Construction of a long-term hourly electricity demand curve and peak load using MAED-EL for Lesotho

by

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Abstract

At the time that this study was undertaken, Lesotho Electrical Company (LEC) had no longterm hourly load curve forecast for electricity consumption. This makes it difficult for the utility to plan for future power plants and cost effective bilateral agreements as well as policy maker to make informed decision and for Independent Power Producers (IPPs) to be developed by investor. Therefore, this study aimed to construct a long-term hourly load curve for future electricity consumption in Lesotho starting with 2018 as the base year, followed by five-year long intervals from 2020 to 2040. The Model for Analysis of Energy Demand (MAED-EL) was used to calculate future hourly load curves for electricity and it uses the end-use approach when calculating the energy projections. Three scenarios were considered in this study to model possible trajectories of future electricity consumption, namely: Business-as-Usual (BAU), Low Economy Scenario (LE) and High Economy Scenario (HE). The annual growth rates of electricity consumption were estimated to be 4.3% for BAU, 2.4% for LE and 6.3% for HE. The projected peak demand for each scenario occurs during winter season (June to July). It was anticipated that the peak load will grow by 224% 123% and 54% for HE, BAU and LE scenarios from 2020 to 2040 while the energy consumption will increase by 223%, 122% and 53% for HE, BAU and LE from 2020 to 2040. The base load was predicted to grow from 58.77 MW,56.79 MW and 54.74 MW for HE,BAU and LE to 190.05 MW, 126.29 and 84.29 in for HE,BAU and LE respectevely in 2040 . Due to growth of electrical energy load the power deficit which was already high in 2018 at 94.44 MW would increase to 539.92 MW, 330.1 MW and 196.44 MW for HE, BAU and LE respectively in 2040. The Peak Load of the system was equal or above 75% of system peak load for 20% of the available time of the year.

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Chapter 1 - Introduction

1.1 Overview of Load Forecasting

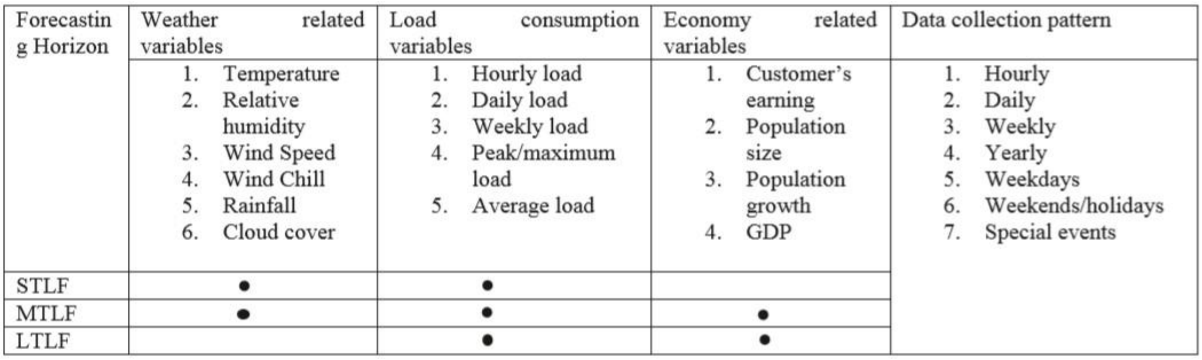
Load forecasting is generally accepted to be vital for the planning and operation of power transmission and distribution networks as well as for guiding the investment of capital in the energy sector. It is a central or integral component for managing power utilities and it acts as the critical mechanism or tool used by the policymakers and the decision-makers in the energy sector. At the corporate strategic management level, it is used for planning the construction of new power plants and for the development of the Integrated Resource Plan (IRP) to utilize locally available resources of energy such as hydropower, solar energy and wind power. At the operating level, load forecasting is also used by the power utility to plan for the load switching of the power system during outages for the maintenance of the electrical infrastructure. It should be obvious that the accuracy of the load forecasting is very important because even a slight percentage error in the electrical load and energy forecast can, for example, have serious repercussions when buying or selling energy. The pricing process relies heavily on accurate forecasting and either under- or overpricing may lead to the utility signing poor bilateral power purchase contracts that could cost the utility large amounts of money, may incur financial losses and may even lead to bankruptcy [1]–[3].

Load forecasting is classified into three phases namely the Short-Term Load Forecasting (STLF), Medium-Term Load Forecasting (MTLF) and Long-Term Load Forecasting (LTLF) [4]. The STLF may range from an hour to several days; it is used to inform the process of energy purchasing; it is useful in the management of the reliability of the power supply; it is an effective utility management tool; and it is useful when planning unit commitment, improving the system security and ensuring optimal reserve capacity [5]. The MTLF refers to the forecasting of the electrical load over periods ranging from several days to several months. It is used during the process of negotiating the bilateral contracts between utilities when purchasing power; used for planning the maintenance of the power plant's generating and distribution infrastructure; as well as the management of load switching and the operations of the power utilities. It is also used for scheduling during the process of negotiating transactions for fuel. The LTLF is often seen as the process of estimating the annual electrical peak load and the annual energy consumption. It serves as the mechanism or tool used by the decision makers, the policymakers and the management of the utility to budget for the future developments in the energy sector as well as further identification of the potential renewable energy resources which could be used for power generation, for example, solar energy, wind power and hydropower [4].

1.2 Techniques of load forecasting

Approaches and methods of analysis used in the field of load forecasting are listed as follows: multiple regression, exponential smoothing, iterative reweighting, adaptive load forecasting, stochastic load forecasting, autoregressive moving average exogenous (ARMAX) model based on the genetic algorithms, fuzzy logic, neural networks, and knowledge-based systems among others [6]. Load forecasting approaches are grouped into two classes of models and methods which apply concepts stemming from time series regression analysis and methods that belong to the fields of artificial and computational intelligence [3]. These methods range from regression-based approaches to artificial neural networks and expert systems. Other methods used in load forecasting are classified into *simple approaches* and *sophisticated approaches* [7]. Other models that are commonly used in load forecasting are econometrics, engineering economy model, the input-output model and the hybrid model [8]. The use of the different types and classes of load forecasting methods is reported to be influenced by a variety of factors [4] . Table 1 depicts the classes of load forecasting and the factors which are considered when forecasting the demand.

Table 1- Factors which influence load forecasting [4]



Forecasting Horizon	Weather related variables	Load consumption variables	Economy related variables	Data collection pattern
	1. Temperature 2. Relative humidity 3. Wind Speed 4. Wind Chill 5. Rainfall 6. Cloud cover	1. Hourly load 2. Daily load 3. Weekly load 4. Peak/maximum load 5. Average load	1. Customer's earning 2. Population size 3. Population growth 4. GDP	1. Hourly 2. Daily 3. Weekly 4. Yearly 5. Weekdays 6. Weekends/holidays 7. Special events
STLF	•	•		
MTLF	•	•	•	
LTLF		•	•	

There are several different models used in the energy sector for load forecasting. A few of these models are: Model for Analysis of Energy Demand (MAED), Long Range Energy Planning System (LEAP) and World Energy Model (WEM) [9], [10]. MAED includes two modules, namely MAED-D (module 1) and MAED-EL (module 2). For this study, MAEDEL is used to calculate the future electrical load, the hourly peak load curves and the load factors for Lesotho. MAED-EL is also used to calculate the annual electricity load growth rate as well as to construct the electrical hourly load curve projections and the load factors. In line with the approach described by Bhattacharyya, the study employs MAED-EL using the total demand for annual electricity for each sector to determine the total electricity demand for each hour of the year [8]. It uses the bottom-up approach to perform the load forecasting.

1.3 Problem statement

Lesotho Electricity Company (LEC) is the only power utility in Lesotho mandated to transmit and distribute power nationally. This mandate includes purchasing electrical energy from the Muela hydropower station which generates 72 MW against the peak load of about 166 MW as of 2018. The additional power is imported from South Africa and Mozambique through bilateral agreements. The utility has no long hourly load forecasting which could assist with determining the future electrical load profile. LEC does not have the model which could forecast the hourly load profile. The model which LEC uses is projecting only the peak loads of the system and its energy requirements but does not provide hourly load projections. The model is also unable to allow for various factors which could affect the electrical load growth such as; the socio-economic situation in Lesotho, it cannot capture the change in energy demand such (*the activity effect, intensity effect and structural effect*) as well as the season of the year, or the day type (whether weekend, working day or the holiday). Therefore, the model is used by the utility purely for peak load forecasting. This practice results in several issues related to the effective running of the LEC. It results in the utility signing bilateral power purchase agreements which are believed to cost the company huge amounts of money due to the inaccuracies in the load forecasts. Its use also makes it difficult for the decisionmakers to develop effective power generation plans which will meet the future energy requirements of the country in different circumstances. Such conditions will, for example, be the requirements during the different seasons of the year when different options of resources mix can be used to adequately meet the required electrical energy of the season of the year. Similarly, decision-makers are hampered in their attempts to develop effective longer-term plans for future power generation and properly sized generators since the electrical power load varies throughout the year. It also makes it difficult for electrical energy planners to develop an Integrated Resource Plan (IRP) when accurate future hourly load curve projections are not available.

1.4 Purpose of the Study

The purpose of the study is to comprehensively review the load forecasting process of the LEC and to produce:

- projected long term (2020 to 2040) hourly load curves for Lesotho;
- a projection of the peak loads and energy consumption at intervals of five years;

- constructing the growth of Lesotho power grid load duration curve and determine the base load growth for all scenarios;
- an examination of the load profile to determine in which season of the year system would peak;
- a forecast of the load factor of the projected load to evaluate the performance of the power systems;
- a forecast of the growth rate of the electrical energy consumption for the different energy-consuming sectors (e.g. services, households, and industries) under various possible scenarios of economic development;
- a forecast of how the annual load growth will affect the existing power system.

The rationale of the study is that if future energy consumption is known, it could be useful in the process of expanding the transmission and distribution networks, upgrading and constructing new power plants equipped with generators of the correct size; facilities optimally suited to cater for the peaks, different seasons of the year, types of weekdays, or hours of the day loads. It would also be able to predict the future load pattern in energyconsuming sectors like the services, households and industrials. The results flowing from this study should help towards the development of new projects which could be planned more easily. The Independent Power Producers (IPPs) will likely be prepared to invest in the country more readily because they will know when and where to commit their investments in power generation. The study is carried out to further find out how developments in technology and their implementation (efficient devices, solar water heating, distributed generation, etc.) could affect different sectors such as the industries, services and households.

1.5 Dissertation Structure

This study report is made up of five chapters. Chapter 1 documents the background of the study and the objectives. Chapter 2 reports the findings of the literature review which critically examined the literature regarding Long-Term Load Forecasting and the methods and the models employed in this field. Chapter 3 explains the methodology of the study by describing the methods that were used in the project to forecast the hourly electricity load for Lesotho. It includes details about the method used for data collection, the scenario assumptions, the calculation of the coefficients which were used as the input to the MAEDEL software, the reconstruction of the base year and then the determination of the projection of hourly electrical load, the load factor, and the energy requirement for the next 20 years. Chapter 4 presents the results, their discussions and analysis: viz. the calculated results, including the hourly, daily, weekly and annual electrical load curves, load factors and energy projections from 2018 to 2040. Chapter 5 contains the conclusion and recommendations. Here the main findings of the study are presented and suggestions formulated for the future approaches and actions by which the Long-Term Load Forecasting process may be improved.

