charged to customers) (Fiji cents/kWh)
β_0 – is the constant term (GWh)
β_1,$\beta_2$andβ_3- are the coefficients of the GDP (GWh/FJD million), population (GWh/thousand people) and tariff (GWh/Fiji cents/kWh) respectively and
ε – is the error term (GWh).

To check if the created model was statistically significant, a number of statistical tests were done at 95% confidence interval. The first was the *Pearson correlation factor* which informs if there is

Equations (2)–(4), the created models for demand (E – total demand, E_D – domestic demand and E_{ND} – non domestic demand), were all statistically significant at 95% confidence. Table 6 presents the created models with the t-statistics and p-value given for each variable. Other statistics of these models is summarized in Table 7.

Considering the error term for total demand models; eqs. (2b) and (2d) were considered good with a high adjusted R^2. Equation (2c) was made by considering population and GDP as explanatory variables but because the p-value for population is more than 0.05, its coefficient is not considered.

Three factors are of main importance to the domestic grid-electricity demand (i) population and (ii) household income and (iii) electricity price (tariff charged to domestic customers). The Fiji population data was available from 1976 to 2011, however for household income the data available from FBoS is just for 3 years namely, 2002–2003, 2008–2009 and 2013–2014. Due to limitation of household income data, this variable was not used in explanatory model. Instead GDP variable was considered. For domestic demand models, eqs. (3d) and (3e) had low error and high adjusted R^2. For these two equations (3d) and (3e), it was also noted that even though Pearson correlation factor was positive between population and demand but the coefficient in the regression model was negative. This may be due to the fluctuation in historical GDP data which caused a negative coefficient for population in regression model.

The non-domestic category includes the industrial and commercial sector plus institutions (schools, churches, etc.) and streetlights. However, industrial and commercial sector dominates (97% of the total non-domestic demand) this category. For growth in non-domestic grid-electricity demand, it was envisioned that GDP plays an important role. From the created explanatory models for non-domestic markets, electricity price does not significantly explain the variance in demand; it is just the coefficients of

[1] R^2 assumes that every single variable explains the variation in the depended variable. The adjusted R^2 tells you the percentage of variation explained by only the independent variables that actually affect the dependent variable [25].

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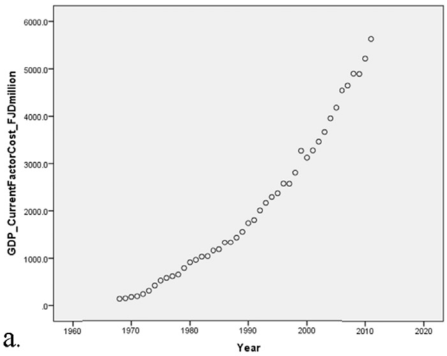
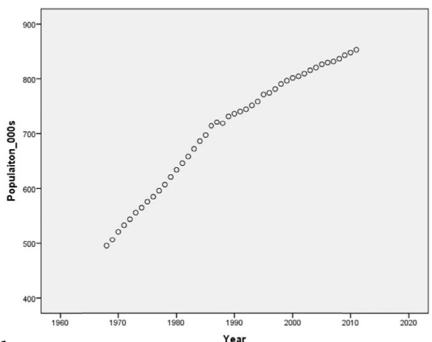


a.



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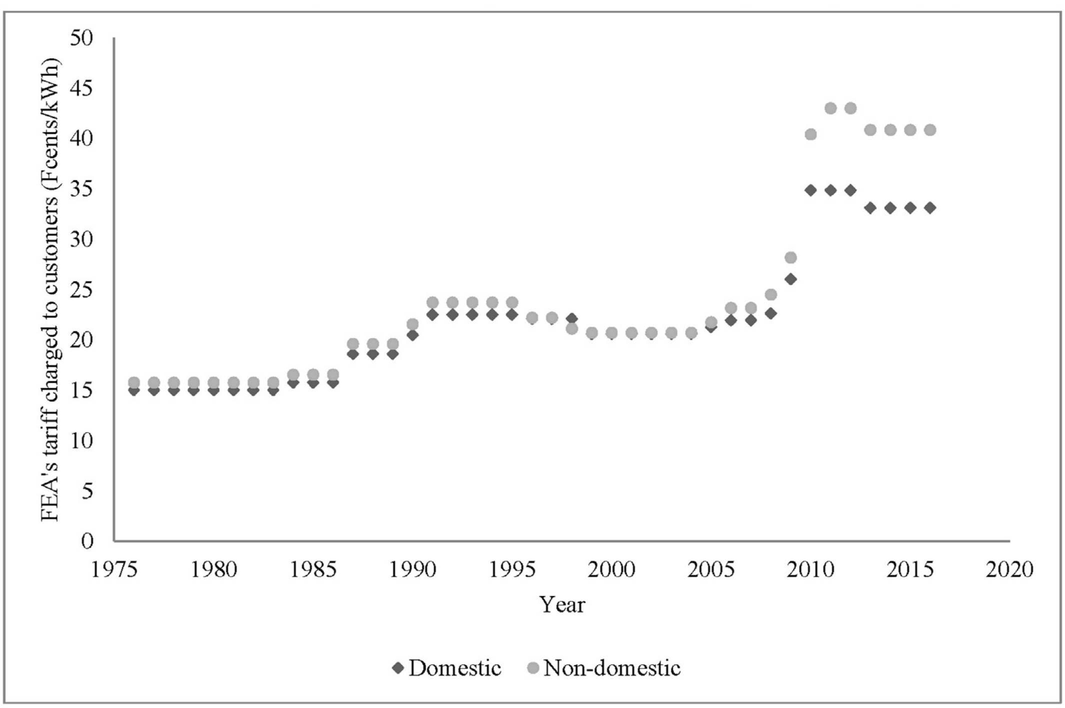

c.

Fig. 3. Explanatory variables' variation with time.

Table 3
Pearson correlation factor between variables for total demand.

	Total demand (GWh)	GDP @ current factor cost (FJD million)	Population (000s)	Average tariff (F cents/kWh)
Total demand (GWh)	1	0.981	0.935	0.726
GDP @ current factor cost (FJD million)	0.981	1	0.929	0.772
Population (000s)	0.935	0.929	1	0.764
Average tariff (F cents/kWh)	0.726	0.772	0.764	1

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Table 4
Pearson correlation factor between variables for domestic demand.

	Domestic Demand (GWh)	GDP @ current factor cost (FJD million)	Population (000s)	Domestic tariff (F cents/kWh)
Domestic demand (GWh)	1	0.992	0.885	0.752
GDP @ current factor cost (FJD million)	0.992	1	0.929	0.792
Population (000s)	0.885	0.929	1	0.801
Average tariff (F cents/kWh)	0.752	0.792	0.801	1

Table 5
Pearson correlation factor between variables for non-domestic demand.

	Non-domestic demand (GWh)	GDP @ current factor cost (FJD million)	Population (000s)	Non-domestic tariff (F cents/kWh)
Non-domestic demand (GWh)	1	0.958	0.94	0.678
GDP @ current factor cost (FJD million)	0.958	1	0.929	0.749
Population (000s)	0.94	0.929	1	0.727
Average tariff (F cents/kWh)	0.678	0.749	0.727	1

population and GDP variables which are statistically significant. Equations (4d) and (4e) are good models with low error and high adjusted R^2.

6. Forecasting grid-electricity demand

In order to forecast total demand, domestic and non-domestic demand, explanatory regression models created in section 5 were used. These models have GDP, population and electricity price (tariff charged to customers) as independent variables. To forecast until 2040, yearly data up to 2040 must be known for each explanatory variable. To obtain this, each of these independent variables was regressed over time and statistically significant equations are shown in Table 8. In this table, t is the year, example 1976.

For the electricity price models (eqs. (7a), (8a) and (9a)), data only up to 2010 was used. This resulted in very small adjusted R^2 values. To overcome this, data up to 2016 was used to create model 7b, 8b and 9b which improved adjusted R^2.

For each demand (total, domestic and non-domestic) five linear regression models were used to forecast the demand till 2040, Table 6. Forecast values at intermediate intervals are given in Table 9 and forecast is shown in Figs. 4–6. As can be seen, the forecast values from various models are quite close to each other. For the models which have electricity price as an independent variable, the improved electricity price model values were used in forecast.

Considering Table 9, the average annual percentage increase in demand forecast for total demand ranges from 1.4 to 2.0 for the 5 models while for domestic demand it ranges from 1.8 to 2.0 and for non-domestic demand it ranges from 1.4 to 1.7. The range of forecast for the 5 models was calculated for the 3 demands. In 2040, for total demand, the 5 models have values between 987 and 1467 GWh. For domestic demand in year 2040, the forecast ranges between 355 and 388 GWh for the 5 models and similarly for non-domestic demand, it is between 885 and 1030 GWh.