Chapter 2 - Literature Review

2.1 Introduction to load forecasting methods and models

Power systems are seen as becoming increasingly complex due to changes and developments in technologies, energy efficiencies, growing populations as well as the economy. Furthermore, a growing number of parameters emerged that influence the demand for electricity and these require accurate power system planning. Accurate forecasting of electricity consumption is important because it determines the dynamics and characteristics of the future of the power facility. Forecasts that are either too low or too high may cause adverse events leading the electrical company to generate too little or too much electricity. This situation led to the evolution and development of many forecasting models over the last decades. Nowadays there are various energy forecasting methods, using different techniques to investigate a wide range of issues in energy sector projection [9], [11], [12].

To assess and validate the performance of a forecasting model, its *error deviation* from the actually measured values needs to be determined so that accurate results would be obtained from its use when projecting the electrical load for future electricity demand. Review of literature shows that Mean Absolute Percentage Error (MAPE) is mostly used as the measurement of the error to assess the performance of a model. MAPE is given by Equation (1) below: [3], [13].

$$MAPE = \frac{100}{T}\sum_{t=1}^{T}\left[\frac{y^t - y^{\wedge t}}{yt}\right] \qquad (1)$$

where y_t is the real value at point t and $y^\wedge{}_t$ the forecasted value [3].

For the MAPE to be more precise, a 95% confidence interval is calculated which contains true values of MAPE with varying degrees of confidence [14]. MAPE is used to assess the average absolute relative deviation of the predicted electricity demand value from the corresponding measured values [15].

2.1.1 Approaches used in forecasting

(i) Multiple Regressions uses the weighted least squares estimation. The statistical relationship between total load and weather conditions as well as the day type can be calculated. The multiple regressions are mathematically given by Equation (2) as:

$$Y_t = v_t \;\; a_t + \varepsilon_t \qquad (2)$$

where Y_t is system total load, t is sampling time, v_t is a vector of adapted variable such as time, temperature, light intensity, wind speed, humidity, day type (working day or weekend), a_t is the transpositional vector of regression coefficients and ε_t is the model error at time t [6][16].

(ii) The Exponential Smoothing Method: the first step in using this approach is to model the load based on the previous data, and then to use this model to predict the future load. The exponential model is mathematically given by Equation (3) as:

$$\gamma(t) = \beta(t)^T f(t) + \varepsilon(t) \qquad (3)$$

where $f(t)$ is the fitting function of a vector of the process, $\beta(t)$ the coefficient factor, $\varepsilon(t)$ the white noise and T is the transpose operator [17].

(iii) The Iterative Reweighted Least Square is a method that uses an operator that controls one variable at a time. The method uses the autocorrelation of the resulting differenced past load data in identifying a sub optional model of the load dynamics. The Iterative Reweighting Leased-Square is given in Equation (4) as:

$$Y = X\beta + \varepsilon \qquad (4)$$

where Y is n + 1 vector of the observation, X is an n x p of known coefficient, β is p x 1 of the unknown parameters and ε is n + 1 vector of the random error [16]

(iv) Adoptive Load Forecasting is a method of load forecasting that can be used as an on-line software package in the utility control center [18].

(v) The stochastic time series is divided in to three categories; Autoregressive (AR) model is used when the load is assumed to be a linear combination of previous loads and is mathematically represented in equation (5) as:

$$\hat{L}_k = -\sum_{i=1}^{m} \alpha_{ik} L_{k-i} + w_k \qquad (5)$$

where $\hat{L}_k$ is predicting the load at time k, w_k is the random load disturbance α_i , i = 1,…m are the unknown [18].

Autoregressive moving average (ARMA) and Autoregressive moving average with exogenous variable (ARIMAX) these methods are using the time-series approach, the model is first developed on the previous data, then future load is projected based on this model. ARMA is the method where the original time of series of monthly peak demand are decomposed into deterministic and stochastic load components.

(vi) Autoregressive Moving Average with Exogenous Variable (ARIMAX) is used for simulating natural evolutionary processes. It includes the metrological influence as an explanatory variable

(Vii) The fuzzy logic approach works in two stages: training and on-line forecasting after enough training were done. It is then linked with a controller to predict load change on-line.

(viii) Neural network is an approach that requires that the input data are multiplied by a weight and are then added to a threshold to form an inner product number called the *net function*.

(ix) The knowledge-based expert systems are computer programs that can "*reason*" and have their knowledge base expanded with new information ("knowledge") as it becomes available [6].

2.1.2 Methods used in load forecasting

2.1.2.1 Simple methods

There are different methods or approaches used for load forecasting. The commonly used methods are "simple approaches" and they are characterized by the "simple indicators" which are further divided into four categories namely: growth rate, elasticity, unit consumption and energy intensity. The mathematical presentation shown[1] indicates how the calculations are done for medium-term and long-term forecasting. All of the above-mentioned approaches relied on a single indicator which rendered them less attractive for long-term load forecasting because they are informed by the assumed changes in the indicator when forecasting [8].

The Trend Analysis method is another approach used in load forecasting [19]. It extrapolates past growth trends and is normally done by applying some form of time trend analysis to past behavior. This method has some advantages such as being simple to use. It could be applied at both aggregate and disaggregate levels and it could be based on whatever data was available. The disadvantages of the method are that it takes inefficient account of structural change and it does not explain what determined the forecasted demand as it does not explicitly include variables on price, income, etc. [8]. Direct Surveys is another method of approach used to generate the information primarily for the short term but surveys could also be used as a direct and reliable tool for demand analysis and forecasting [8]. This approach is a time-consuming process and consequently involves high cost. Again, its accuracy depends on the quality of the response obtained from the respondents which may not be correct.

2.1.2.2 Complex methods

Other methods (approaches) used in load forecasting are sophisticated techniques and they are classified as top-down and bottom-up models. Top-down models tend to focus on an aggregated level of analysis while the bottom-up models identify the homogenous activities or the end-use for which the demand is forecasted [8], [19]. Other models used in electrical energy forecasting rely on the modeling philosophy such as econometrics, engineering economy

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[1] See Bhattacharyya (2009) for simple approaches calculation methods

models, input-output models and hybrid models. Econometrics is grounded in the economic theories and its mathematical models use data to develop theories. It is used to forecast future trends from historical data. Econometrics is seen to have some advantages in that it can identify the important determinants of demand and that it is a flexible method that could be applied at the country level. It is also seen to have some disadvantages since econometrics requires experienced econometricians well-trained in both economics and econometric theory−skills which are scarce in developing countries. Also, the statistical analysis of energy demand requires consistent data of sufficient quality which, in many cases, may not be available [8].

Another complex method or approach to load projection is the engineering-economy model or the end-use attempt to establish accounting coherence using a detailed engineering representation of the electricity system [8]. This method relies on a detailed representation of the end-use of the electricity. It requires that a few key driver variables are used on each level. The model uses a few policy variables which can be changed to reveal the effect on the overall demand. Such variables can, for example, include energy intensity, unit consumption, and fuel mix. The Input-Output Model is another approach that relies on forward and backward linkages in the economy to determine the demand for energy [8]. The Hybrid Model is yet another forecasting approach and it reduces the methodological divergence between the econometric and engineering models by combining features of the traditions together [8]. Other models[2] that are described in the literature but are not included in this study are approaches like the dynamic models, scenario approaches, decomposition models and process models.

2.2 Models used for evaluating Long-Term Load Forecasting

Several models are reportedly used to forecast the electrical power demand and energy supply for the long term. The commonly used models are LEAP, WEM and MAED [9], [15], [20]. These models handle the complex planning of power system networks for the long-term planning of the transmission and distribution power lines, upgrading and construction of new power plants, as well as developing the policies which could be used to meet future energy demand. Long-term load forecasting is used to project future energy consumption for periods ranging from one year to several years [9].

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[2] See Bhattacharyya (2009) for the methods which are not presented in detail in this study

The LEAP model is used in the process of tracking resource extraction, electricity production and energy consumption in all sectors of the economy. The fact that it, firstly, does not automatically generate the optimization and market equilibrium scenarios and secondly does not consider the economic factors by determining energy supply and fuel, is seen as a weakness [9]. WEM is another model used and it covers the energy demand, energy transformation, and energy supply, for the majority of end-use sectors and also takes into account the energy-related carbon dioxide emissions. The model is not available to the public. MAED evaluates future energy demand based on medium to long-term scenarios of socioeconomic, technological and demographic developments. The model forecasts the specific energy demands for different sectors (industrials, services and households). It is also capable of projecting the hourly load curve for the electricity load.

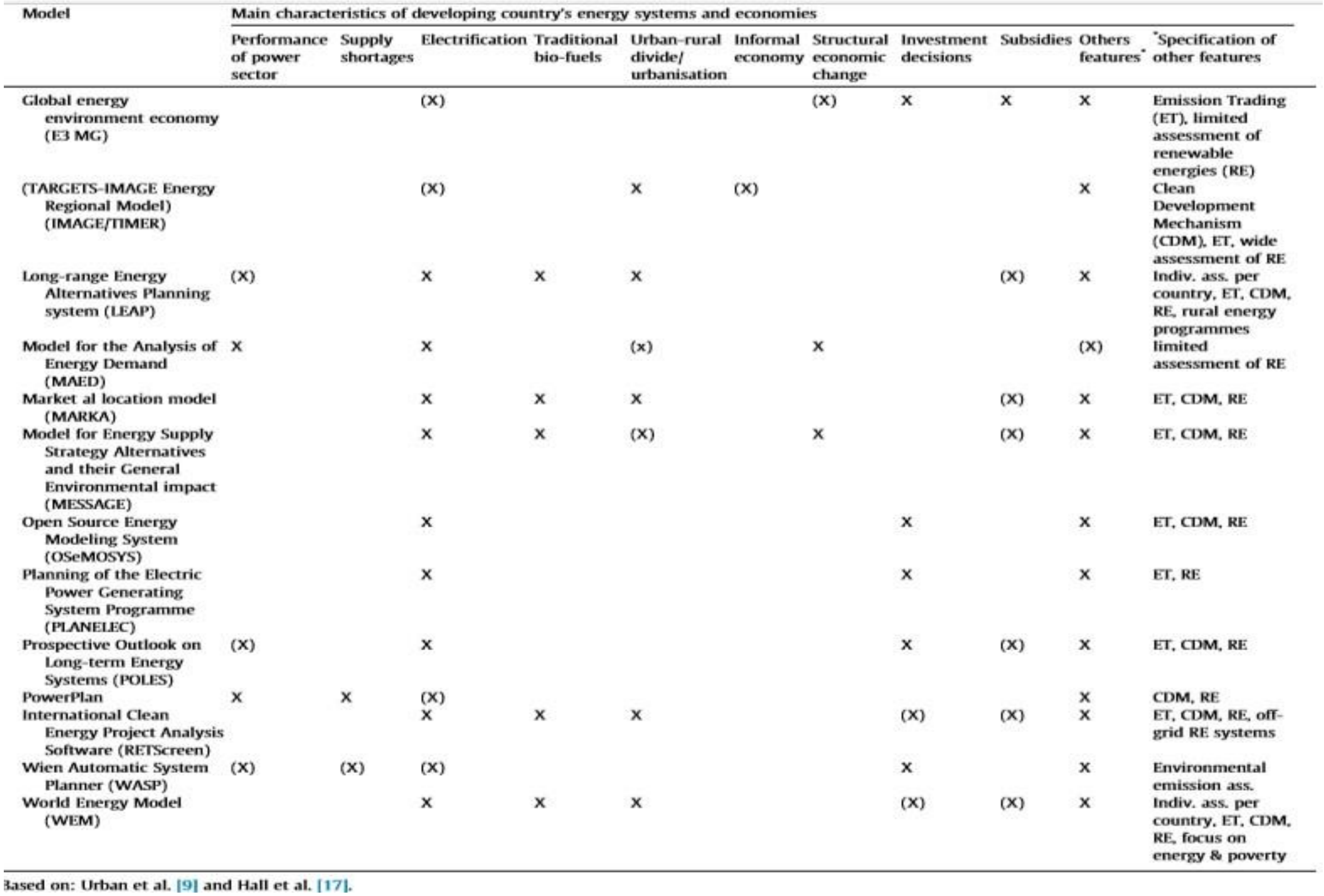
Table 2 contains a comparison of the main characteristics of developing countries' electricity systems and their economies per energy model, where [X] represents explicitly modeled characteristics and [(X)] represents the implicitly modeled characteristics [9]. It further shows the commonly used long-term global energy forecasting models that are primarily built and used in developed countries. Other models in Table 2 are used to assess energy systems in developing countries including Sub-Saharan Africa countries. The electricity systems of the developing countries are different from those of the developed countries and, hence majority of the forecasting models cannot adequately meet the characteristics of the requirements of the developing countries. These characteristics include the nature of the informal economy, supply shortages, poor services of the power sector, changes in the structural economy, low electrification rates, the high proportion of the total load attributable to the size of the traditional biomass and rural households [9].