For total demand forecast (Fig. 4), model 3 is the worst because forecast values are low compared to current trend. Models 1 and 2 are in line with past trend and models 4 and 5 have high forecast. Model 4 forecast is 15% more than model 1 and 12% more than model 2. While model 5 forecast was 23% more than model 1 forecast and 20% more than model 2 forecast. For domestic demand forecast (Fig. 5), all the 5 model forecast values are very close to each other. This is also confirmed in Table 9 with small range in the forecast value from 5 models in the year 2040. For non-domestic forecast (Fig. 6), models 3 and 5 are giving high forecast values while models 1, 2, and 4 forecast are in line with the past trend. Model 3 forecast is 9–12% more than model 1, 2 and 4 forecasts while Model 5 forecast is 14–17% more than models 1, 2 and 3 forecasts. At this stage, it is difficult to choose best model for each demand forecast. Therefore, we need one more criteria, validation of models, to then decide the best model.

7. Validation for demand forecasts

Model validation is determining the deviation between model results and actual data. The models for forecast for total electricity demand (total, sector wise and location wise) were validated using the real demand data. The mean absolute percentage error (MAPE) is calculated by dividing the absolute difference between forecast and actual value by actual value. This is then multiplied by 100 and then individual % errors are summed and divided by the number of series, eq. (10).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Actual_i - forecast_i|}{actual_i} \times 100 \tag{10}$$

The results are shown in Table 10. For the total grid-electricity demand, the regression models 1 and 2 have small average deviation (1.2% and 2.4% respectively) between the actual and forecast results with maximum deviation of 3.4% and 5.3% respectively. Regression model 5 which just considers electricity price is the worst model with average deviation of 32.2%. Model 4 which consider all three explanatory variables (GDP, population and electricity price) have an average of 20.2% deviation in forecast values compared to actual values.

For domestic demand forecast using regression models, all 5 models have low MAPE (less than 5%) indicating forecast values close to actual values. For non-domestic only models 3 and 5 (both of which have electricity price as an explanatory variable) have high MAPE (about 20%). Model 4 is considered to be the best considering it has two explanatory variables and low MAPE.

Now, in order to choose the best model, all three factors (adjusted R^2, error term and validation value) for each model needs to be studied simultaneously. This was done using multi-criteria decision making tool as shown in the next section.

8. Decision making of model selection

Considering that for each demand (total, domestic and non-domestic) there were 5 regression models considered (population, GDP, electricity price, GDP + Pop and GDP + Pop + Price), it was necessary to decide which model would be the best for decision making. For decision making, analytic hierarchy process (AHP)

Table 6
Equations for created models for domestic.

Eq. #	Model No.	Independent variable considered	Created Models (Brackets contain p-value for t-test) *t-statistic is in italics*
TOTAL DEMAND			
2a	Model 1	Pop	E = 2.330 Pop – 1305.007 (0.000) (0.000) *15.171* *-11.372*
2b	Model 2	GDP	E = 0.133 GDP + 106.716 (0.000) (0.000) *29.345* *8.445*
2c	Model 3	Pop +GDP	E = 0.112 GDP (0.000) *9.496*
2d	Model 4	Pop + GDP + Price	E = 0.516 Pop + 0.118 GDP – 4.426 P (0.020) (0.000) (0.047) *2.461* *10.164* *-2.066*
2e	Model 5	Price	E = 31.757 P (0.000) *6.073*
DOMESTIC DEMAND			
3a	Model 1	Pop	E_D = 0.713 Pop – 421.410 (0.000) (0.000) *10.947* *-8.664*
3b	Model 2	GDP	E_D = 0.044 GDP (0.000) *44.136*
3c	Model 3	Price	E_D = 11.399 P – 118.023 (0.000) (0.002) *6.545* *-3.346*
3d	Model 4	Pop +GDP	E_D = 0.054 GDP – 0.209 Pop +133.863 (0.000) (0.000) (0.000) *30.080* *-6.345* *6.500*
3e	Model 5	Pop + GDP + Price	E_D = 0.055 GDP – 0.190 Pop – 0.772 P + 132.862 (0.000) (0.000) (0.048) (0.000) *31.247* *-5.783* *-2.055* *6.766*
NON-DOMESTIC DEMAND			
4a	Model 1	Pop	E_{ND} = 1.618 Pop – 883.597 (0.000) (0.000) *15.895* *-11.621*
4b	Model 2	GDP	E_{ND} = 0.090 GDP + 102.989 (0.000) (0.000) *19.111* *7.879*
4c	Model 3	Price	E_{ND} = 19.014 P (0.000) *5.301*
4d	Model 4	Pop +GDP	E_{ND} = 0.058 GDP + 0.638 Pop – 293.707 (0.000) (0.004) (0.030) *5.077* *3.073* *-2.266*
4e	Model 5	Pop + GDP + Price	E_{ND} = 0.063 GDP + 0.685 Pop – 274.152 (0.000) (0.002) (0.037) *5.541* *3.381* *-2.178*

was considered. This process was developed by Dr. Saaty TL in the early 1970s. AHP is a multi-criteria decision making tool which uses logical framework to evaluate the benefit of each alternative in terms of percentage. The main advantage of AHP is that it condenses a multidimensional problem into a one dimensional one where decisions are determined by a single number for the best outcome [26].

The steps involved in analytic hierarchy process are as follows:

1. Objective is defined. In this case: to choose a model.
2. Elements in criteria, sub-criteria and alternatives are structured, Fig. 7. In this case the criteria considered are adjusted R^2, error term and validation.
3. A pair-wise comparison of each element in each group is made as shown in Table 11.
4. Weighting and consistency ratio are calculated.
5. Alternatives are evaluated according to weighting and ranking is done.

Considering the weightings of the criteria in Fig. 7, the most important criteria is validation (57%) followed by error term (33%) followed by adjusted R^2 (10%). For the sub-criteria (from Fig. 7), weightings from normalized tables are given the middle column of sub-criterion box. The weightings (last column) of the sub-criterion box were calculated according to the main criterion weighting. The alternatives were evaluated using the weightings of the sub-criteria

Table 7
Summary of explanatory models created.

Eq.#	Adjusted R^2	Error	ANOVA table F-statistic (p-value)	Terms not considered (p-value) *t-statistic*
Total demand				
2a	0.871	69.63423	230.157 (0.000)	
2b	0.962	37.77671	861.152 (0.000)	
2c	0.965	36.18964	471.148 (0.000)	+0.427Pop-159.844 (0.055) (0.244) *1.989* *−1.188*
2d	0.968	34.47192	347.604 (0.000)	−149.606 (0.252) *−1.167*
2e	0.513	135.13150	36.879 (0.000)	−217.494 (0.053) *−2.004*
Domestic demand				
3a	0.777	29.52633	119.795 (0.000)	
3b	0.983	8.19747	1947.959 (0.000)	+3.729 (0.183) *1.359*
3c	0.552	41.89590	42.839 (0.000)	
3d	0.992	5.53979	2152.796 (0.000)	
3e	0.993	5.28039	1581.075 (0.000)	
Non-domestic demand				
4a	0.881	46.13754	252.650 (0.000)	
4b	0.915	39.07583	365.224 (0.000)	
4c	0.444	99.75607	28.103 (0.000)	−75.561 (0.329) *−0.991*
4d	0.932	34.86941	234.048 (0.000)	
4e	0.936	33.72920	167.827 (0.000)	−3.3002 P (0.083) *−1.789*

Table 8
Explanatory variable forecast models.

Eq.#	Created models	Adjusted R^2
5	$GDP = 136.453\ t - 269551.601$	0.961
6	$Pop = 7.446\ t - 14096.612$	0.962
7a	$P_{avg} = 0.340\ t - 656.423$	0.605
7b	$P_{avg} = 0.527\ t - 1028.892$	0.713
8a	$P_D = 0.328\ t - 634.848$	0.656
8b	$P_D = 0.456\ t - 888.704$	0.758
9a	$P_{ND} = 0.351\ t - 677.997$	0.554
9b	$P_{ND} = 0.598\ t - 1169.374$	0.675

in the last column and adding it for each criterion. This value is given as benefit in %. Using the benefit %, each alternative (i.e. model) is ranked, Table 12.

Considering, Table 12, the best model for each demand forecast is shown in bold. For total demand forecast, model 2 has the highest rank. Model 2 considers only GDP as the explanatory variable for forecast. For domestic demand forecast, models 2, 4 and 5 have the same % benefit. However, model 4 is ranked 1 because it has more than one variable as explanatory variable and its validation percentage is more than model 5. For non-domestic demand forecast, model 4 has the highest rank. This model has GDP and population as the explanatory variables for forecast. Therefore, based on these best model forecasts, supply options for future expanding demand can be determined.

Table 9
Demand forecast for intermediate years.

Year	2015	2020	2025	2030	2035	2040
Total demand (GWh)						
Model 1	808	895	982	1069	1155	1242
Model 2	**825**	**916**	**1007**	**1097**	**1188**	**1279**
Model 3	605	681	758	834	911	987
Model 4	959	1047	1135	1223	1311	1400
Model 5	1048	1132	1216	1299	1383	1467
Domestic demand (GWh)						
Model 1	225	252	278	305	332	358
Model 2	238	268	298	328	358	388
Model 3	225	251	277	303	329	355
Model 4	**236**	**265**	**294**	**323**	**352**	**381**
Model 5	234	263	292	320	349	378
Non-domestic demand (GWh)						
Model 1	584	644	705	765	825	885
Model 2	589	651	712	773	835	896
Model 3	677	734	791	847	904	961
Model 4	**598**	**662**	**725**	**788**	**852**	**915**
Model 5	687	756	824	893	961	1030

The bold figures in the table represent the best model for forecast.