2.3 Long-term electricity load forecasting

The literature study found that long-term load forecasting approaches were developed by numerous researchers to analyze future energy use in different parts of the world. For this purpose they used different specific methods of approach for individual regions or individual countries. For example, LEAP and PLEXOS were used to investigate future energy growth in the West African countries [15], [21]. Recently, LEAP was also used for the SADC region to evaluate the future energy demands of the Southern Africa Power Pool (SAPP) grid by Spalding-Fetcher et al [20]. Long-term electricity load forecasting study for twelve SADC countries (including Lesotho) was done using the End Use Method of evaluating the projected peak loads using LEAP [20]. These studies focused only forecasting the supply and demand scenarios for SADC countries not the hourly load curves as well as the base loads. The study did not produce accurate projections of the peak loads in Lesotho since at the time of the study, only the hourly load data of South Africa, Mozambique, Swaziland and Zambia were available. As a result, the South African hourly load data was used as the proxy to represent the other countries; the electrical energy consumption per household of Mozambique was used as the substitute to represent the other countries [20].

Hourly electricity forecasting model was developed for 14 West African countries, covering a period ranging from 2016 to 2030 by using the LEAP model [15]. The model was used to address the challenging gap in historical demand data because in developing countries the main challenge in load forecasting is the scarcity of historical data and methodological frameworks that adequately captured aspects of the past technology transitions and information about the historical evolution of the urban-rural communities. The study took into account the electrification rate, growth in the use of household appliances, the changes in the occupancy patterns of household members, type of the day, available daylight hours and hourly weather conditions [15]. This study did not produce the load profile for western country which include the peak and the baseload.

Table 2 Comparison of main characteristics of the energy model in developing countries [9]



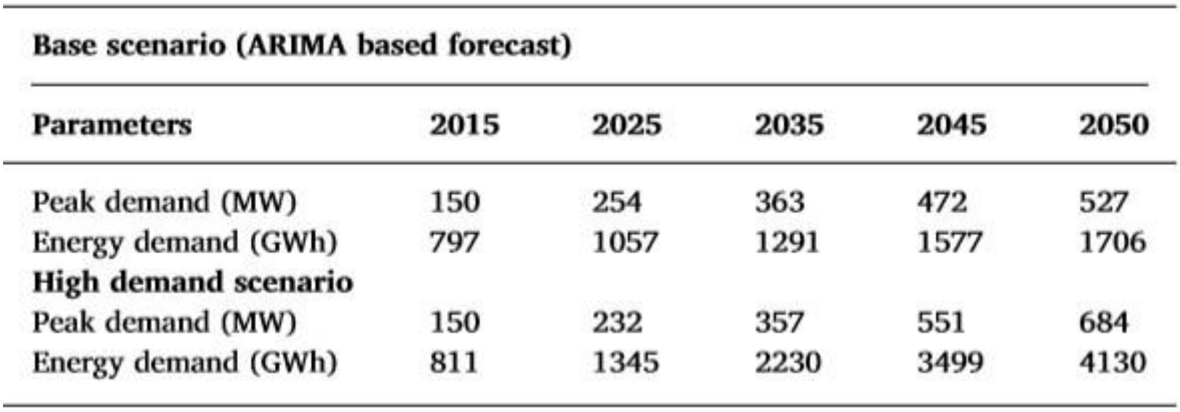
Model	Main characteristics of developing country's energy systems and economies										
	Performance of power sector	Supply shortages	Electrification	Traditional bio-fuels	Urban-rural divide/ urbanisation	Informal economy	Structural economic change	Investment decisions	Subsidies	Others features*	*Specification of other features
Global energy environment economy (E3 MG)			(X)				(X)	X	X	X	Emission Trading (ET), limited assessment of renewable energies (RE)
(TARGETS-IMAGE Energy Regional Model) (IMAGE/TIMER)			(X)		X	(X)				X	Clean Development Mechanism (CDM), ET, wide assessment of RE
Long-range Energy Alternatives Planning system (LEAP)	(X)		X	X	X				(X)	X	Indiv. ass. per country, ET, CDM, RE, rural energy programmes
Model for the Analysis of Energy Demand (MAED)	X		X		(x)		X			(X)	limited assessment of RE
Market al location model (MARKA)			X	X	X				(X)	X	ET, CDM, RE
Model for Energy Supply Strategy Alternatives and their General Environmental impact (MESSAGE)			X	X	(X)		X		(X)	X	ET, CDM, RE
Open Source Energy Modeling System (OSeMOSYS)			X					X		X	ET, CDM, RE
Planning of the Electric Power Generating System Programme (PLANELEC)			X					X		X	ET, RE
Prospective Outlook on Long-term Energy Systems (POLES)	(X)		X					X	(X)	X	ET, CDM, RE
PowerPlan	X	X	(X)							X	CDM, RE
International Clean Energy Project Analysis Software (RETScreen)			X	X	X			(X)	(X)	X	ET, CDM, RE, off-grid RE systems
Wien Automatic System Planner (WASP)	(X)	(X)	(X)					X		X	Environmental emission ass.
World Energy Model (WEM)			X	X	X			(X)	(X)	X	Indiv. ass. per country, ET, CDM, RE, focus on energy & poverty

Based on: Urban et al. [9] and Hall et al. [17].

PLEXOS software was used to develop the multi-regional economy dispatch using hourly simulation to investigate the impact of increased PV on the interconnected electricity network in West Africa. The electricity load hourly profile from 2009 to 2025 was generated in this study where the population in each region of the West African Countries was weighted into urban and rural. The reliability of the results of this study was limited by the use of this method in as much as it was based on population data from 2015, which could change significantly with time and could result in a shift of the regional demand electricity distribution in each country [21].

The study which produced the integrated electricity plan for Lesotho using the Autoregressive Integrated Moving Average (ARIMA) model for forecasting electricity demand and the PLEXOS model was conducted to evaluate the cost of investing in facilities and of producing future electrical load for Lesotho [22]. Though the projected peak demand was produced as shown in Table 3, the hourly load profiles were not produced. This situation could make it difficult for investors to appreciate the load profile of the LEC grid. Appreciating the load profile would have assisted with determining the appropriate sizes of generators which could have enabled the utility to effectively meet the inconsistent, fluctuating energy demand in the different seasons of the year and on the different types of the day. Generators of proper size could then be scheduled to easily address the base load without them generating excess power and others scheduled to meet the peak load at times when they were needed. Similarly, the hourly load forecast could have assisted the planners to develop the IRP with generators of the appropriate size to meet future electricity load during the different seasons of the year. Therefore, the investigator concluded that there was a need for hourly load curves which considered the different seasons of the year (summer and winter),and the types of the days, (working days, weekends and holidays). The patterns of the electricity demand curves throughout the year would have allowed the LEC to deploy generators of appropriate capacity depending on the demand of each time of the year and the energy resource which were available for use [22] .

Table 3 Comparison of Base and High Demand Growth for Lesotho [22]



Base scenario (ARIMA based forecast)					
Parameters	**2015**	**2025**	**2035**	**2045**	**2050**
Peak demand (MW)	150	254	363	472	527
Energy demand (GWh)	797	1057	1291	1577	1706
High demand scenario					
Peak demand (MW)	150	232	357	551	684
Energy demand (GWh)	811	1345	2230	3499	4130

Hourly demand forecasting method was developed for Turkey based on an annual, weekly and daily time horizon using a linear model that took into account the harmonics of these variations and the modulation of diurnal periodic variation by seasonal variations [13]. This model was only developed to project the hourly load demand for one year despite the need for a forecast to cover up to 20 years as the energy project needed a long-term plan given the high future capital cost involved. Another study was undertaken in Spain, to improve the forecasting methods through combining their long-term and short-term features by employing temporal disaggregation techniques [23]. The variables like temperature, weekday effects and daylight duration, were incorporated in the study but that could have created problems since it was so difficult to obtain accurate data gathered over a long period and this could have led to a huge error in the load forecast. A similar study was carried out on the future energy curves for Germany and Britain due to their swift transformation in the use of energy [24]. For this study they used the Electricity Load Curve Adjustment (eLOAD) and the Demand for Energy Service and Supply in Europe (DESSTinEE). The trends for Germany were not observed for the long-term due to the lack of data.

A study was undertaken in Denmark in which the data for aggregated hourly electricity demand showed the variation over the day, week and season and the forecasting of the aggregated hourly electricity load was conducted [25]. For example, the study showed that the consumption profiles of the customers were equally systematic but very different for the distinct categories. In other words, the distinct categories of customers contribute differently to the aggregated electricity load profile. Malaysian large steel mills used a combination of the bottom-up and the top-down approaches to forecast the daily and annual maximum demand of the steel mills [26]. Regression analysis was used in the top-down approach to forecast the annual electricity consumption of the steel mills. The bottom-up approach used the MAED-EL to convert the annual electricity consumption of the steel mills into the hourly load of the steel mills. The study addressed the load forecasting of one sector (industrial) not considering other sectors such as services, household and transport.

The construction of a long-term load forecasting for Syria covering the period of 1999 to 2030 using the bottom-up method of analysis using MAED-EL has also been reported [27]. The study evaluated the electricity hourly load curves for the different sectors which contributed to the total electrical load of the country, namely the Household sector, Services sector and Industries sector. In this study the load profile was presented but growth the base load was not discussed. The study considered the peak load growth and load factor

Though the existing literature regarding long term load forecasting in developing countries has predicted hourly load forecast, It does not including the base load which is also of the most importance when it comes to scheduling of fuel and designing the suitable size of the generator for the power plant which can meet the exact electrical demand without generating excess power which could end up being dumped into the power pool grid. Therefore, in this study the projection of the hourly peak load and the base load are considered this study addresses.