9. Supply options for future grid-electricity demand

The best model for the future demand as discussed in the previous section is highlighted in Table 9 which gives the demand figures for intermediate years till 2040. The total demand for 2040

Please cite this article in press as: Prasad RD, Raturi A, Grid electricity for Fiji islands: Future supply options and assessment of demand trends, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.11.054

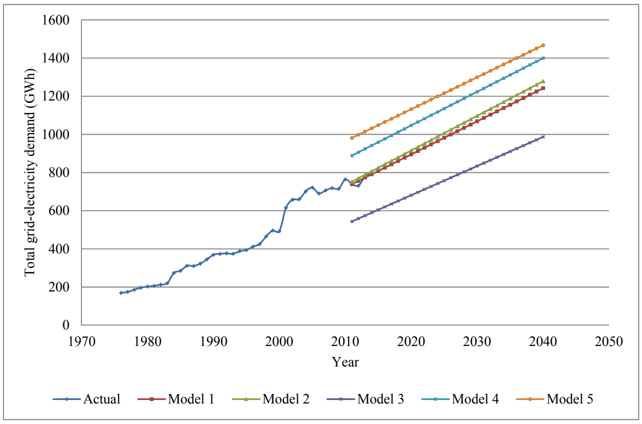

Fig. 4. Total demand forecast till 2040.

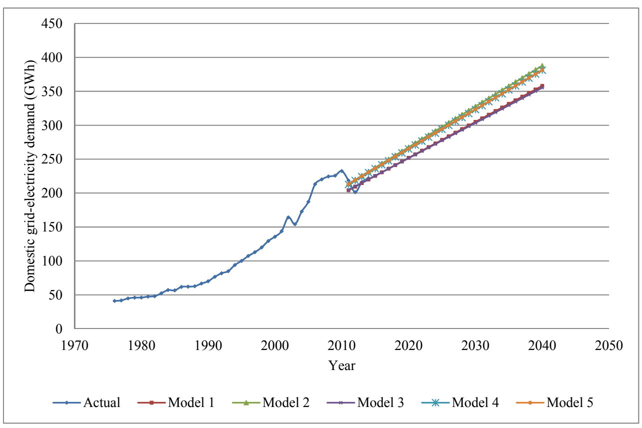

Fig. 5. Domestic demand forecast till 2040.

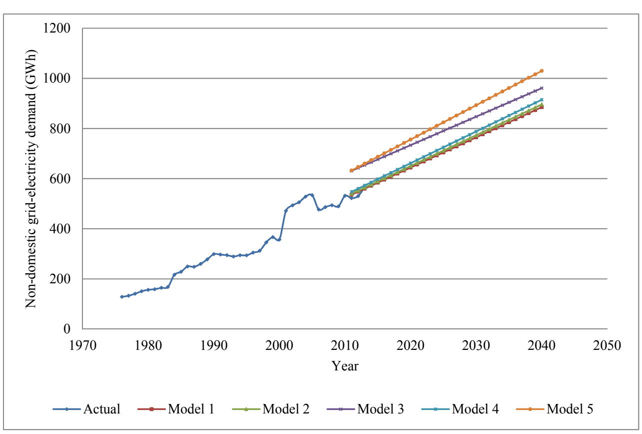

Fig. 6. Non-domestic demand forecast till 2040.

is 1279 GWh for model 2 which has an average annual percentage increase of 1.8. The domestic demand for year 2040 is 358 GWh with average annual percentage increase of 1.9%. While non-domestic demand for year 2040 is 915 GWh with average annual percentage increase of 1.7%.

An estimate of the peak demand is also useful during the planning process as it ensures sufficient generation capacity to cater for peak load. The peak demand and electricity consumption by location is shown in Fig. 8. The data for Levuka is small, so it was combined with Vanua Levu data. The average annual percentage increase in consumption for Viti Levu and Vanua Levu was 1.7 and 1.6 respectively while for peak demand it was 3.2 and 1.4 respectively. Similarly, for generation, the average annual increase is 3.4 and 2.5% respectively. To cater for this increase in demand, generation should also increase. Using these average annual percentage increase, the peak demand and generation was forecast till 2040 (Table 13). In 2040, the peak demand reaches to 355 MW and total generation would be 2104 GWh.

To cater for the increase in demand, there must be increased generation. Earlier paragraph presents the increase in grid-electricity generation till year 2040. FEA has signed a number of power purchase agreements (PPAs) with independent power producers (IPPs) as early as 2003 but to date, there are very few realized projects. Only Fiji Sugar Corporation (FSC) and Tropik Wood Industries Ltd (TWIL) are selling part of their biomass generated electricity to the grid. These companies are state-owned IPPs. For FSC, there are 4 mills and its power generating capacity 41 MW in total, Table 14 and 52 MW planned for future expansion. It should be noted that Ba and Rakiraki are currently (2015) not supplying to grid but in future there are plans to supply to grid. For TWIL, current installed capacity is 12.3 MW.

FEA in the short-term has catered for demand increase and to supplement low output from hydro power stations by commissioning additional 40 MW of containerized diesel generating sets around Viti Levu. Ilkan et al. (2005) discuss how the use of wind or solar can help satisfy the increasing peak demand while saving the cost of fossil fuels [30]. Therefore, the way forward is increasing use of renewable resources based electricity generation that would also help in Fiji's sustainable development.

The first choice can be grid-connected photovoltaic (GCPV). At present, there are 1.16 MW GCPV connected to the grid. Studies have shown that up to 20% of grid can be connected with PV without any technical problems. This means for Fiji where average grid peak demand is 130 MW, maximum of 26 MW of GCPV can be installed with negligible disruptions to grid. Raturi [31] suggests that this capacity of GCPV be spread over the whole island of Viti Levu with individual systems 10–15 km apart. With this capacity and with average of 3.5 peak sun hours 33 GWh of GCPV can be generated annually.

Another option can be biomass power plants for electricity generation. Biomass feedstock can be agricultural residues, forest and wood residues, energy crops, urban wood waste, and biogas from animal waste. Considering Table 14, for future expansion, Ba mill with addition 40 MW generator set would be able to generate 112–140 GWh annually and Lautoka with additional 12 MW would be able to generate around 42–48 GWh annually. Currently (from 2015), a 10 MW biomass power plant is under construction in Nabou, Western part of Viti Levu and is expected to complete by end of 2016 [32,33]. For a typical value of 3.5 GWh of electricity generation per MW of installed capacity then this power plant would produce 28–35 GWh annually. Another 17.8 MW wood fuel based power generation in Vuda, Viti Levu has been under development from 2014 [34]. This project has a potential of electricity generation of 125–130 GWh. With these developments in near future (3–5 years) additional 307–353 GWh can be supplied to grid annually. However, for an IPP to successfully supply (i.e. from idea conception to electricity generation and selling to FEA) there needs to be an enabling policy environment in Fiji.

Hydro power expansion is another option for electricity supply. This technology has a long proven track record in Fiji since 1983. FEA is looking at developing (through PPP model) various hydro power projects at different locations with total capacity of 142 MW

Table 10
Validation for grid-electricity demand forecast models.

Year	Actual demand (GWh)	Forecast					Average deviation of as percentage of actual demand				
		Mod 1	Mod 2	Mod 3	Mod 4	Mod 5	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5
Total											
2011	741	739	752	544	889	981	*0.2*	*1.6*	*26.6*	*20.0*	*32.5*
2012	732	756	771	559	906	998	*3.4*	*5.3*	*23.6*	*23.9*	*36.4*
2013	780	774	789	574	924	1015	*0.8*	*1.1*	*26.4*	*18.5*	*30.1*
2014	794	791	807	590	942	1032	*0.4*	*1.6*	*25.7*	*18.6*	*29.9*
Average							*1.2*	*2.4*	*25.6*	*20.2*	*32.2*
Domestic											
2011	219	204	214	205	213	211	*6.6*	*2.2*	*6.3*	*2.7*	*3.3*
2012	201	209	220	210	219	217	*4.1*	*9.2*	*4.3*	*8.6*	*7.9*
2013	216	215	226	215	224	223	*0.7*	*4.4*	*0.5*	*3.8*	*3.1*
2014	222	220	232	220	230	229	*0.9*	*4.3*	*0.8*	*3.6*	*2.9*
Average							*3.1*	*5.0*	*3.0*	*4.7*	*4.3*
Non-domestic											
2011	522	536	540	631	548	633	*2.6*	*3.4*	*20.9*	*4.8*	*21.1*
2012	530	548	552	643	560	646	*3.3*	*4.1*	*21.2*	*5.6*	*21.9*
2013	564	560	565	654	573	660	*0.7*	*0.1*	*16.0*	*1.6*	*17.1*
2014	572	572	577	665	586	674	*0.0*	*0.8*	*16.3*	*2.4*	*17.8*
Average							*1.6*	*2.1*	*18.6*	*3.6*	*19.5*