2.4 Overview of MAED model

MAED is a bottom-up model used for forecasting medium- to long-term load energy demand [19], [26], [27]. The model follows the End-Use Demand Forecasting steps of the engineering-economic model. It systematically relates the specific energy demands for producing various goods and services to the corresponding social, economic and technological considerations which affect energy demand. The nature and level of demand for goods and services are a function of several determining factors, including population growth, number of households per dwelling, number of electrical appliances used per dwelling, people's mobility and preference for transportation modes, national priorities for the development of certain industries or economic sectors, the evolution of the efficiency of certain types of equipment, the market penetration of new technologies and energy forms [19].

Figure 1 diagrammatically depicts the flow of the process by which the energy demand is calculated by the MAED model as a function of the possible scenario of possible future developments. This scenario covers two types of scenario elements. One scenario is related to the socio-economic system and describes the fundamental characteristics of the social and economic evolution of the country. The second one is related to the technological factors which should be taken into account in the calculation of energy demand, for example the efficiency of each alternative energy form and its penetration into its potential markets.

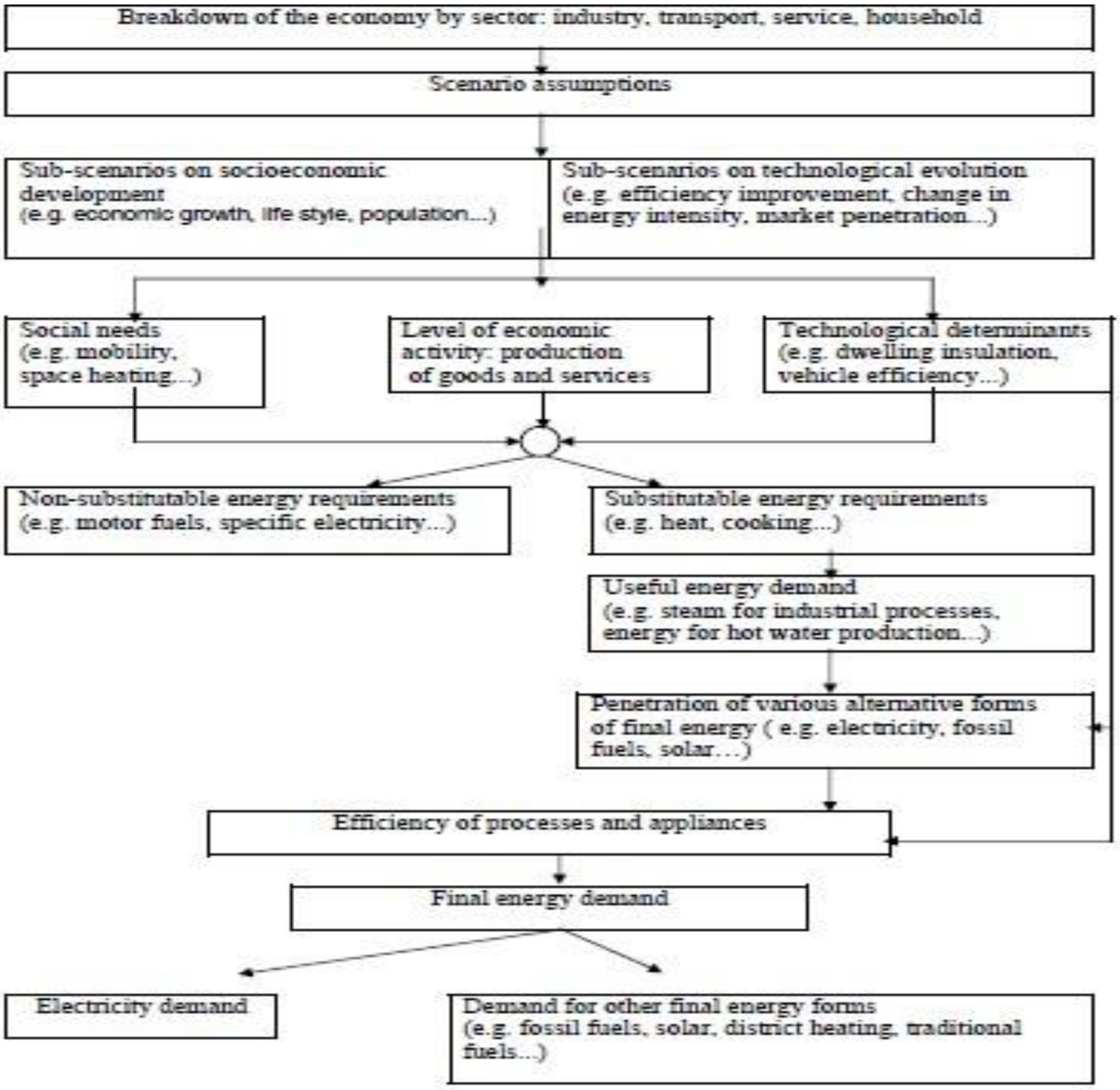


Figure 1 Application manual for MAED [28]

2.4.1 Construction of the hourly load curve

The hourly load calculations are performed using various modulation coefficients which correlate changes in hourly electricity consumption with average consumption. In determining hourly, daily and weekly electricity loads from the total electricity demand of the sector, the model takes into account varying load pattern throughout the year. Figure 2 shows the main input into the MAED model and the output from it. The model considers the trend of the average annual growth rate of the electricity demand, the seasonal changes in electricity consumption, the changes in electricity consumption owing to the type of the day being considered and the hourly variation in electricity consumption during the given type of day being considered.

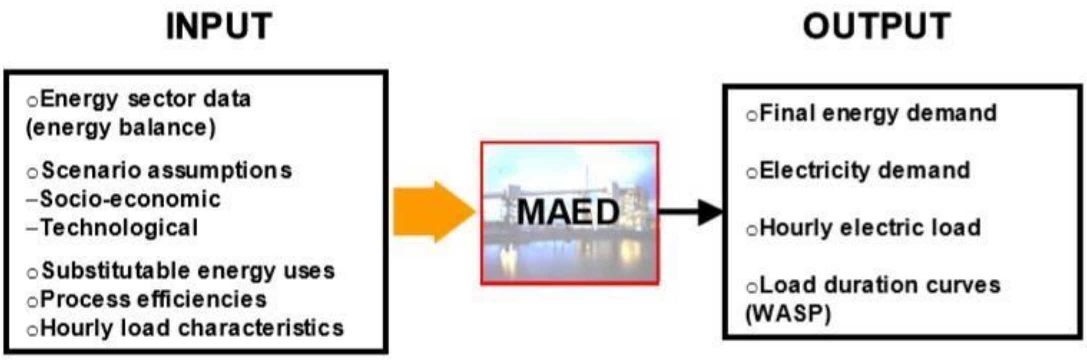


Figure 2 Main inputs and outputs of MAED [28]

2.4.2 Modulation coefficient calculations

Different modulation factors are used to derive the hourly demand from annual electricity demand. The modulation factors characterize the changes in electricity demand, and in turn change for the average electricity consumption in a year, a week or a day. The variation of a given sector by an hour, a day, or a week is characterized by a set of modulation coefficients that are defined for 24 hours in a day, by type of days in a week, for each week in the year [27]. These calculations are performed to establish a *standard day*. The first correction to be made corresponds to the general trends of growth of electricity consumption during the year.

The weekly coefficient T(I) is given in Equation (6) as:

$$T\,(I) = 1 + \left(\frac{Growth}{100}\right)^{\frac{I-26.2}{53}} \qquad (6)$$

where "*I*" is the weekly coefficient and the "*Growth*" is the average annual growth rate of the electricity demand for each sector between the previous and the current year while "*53*" is the total number of weeks in a year.

The Seasonal Coefficient K(I) represents the fluctuating level of electricity consumption due to the different seasons of the years (by week), for example, winter and summer loads where in winter the consumption of electrical energy is high because of space heating, and low in summer in areas where air conditioning is not used extensively for cooling. The Seasonal Coefficient is given in Equation (7) as:

$$(I) = \frac{Week\ (I) \times T(I)}{\frac{1}{53}\sum_{1}^{53} Week \quad consumption \times T \quad I} \qquad \underset{(I)}{K} \qquad ( ) \tag{7}$$

The Daily Coefficient P(I, ID) represents the changing electricity load patterns due to different type-of-days, like working days, weekends and holidays. The Daily Coefficient for the day is given in Equation (8) as:

$$P(I, ID) = \frac{Day\ (ID)_{consumption}\ of\ \ week\ (I)}{Average\ day\ in\ a\ week\ (I)_{Consuption}} \tag{8}$$

where (*ID*) is 7 days if the week from 1 up to 7

The Hourly Coefficient of the type-of-day represents the varying electrical load patterns during the particular type-of-day. The hourly coefficient is given in equation (9) as:

$$LCOEF(L, J, IS, ID) = \frac{HE(L,J,IS,ID)}{EAHE(J,IS,ID)} \tag{9}$$

Where:
L = 1,.,.,24 (hour of the day)
J = 1,.,3 clients of the sector
IS = 1,.,.,3 seasons of the year
ID = 1,.,.,week days for daily load curve

$HE(L, J, IS, ID)$ is the electricity consumption in hour L of the day ID in sector J and season IS.

$EAHE(J, IS, ID = \frac{\sum_{L-1}^{24} HE(L,J,IS,ID)}{24}$ is electricity consumption in an equivalent average hour in a day *ID* in sector *J* and season *IS*, (10)

The share of total consumption in each day type for each season is:

$$LCS_{IS}\ (L, ID) = \sum{}^{3}{}_{J-1} LCONT_{IS}\ (J, ID) \times LCOEF_{IS}\ (L, J, ID) \tag{11}$$

where LCS_{IS} is the aggregated coefficient of the sector for each season and $LCONT_{IS}$ is the weight of the client type in the sector for each season.

The total number of Equivalent Working Days for the current year's season is given in Equation (12) as:

$$N = \sum^{NODAYT}{}_{J-M+1} P\ (I, ID) \times K(I) \times T(I) \tag{12}$$

where *NODAYT* is the total number of days in that year.

The energy consumption of the sector in the equivalent average working day is given in Equation (13) as:

$$EDWS = \frac{Energy}{N} \tag{13}$$

where *Energy* is the annual electricity consumption of the current sector in the current model year derived from the final electricity demand projection.

The total electricity consumption of the current sector for the calendar is given Equation (14) as:

$$E(M) = EWDS \times K(I) \times T(I) \times P(I, ID) \tag{14}$$

The electrical demand of the sector is given in Equation (15) as:

$$PV_{IS}\ (IT, L, M) = E(M) \times \frac{LCS^{IS}\ (L, ID)}{24} \tag{15}$$

where *IT* is the power demand of each sector.

The total annual electricity demand of the sector is given in Equation (16) as:

$$ESUM(ID) = \sum^{NODAYT}{}_{M-1} E(M) \tag{16}$$

Total annual demand is given in Equation (17) as:

$$ET = \sum^{4}{}_{IT-1} ESUM(IT) \tag{17}$$

The growth rate is calculated in Equation (18) as:

$$GROWAV = \sum_{4IT-1} ESUM(IT) \times \frac{GROWTH}{ET\ (IT)} \tag{18}$$

The Total hourly load on the plant is given in Equation (19) as:

$$PT_{IS}\ (L, M) = \sum_{4IT-1} PV_{IS}\ (IT, L, M) \tag{19}$$

2.4.3 Choice of the base year

When the MAED model is used, the choice of the base year is critical because it determines the base of the projection when the reliability of the model is evaluated. It serves to verify the reliability of the results produced by the model when the calculated results are to be compared to the actual results to confirm the accuracy of the model. According to Agrawal et al the allowable error in load forecasting is 5% [14]. If a forecast that exceeds this allowable error is accepted, its use can lead to huge amounts of unnecessary expenditure, for example, when the utility constructs a power plant with capacity that exceeds the required demand [14]. The accurate reconstruction of the energy consumption patterns of the base year within the MAED model is the starting point for the MAED-EL to perform the forecasting.

2.4.4 Load duration curve

The Load Duration Curve (LDC), as one of MAED-EL's outputs, illustrates the variation of a certain load in descending order such that the greatest load is plotted from the beginning of the x-axis of the graph. The area under the LDC represents the energy demand of the system. The LDC is used in economic dispatching system planning and reliability evaluation of electrical energy. The LDC is also used for power dispatch generation to determine the duration of time at which a certain load will require generation.

2.4.5 Load factor

The Load Factor of the system is the ratio of the *peak load* to the *average load* in a specific period. This is the measure of the utilization rate of electrical energy usage. This means that a high Load Factor indicates that the load is using the electricity system more efficiently. The value of the Load Factor is less than one because the maximum demand is never lower than the average demand. The Load Factor plays an important role in the unit generated per kWh because the higher the Load Factor the cheaper the unit cost per kWh because it would signify that the *average value* is closer to the *peak value* of the system and that the plant is being utilized almost fully and not idling without generating power.

2.5 Factors which influence the consumption of electricity

There were numerous studies conducted regarding the correlation between electricity consumption and GDP, and population growth and electricity price. For example, a study was conducted to analyze the influence of economic variables on the electricity consumption for Northern Cyprus by using multiple regression analysis. It was found that the number of customers, the price of electricity and the number of tourists correlated to the annual consumption of electricity [29]. Earlier, in 1993, it was found that price also played a part in the consumption of electrical energy [30]. It was also reported that weather conditions and the demographics of the population played vital roles in electrical energy consumption in their study of electricity consumption in Delhi [31].

In 2015 it was reported that, in the case of Lesotho, the price of electricity and the GDP influenced the consumption of electrical energy [32]. It was, however, found that the price of electricity did not have a great impact on the use of electricity in Lesotho, while the GDP played a major role as shown in Figure 3, clearly illustrating the positive correlation between electricity consumption and GDP from 1995 to 2012. It demonstrates that as the GDP increases, the electricity consumption is also increasing.

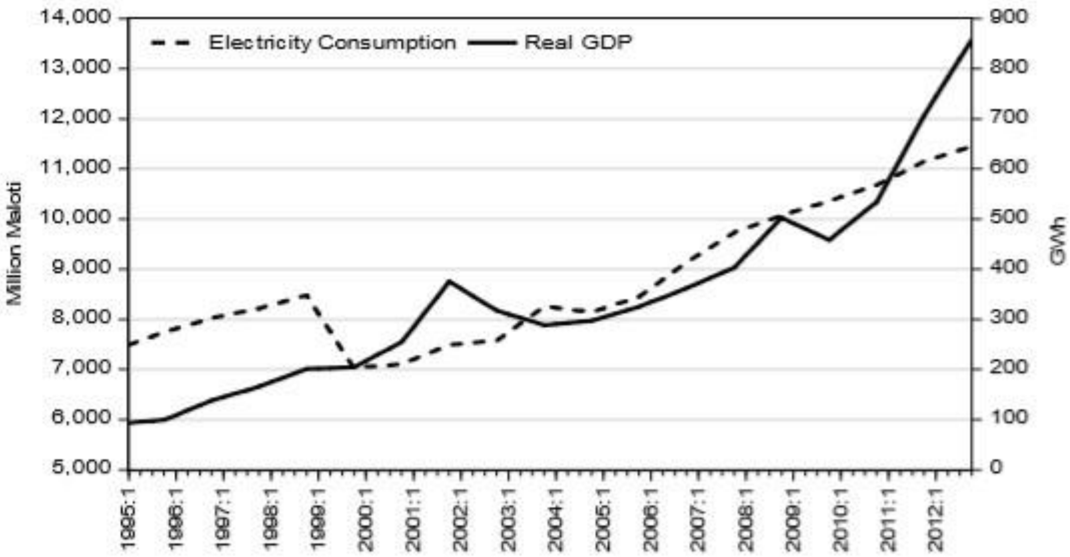


Figure 3 Lesotho Electricity Consumption and real GDP [32]

The population growth in the growing economy will also have a similar impact on the use of electricity because as people earned more, they used more electrical appliances at home for lighting, heating, cooking, washing, refrigerating, communicating, etc. Depending on the energy intensity of the country, the use of electricity would be higher in developing countries like Lesotho. Because of the lower energy efficiency, people would, when they start using electricity, buy low-efficiency appliances that are affordable. When people earn more money they would look for more energy-efficient appliances and equipment and the use of automated machines would be more extensive.

Chapter 3 – Methodology

3.1 Introduction

The method of approach stated in Figure 2 was adopted in this study. Figure 4 illustrates the method followed when this study was executed. The first step was to collect electrical load profile for LEC grid and analysing it, the scenarios assumption for the study were determined, factors which affect electrical load growth were considered, the coefficients were calculate and then uploaded into MAED-EL, then the construction of the base year was made, followed by validation of results by comparing the calculated and actual results. Finally the forecasting of hourly electrical load for LEC, then, the results of the project was analysed.

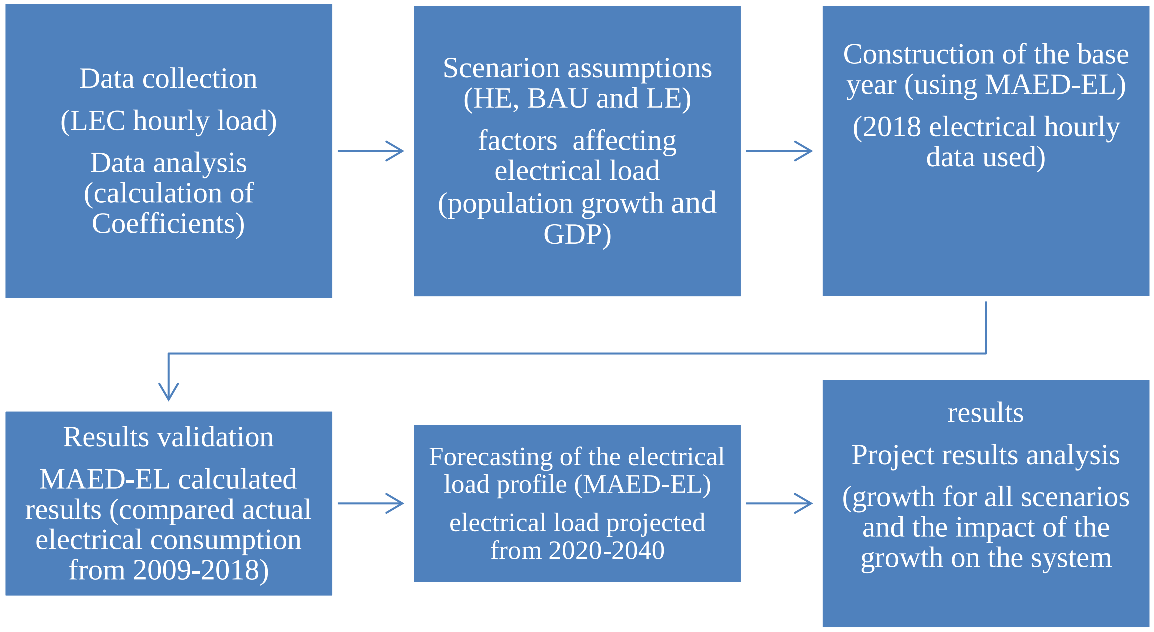


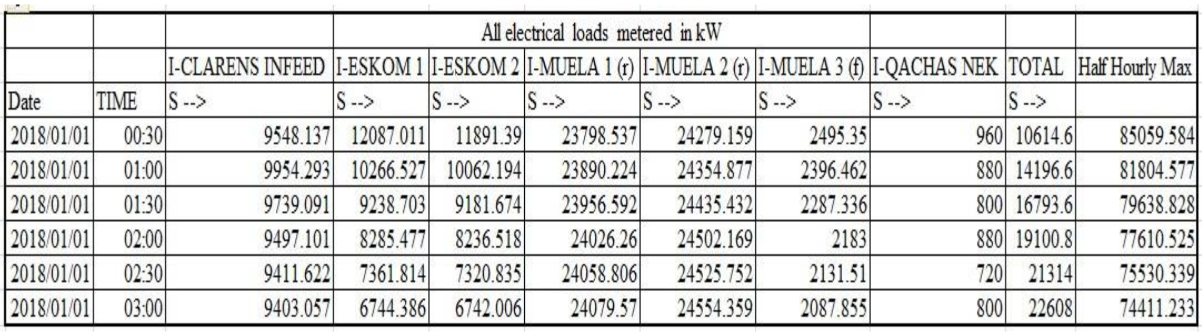
Figure 4 Process followed to execute the project

3.2 Data collection

Raw half-hourly electrical load data of 2018 from January to December for Lesotho Electricity Company (LEC) was collected from the statistical energy meters at different electricity supply points which were: Muela hydro station at Muela, Eskom's infeed supply point at Mabote substation, the Clarence infeed supply at Khukhune substation and the infeed supply at Qacha's Nek substation. Enermax software was used to download the electrical load data. In order to prepare input data into MAED-EL, the first step was to convert halfhourly electrical load to hourly peak load by considering the peak of each hour from the halfhour meter interval readings. The Load Profile graph for 2018 was developed to appreciate the pattern electrical load in a year, which informs the number of the seasons in a year that the electrical load profile have. The hourly peak loads were then used to calculate the weekly, daily and hourly coefficients. The coefficients were used as the input to MAED-EL and to inform the varying load pattern when the simulation was performed for load forecasting.

Table **4** shows the snapshot of a part of a typical sample of 3 hours' raw data for 01/01/2018 to illustrate the half-hour meter reading intervals before different sources were added together to produce the hourly load profile for a year which was then used as input to MAED-EL. This formed part of the data used in MAED-EL when calculating the load curve and the load factor.