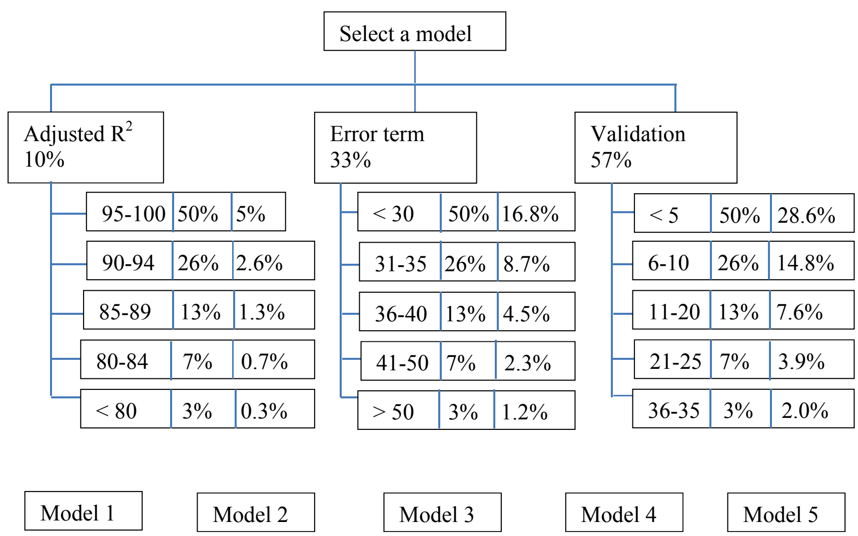

Fig. 7. Elements in criteria, sub-criteria and alternatives.

Table 11
Pair wise comparison of each element in main criteria.

Criteria	C1	C2	C3
C1	1	0.25	0.2
C2	4	1	0.5
C3	5	2	1
Total	10	3.25	1.7

Where C1 is adjusted R^2, C2 is error term and C3 is validation.

with annual generation potential of 546 GWh [35]. This alone will provide a major contribution to meeting the increasing demand in future. Viti Levu has a total 83.3 MW of additional hydro power potential with locations spread around the island ranging from 1.1 MW to 10.3 MW [36]. However, majority of these sites can be considered for off-grid hydro power generation.

Other supply options are wind energy and geothermal but at present these technologies have huge initial capital expenditure. For geothermal there are keen interests from 1 or 2 investors to do initial or pilot projects. For wind energy, for most locations in Fiji,

Table 12
Ranking models for total, domestic and non-domestic electricity demand.

	Adjusted R^2	Error term	Validation	Benefit	Rank
Total demand					
Model 1	0.871	69.63423	1.2	31.04	2
Model 2	**0.962**	**37.77671**	**2.4**	**37.98**	**1**
Model 3	0.965	36.18964	25.6	11.40	4
Model 4	0.968	34.47192	20.2	17.48	3
Model 5	0.513	135.1315	32.2	3.48	5
Domestic demand					
Model 1	0.777	29.52633	3.1	45.69	4
Model 2	0.983	8.19747	5	50.28	3
Model 3	0.552	41.8959	3	30.06	5
Model 4	**0.992**	**5.53979**	**4.7**	**50.28**	**1**
Model 5	0.993	5.28039	4.3	50.28	2
Non-domestic demand					
Model 1	0.881	46.13754	1.6	32.14	3
Model 2	0.915	39.07583	2.1	35.60	2
Model 3	0.444	99.7567	18.6	9.13	5
Model 4	**0.932**	**34.86941**	**3.6**	**39.80**	**1**
Model 5	0.936	33.7292	19.5	18.87	4

The bold figures in the table represent the best model for forecast.

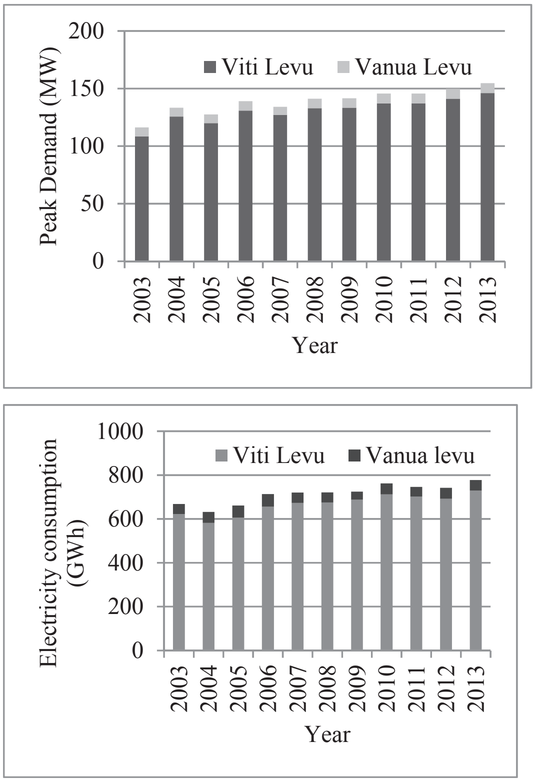

Fig. 8. Peak demand and electricity consumption by location. [Data source [27]: and [28] respectively].