Table 4 Load profile for power supply into LEC grid



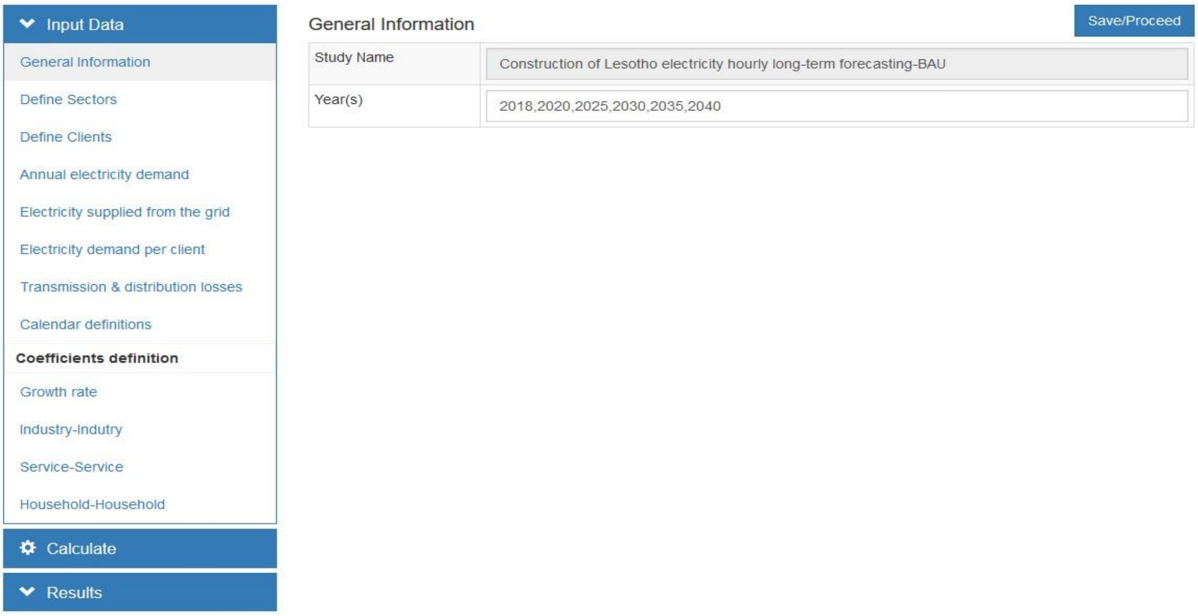
			All electrical loads metered in kW							
		I-CLARENS INFEED	I-ESKOM 1	I-ESKOM 2	I-MUELA 1 (r)	I-MUELA 2 (r)	I-MUELA 3 (f)	I-QACHAS NEK	TOTAL	Half Hourly Max
Date	TIME	S -->	S -->	S -->	S -->	S -->	S -->	S -->	S -->	
2018/01/01	00:30	9548.137	12087.011	11891.39	23798.537	24279.159	2495.35	960	10614.6	85059.584
2018/01/01	01:00	9954.293	10266.527	10062.194	23890.224	24354.877	2396.462	880	14196.6	81804.577
2018/01/01	01:30	9739.091	9238.703	9181.674	23956.592	24435.432	2287.336	800	16793.6	79638.828
2018/01/01	02:00	9497.101	8285.477	8236.518	24026.26	24502.169	2183	880	19100.8	77610.525
2018/01/01	02:30	9411.622	7361.814	7320.835	24058.806	24525.752	2131.51	720	21314	75530.339
2018/01/01	03:00	9403.057	6744.386	6742.006	24079.57	24554.359	2087.855	800	22608	74411.233

Since the loads were from different sources, the grid peak load was achieved by adding the meter readings of all the sources of power together, i.e. those at Muela hydro, Eskom intake at Mabote substation Clarence and Qacha intake.

3.3 MAED-EL Modeling

3.3.1 Defining the project

Figure **5** is a copy from the software's documentation, of an overview of MAED-EL shows the data input. The information about the project name was defined and the reference years for the duration of the project were set at an interval of five years starting from 2020 to 2040. The data which captured into MAED-EL shown on input data column and the reference years under the general information. Although MAED-EL is designed to consider four economic sectors namely: service, households, industries and transport, in this study transport was not considered as there was no specific use of electricity for transport in Lesotho. MAED-EL also allows major clients in sectors like mining, agriculture and manufacturing to be considered individually when deriving the hourly distribution from the annual electricity demand but for this study such information was not available and the sectors were treated as the clients [27].

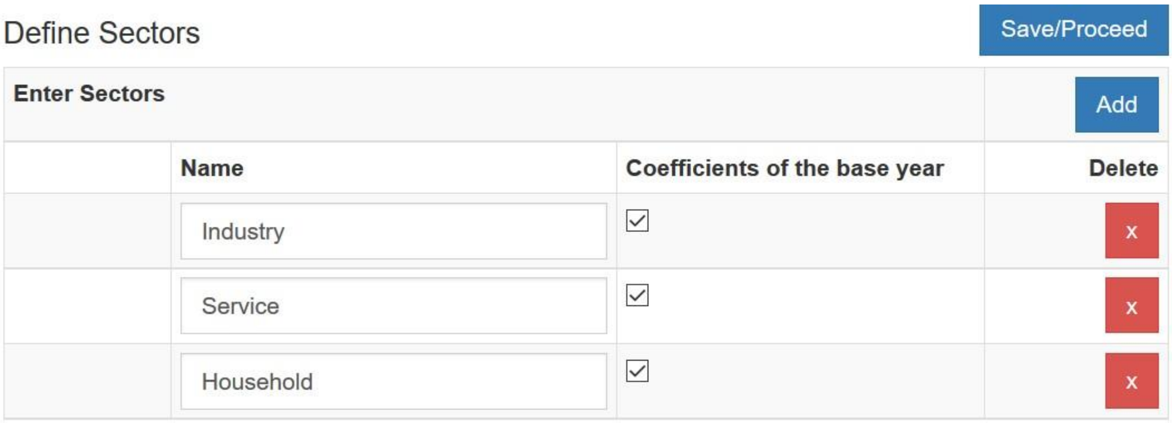


General Information

Study Name	Construction of Lesotho electricity hourly long-term forecasting-BAU
Year(s)	2018,2020,2025,2030,2035,2040

Figure 5 MAED-EL data input file

Consumption of electrical energy varies with the purpose it is used for, example, industrial or domestic. MAED-EL is designed to forecast the electrical load for four sectors namely: industry which can further be disaggregated into clients such as mining and textile industries to mention few, Service such as Government offices and retail businesses, domestic and transport. In this study only three sectors were considered namely; industry, service and domestic. Since MAED-EL uses the End-Use Approach it considers the disaggregation of electricity consumption by different clients which contributed to the sectors. For this study, such detailed data was not available since the statistical meters, installed at the main substation, metered the combined load of all the sectors because there were no statistical meters dedicated to each client. For this study the data related to the individual sectors were also treated as the clients.



Define Sectors

Enter Sectors

Name	Coefficients of the base year	Delete
Industry	☑	x
Service	☑	x
Household	☑	x

Figure 6 Sectors considered for load forecasting

3.3.2 Electricity Demand and Losses

For MAED-EL to forecast electrical energy, the annual hourly electrical data was inserted into MAED-EL for industry, service and household sectors. **Table 6** shows the copy of base year (2018) and reference years (2020, 2025, 2030, 2035 and 2040) for electricity demand. The total electricity purchased in 2018 was 891 GWh while the total consumption was 790 GWh hence the total losses of 12%.The customers of LEC were categorized into two main categories namely; a) Postpaid customers and b) Prepaid customers. The Postpaid category was further broken down into Credit Domestic, Credit General Purpose, Commercial LV, Commercial MV, Industrial MV and Industrial LV while the Prepaid category was broken into Prepaid Domestic and Prepaid General Purpose. Other consumers of electricity on the LEC's grid were the street lights and the electricity provided to staff and board members of the LEC. For MAED-EL to perform its calculations the sectors and clients as defined were grouped into three groups: Services, Households and Industrials. The Services group consisted of Credit Domestic, Credit General Purpose, Commercial LV, Commercial MV and Prepaid General Purpose. The Prepaid customers were grouped into Households comprising Prepaid Domestic and Credit Domestic. Industrials included the Industrial LV, Industrial MV and LHDA. The total collected data in each category are shown in Table **5**, below.

Table 5 Total Energy Consumption by Customer Category

Customer category	Annual energy 2018/2019 (MWh)
Credit domestic	530
Credit general purpose	1929
Commercial	145 254
Industrial	274 528

LHDA	7 038
Prepaid domestic	258 953
Prepaid general purpose	92 786
Street lights	3 686
Staff including board members	5 228
Total consumption	**789 932**

Therefore, the total annual energy consumed by the sectors are:

Services = Commercial + Prepaid general purpose + Credit general purpose + street light

Households = Credit domestic + Prepaid domestic + Staff including the board **Industrials** = Industrial + LHDA

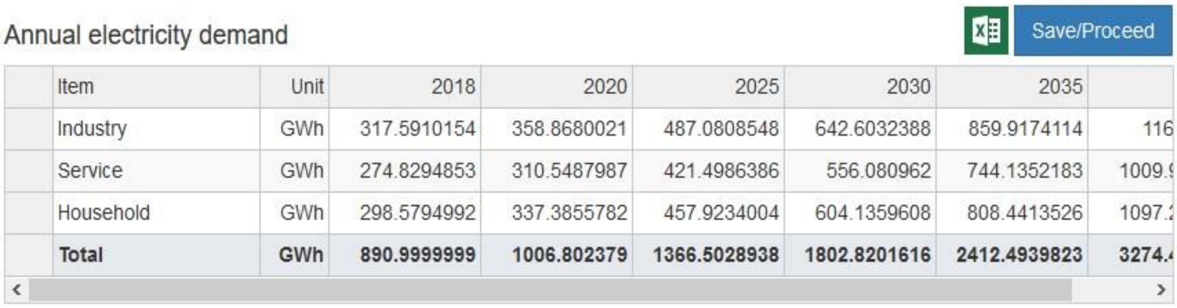
Services = 243.655 MWh

Households = 264.711 MWh

Industrials = 281.566 MWh

Total annual consumption = 789 932 MWh

Table 6 reference years for electricity demand



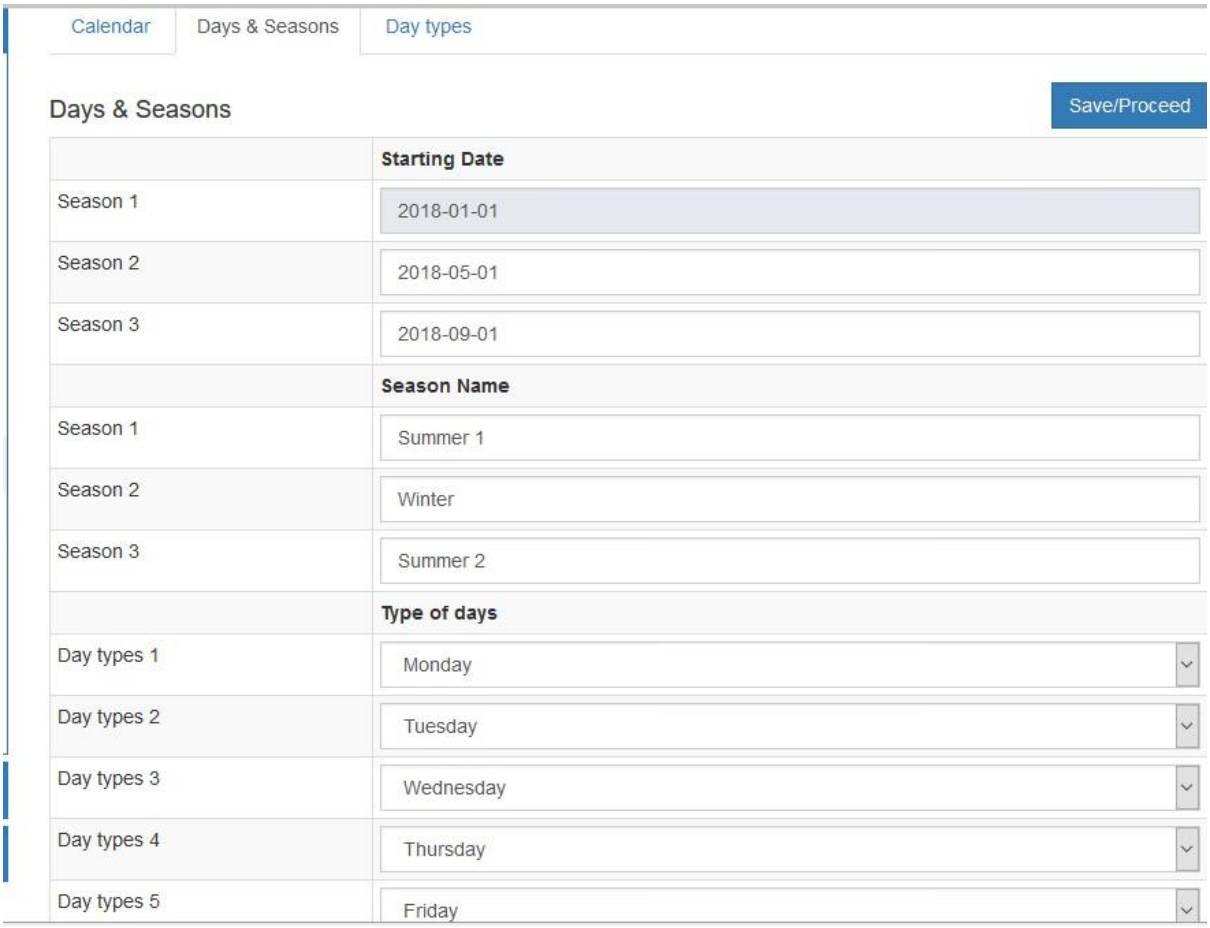
Annual electricity demand

Item	Unit	2018	2020	2025	2030	2035	
Industry	GWh	317.5910154	358.8680021	487.0808548	642.6032388	859.9174114	116
Service	GWh	274.8294853	310.5487987	421.4986386	556.080962	744.1352183	1009.
Household	GWh	298.5794992	337.3855782	457.9234004	604.1359608	808.4413526	1097.
Total	**GWh**	**890.9999999**	**1006.802379**	**1366.5028938**	**1802.8201616**	**2412.4939823**	**3274.**

3.3.3 Calendar Definitions

When forecasting, MAED-EL considered the varying load patterns throughout the year according to the different seasons of the year. The calendar was prepared by defining the first day of the week as Monday and last day as Sunday, the number of types-of-day to be two: type 1 was Working Day (Monday to Friday) and Day Type 2 was Weekend (Saturday and Sunday) and the Holiday. MAED-EL is designed to cater for 12 seasons of the year which represent different patterns of the load throughout the year. For this study only three seasons were used since the load curve pattern of Lesotho was the same for two seasons, namely Summer 1 and Summer 2; the third season, Winter, was different as the season when the peak load occurred. Each season lasted a third of the year, i.e. they each lasted 4 months. Summer 1 lasted from 1st January 2019 to 28th April 2018. The hours of each season were calculated by converting the days to hours, there were 120 days which converted to 2880 hours as the duration of Summer 1. Winter lasted from 1st May 2018 to 30th August 2018, i.e. 123 days which converted to 2952 hours. Summer 2 lasted from 1st September 2018 to 31st December 2018, i.e. 122 days which converted to 2928 hours. MAED-EL calculated the Load Curve Projections based on the number of hours from 1st January 2018 to 31st December 2018 with three seasons. **Figure 7** is the copy of MAED-EL

calendar for year, weekdays and seasons.



Days & Seasons

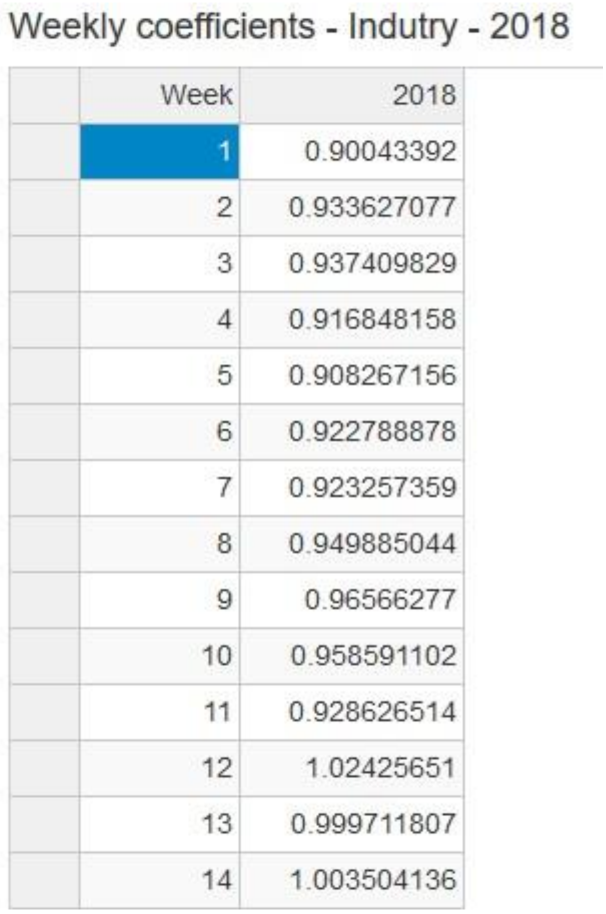
	Starting Date
Season 1	2018-01-01
Season 2	2018-05-01
Season 3	2018-09-01
	Season Name
Season 1	Summer 1
Season 2	Winter
Season 3	Summer 2
	Type of days
Day types 1	Monday
Day types 2	Tuesday
Day types 3	Wednesday
Day types 4	Thursday
Day types 5	Friday

Figure 7 calendar

3.3.4 Coefficients Definitions

Equation (7) was used to calculate the weekly Coefficients, they were uploaded into MAEDEL. They are used to calculate for standard day in relation with the general trends of electricity consumption in a year ( ). Even though there are actually 52.142 weeks in the year, MAED-EL considers round numbers only, hence 53 weeks was used. Table **7** shows the weekly coefficients which are used in MAED-EL to calculate the varying hourly load for 53 weeks of the year.

Table 7 weekly coefficients

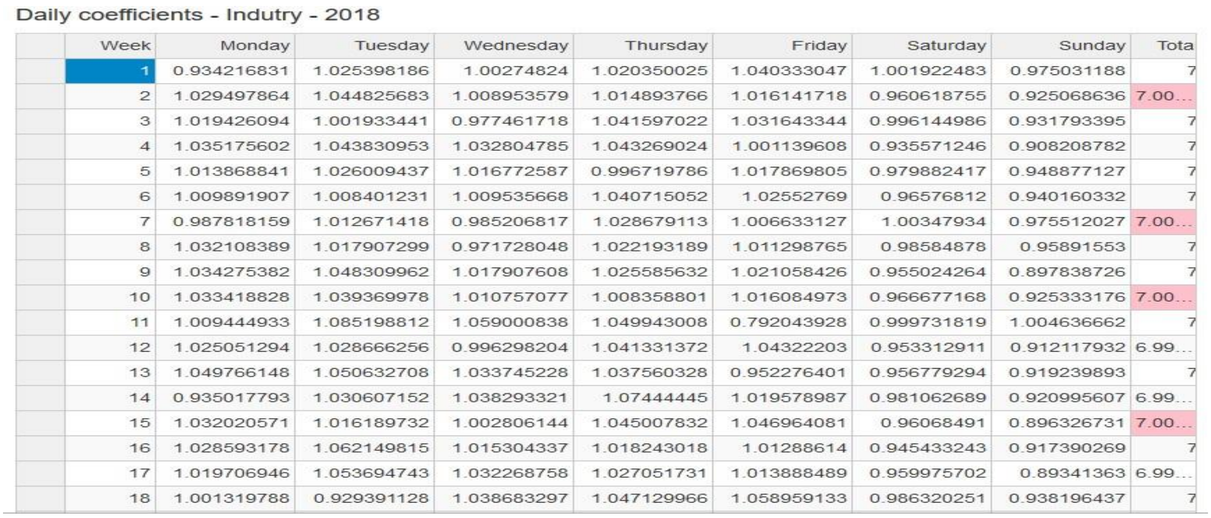


Weekly coefficients - Indutry - 2018

	Week	2018
	1	0.90043392
	2	0.933627077
	3	0.937409829
	4	0.916848158
	5	0.908267156
	6	0.922788878
	7	0.923257359
	8	0.949885044
	9	0.96566277
	10	0.958591102
	11	0.928626514
	12	1.02425651
	13	0.999711807
	14	1.003504136

Table **8** shows the daily coefficient from MAED-EL as they were calculated using equation (8). It was used to determine the changing consumption of electrical load due to varying day types of the week such as working days, weekends and holydays for 53 weeks of the year.