Table 13
Peak demand and generation forecast using average annual percentage increase.

Year	Peak demand (MW)			Electricity generation (GWh)		
	Viti Levu	Vanua Levu	Total	Viti Levu	Vanua Levu	Total
2014	150.9	8.72	159.60	842.1	50.26	892.3
2015	155.7	8.84	164.55	870.7	51.51	922.2
2020	182.3	9.48	191.74	1029.2	58.28	1087.4
2025	213.4	10.16	223.52	1216.4	65.94	1282.4
2030	249.7	10.89	260.64	1437.8	74.60	1512.4
2035	292.3	11.68	304.03	1699.4	84.41	1783.8
2040	342.2	12.52	354.73	2008.6	95.50	2104.1

Table 14
Biomass for power generation installed capacity at FSC. Data Source: [29].

Location	Current installed capacity (MW)	Total capacity (MW)	Future plan (MW)
Lautoka	5	5	12
Ba	4 and 5[a]	9	2 × 20 MW. Expected to be fully commissioned in 2017
Rakiraki	3	3	
Labasa	4 and 2 × 10 MW[b]	24	
		41	

[a] 5 MW installed in 2014.
[b] 2 × 10 MW commissioned in 2015 crushing season.

wind speeds vary from 2 to 7 m/s [37]. Several authors [38–40] have done preliminary wind energy assessments for different locations in Fiji. There are few locations (mostly coastal and smaller islands) with wind speeds exceeding 7 m/s. For locations with high wind speeds and suitable topography, installing a wind farm with pumped hydro storage can prove to be one of the feasible solutions. Several studies [41–43] have shown that pumped hydro storage increase the use of wind power more effectively.

10. Conclusions

The power utility in Fiji supplies grid electricity only to Viti Levu, Vanua Levu and Levuka in Ovalau. The other smaller islands have distributed generations. There are no interconnections of grids between islands. The current peak demand for grid electricity is 170.64, 7.4 and 1.82 MW for Viti Levu, Vanua Levu and Levuka respectively where on average the peak demand is increasing at 3% annually. At present, Viti Levu is consuming 93% of the total grid electricity (GWh) consumed and the remaining is for Vanua Levu and Levuka. On average the annual growth in grid electricity demand is 1.6%. For sectors, non-domestic sector is consuming 75% of the total grid electricity and the remainder is consumed by domestic sector.

The future demand will be affected by both demand & supply side efficiencies and the advent of smart grids. Attempts to forecast grid electricity demand in long-term (until 2040) for total, domestic and non-domestic in Fiji are made in this work using regression models with variables population, GDP and electricity price. Even though no forecast is 100% accurate having some indication as to how grid-electricity demand is increasing can help utilities, energy department and investors better plan their generation capacities. Regression model is constructed using 95% confidence interval on SPSS and the obtained equations are used to forecast demand (total, domestic and non-domestic). However, since for each demand, there were 5 models considered, AHP is used to choose the best model to discuss the future supply. AHP ranked the 5 models for each demand based on the weightings of criteria (adjusted R^2, error term and validation value) and sub-criteria given by author. The result reveals that the best model for total demand is eq. (2b), domestic demand is eq. (3d) and non-domestic demand is eq. (4d). The annual average percentage increase for best model for total, domestic and non-domestic demand is 1.8, 1.9 and 1.7 respectively.

Viable supply options for grid-electricity expansion can be GCPV, biomass power plants and new hydro power stations. Wind energy (offshore and onshore) and geothermal energy can be considered in future when the costs of these are comparable to hydro or other conventional generation. Distributing a total of 25 MW GCPV modules throughout the main island can have good impact on the generation since adverse effects of cloud cover and risk of damage from natural disasters would be reduced. Co-generation plants at FSC in the near future (2–4 years of time) have a potential of 154–188 GWh of annual electricity generation while new IPPs biomass power plants have a yearly potential of 153–165 GWh. FEA has identified a 142 MW of potential hydropower project that can be done using PPP model.

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