Table 8 daily coefficients

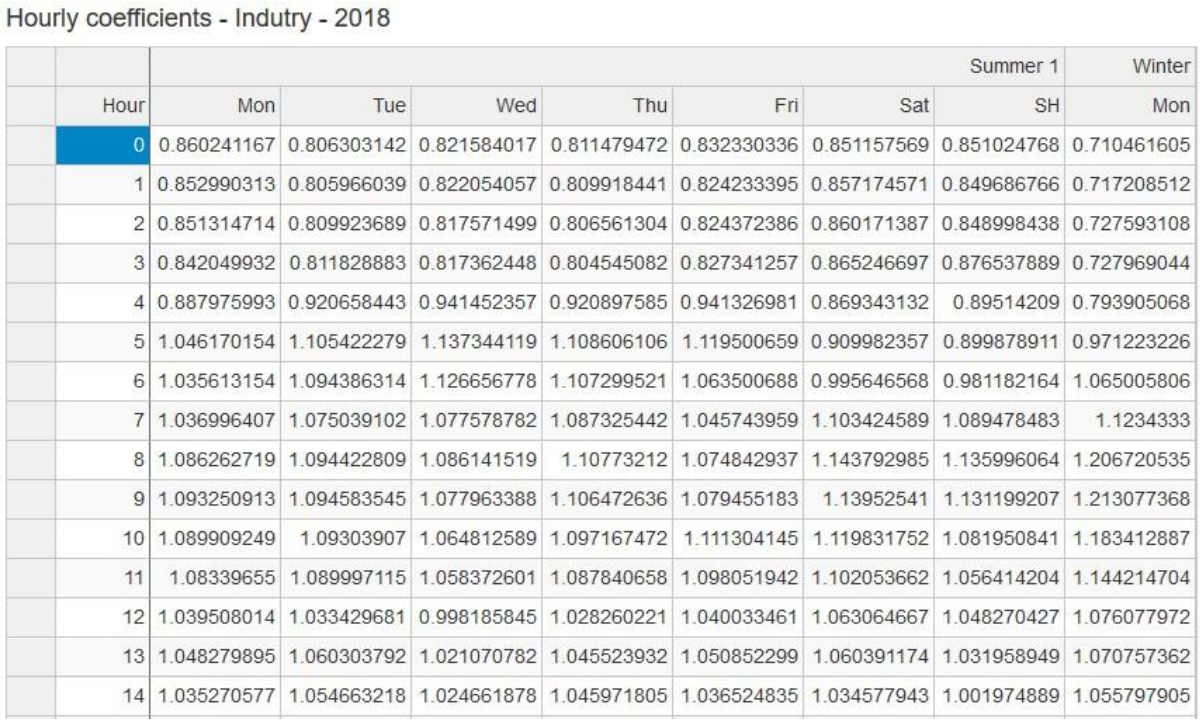


Daily coefficients - Indutry - 2018

	Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Tota
	1	0.934216831	1.025398186	1.00274824	1.020350025	1.040333047	1.001922483	0.975031188	7
	2	1.029497864	1.044825683	1.008953579	1.014893766	1.016141718	0.960618755	0.925068636	7.00...
	3	1.019426094	1.001933441	0.977461718	1.041597022	1.031643344	0.996144986	0.931793395	7
	4	1.035175602	1.043830953	1.032804785	1.043269024	1.001139608	0.935571246	0.908208782	7
	5	1.013868841	1.026009437	1.016772587	0.996719786	1.017869805	0.979882417	0.948877127	7
	6	1.009891907	1.008401231	1.009535668	1.040715052	1.02552769	0.96576812	0.940160332	7
	7	0.987818159	1.012671418	0.985206817	1.028679113	1.006633127	1.00347934	0.975512027	7.00...
	8	1.032108389	1.017907299	0.971728048	1.022193189	1.011298765	0.98584878	0.95891553	7
	9	1.034275382	1.048309962	1.017907608	1.025585632	1.021058426	0.955024264	0.897838726	7
	10	1.033418828	1.039369978	1.010757077	1.008358801	1.016084973	0.966677168	0.925333176	7.00...
	11	1.009444933	1.085198812	1.059000838	1.049943008	0.792043928	0.999731819	1.004636662	7
	12	1.025051294	1.028666256	0.996298204	1.041331372	1.04322203	0.953312911	0.912117932	6.99...
	13	1.049766148	1.050632708	1.033745228	1.037560328	0.952276401	0.956779294	0.919239893	7
	14	0.935017793	1.030607152	1.038293321	1.07444445	1.019578987	0.981062689	0.920995607	6.99...
	15	1.032020571	1.016189732	1.002806144	1.045007832	1.046964081	0.96068491	0.896326731	7.00...
	16	1.028593178	1.062149815	1.015304337	1.018243018	1.01288614	0.945433243	0.917390269	7
	17	1.019706946	1.053694743	1.032268758	1.027051731	1.013888489	0.959975702	0.89341363	6.99...
	18	1.001319788	0.929391128	1.038683297	1.047129966	1.058959133	0.986320251	0.938196437	7

Equation (9) was used to calculate the hourly coefficients; they are defined as the factors which determine the varying electrical load consumption due to changing hours of the day. Table **9** shows the hourly coefficient which is the input into MAED-EL for 24 hours of the day in seven days of the week for 53 weeks of the year.

Table 9 hourly coefficients



Hourly coefficients - Indutry - 2018

								Summer 1	Winter
	Hour	Mon	Tue	Wed	Thu	Fri	Sat	SH	Mon
	0	0.860241167	0.806303142	0.821584017	0.811479472	0.832330336	0.851157569	0.851024768	0.710461605
	1	0.852990313	0.805966039	0.822054057	0.809918441	0.824233395	0.857174571	0.849686766	0.717208512
	2	0.851314714	0.809923689	0.817571499	0.806561304	0.824372386	0.860171387	0.848998438	0.727593108
	3	0.842049932	0.811828883	0.817362448	0.804545082	0.827341257	0.865246697	0.876537889	0.727969044
	4	0.887975993	0.920658443	0.941452357	0.920897585	0.941326981	0.869343132	0.89514209	0.793905068
	5	1.046170154	1.105422279	1.137344119	1.108606106	1.119500659	0.909982357	0.899878911	0.971223226
	6	1.035613154	1.094386314	1.126656778	1.107299521	1.063500688	0.995646568	0.981182164	1.065005806
	7	1.036996407	1.075039102	1.077578782	1.087325442	1.045743959	1.103424589	1.089478483	1.1234333
	8	1.086262719	1.094422809	1.086141519	1.10773212	1.074842937	1.143792985	1.135996064	1.206720535
	9	1.093250913	1.094583545	1.077963388	1.106472636	1.079455183	1.13952541	1.131199207	1.213077368
	10	1.089909249	1.09303907	1.064812589	1.097167472	1.111304145	1.119831752	1.081950841	1.183412887
	11	1.08339655	1.089997115	1.058372601	1.087840658	1.098051942	1.102053662	1.056414204	1.144214704
	12	1.039508014	1.033429681	0.998185845	1.028260221	1.040033461	1.063064667	1.048270427	1.076077972
	13	1.048279895	1.060303792	1.021070782	1.045523932	1.050852299	1.060391174	1.031958949	1.070757362
	14	1.035270577	1.054663218	1.024661878	1.045971805	1.036524835	1.034577943	1.001974889	1.055797905

Figure 8 hourly coefficients

After all coefficients (weekly, daily and hourly) were built-in into MAED-EL for all sectors (industry, services and household) the calculation for hourly load profile were performed.

3.7 Reconstruction of the Base Year

The 2018 hourly electrical load data was used to construct the Base Year for the study. The base year in this study was contracted to compare calculated results to actual results. When constructing the Base Year the consumption purchased, consumption per sector, types of sectors, transmission and distribution losses and electricity penetration were considered. The LEC reported that the combined electricity losses transmission and distribution were 12% and that the total electricity purchased was 891 GWh while the consumed electrical energy was 790 GWh in 2018. This combination of losses made to have the exact value for transmission and distribution losses which are required as input in MAED-EL.

To project the future electrical energy growth, the combined 12% transmission and distribution losses were divided 5% and 7% transmission and distribution and the calculated Peak Load result for the Base Year was 166 MW. The actual Peak Load in 2018, was 162 MW and therefore the deviation of calculated results to the actual was 2.4%. This deviation was within the ranges of the allowed deviation error of 5% [14].

In order to validate accuracy of the model, past electrical energy consumption for LEC was further calculated from 2009 to 2018 to compare the actual and the calculated results. According to LEC annual electrical energy consumption report the purchased electrical energy was 568.39 GWh and peak load was 116 MW in 2009. The average annual growth rate from 2009 to 2018 was 4% and used to project the growth for the validation calculations.

3.8 Scenario selection

This is the process of analysing possible future events by considering alternative possible outcomes. Three scenarios were used in this study, namely Business-As-Usual (BAU), Low Economy Scenario (LE) and High Economy Scenario (HE). The Business-As- Usual scenario assumes that the economic growth and the demographics of the population would keep to the then- current-trends in the rate of growth. The Low Economy scenario considers the factors that could impact economic growth such as lack of investment in the country and political instability. The High Economy scenario presents the situation when the economy is growing at a high rate which could be the result of, for instance, the opening of new mines, the creation of a greater variety of industries, and the commercialization of farming.

3.8.1 Economic Growth

Mohamed (2005) pointed out that the main factors which influenced the consumption of electricity are the GDP and the growth in the population. Future electrical consumption is therefore forecasted based on the projection of the economic growth and the population's growth as there is a correlation between electricity consumption and the GDP [29]. The trend in the consumption of electricity over the past 10 years was used to predict future economic growth which would influence the electrical load growth. Since the growth of the economy is fluctuating, three scenarios were considered for load forecasting in this study. According to the Annual National Accounts of Lesotho of 2008-2017 the average growth of the GDP for the 10 years, 2008 to 2017, was 3.8%[3], the low economic growth was 1.8% and the high economic growth was 5.9%.

Figure **9** Lesotho Annual National Accounts contains the actual GDP growth rate from 2008 to 2017 as it is reflected in the current Lesotho National Accounts for the past 10 years. These National Accounts were used to predict future GDP growth which would affect the electrical energy consumption forecast in this study.

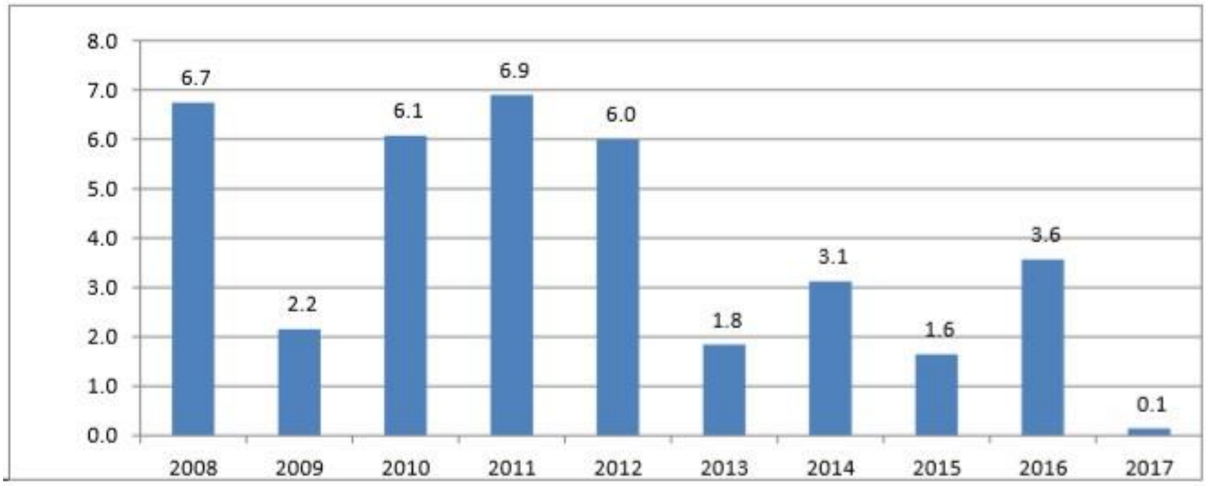


Figure 9 Lesotho Annual National Accounts

3.8.2 Population Growth

The second factor which affects the electrical energy consumption is population growth. Lesotho Bureau of Statistics conducted a study to predict the growth in the population from 2016 to 2036. Four variant scenarios were considered for the population growth which was High Two variant and Medium variant where population growth was assumed to decline from 3.2% to 2.7% from 2016 to 2026; then remain constant at 2.7% until 2036. High one variant

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[3] See Lesotho Bureau of Statistics report of 2008-2017

declined from 3.2% to 2.2% from 2016 to 2026 then remain constant at 2.2% until 2036. The Low variant assumed the population to decline from 3,2% to 2.12% from 2016 to 2026 and remain constant at 2.12% until 2036. Therefore the population growth was expected to grow from 2.0 million in 2016 to between 2.2 million and 2.5 million if the then-current trends in fertility, mortality and migration continue[4]. It is also estimated that by 2030 the population in rural areas would be equal to the population in urban areas due to migration from rural to urban areas. Figure **10** depicts the people's migration from rural areas to urban areas which would result in the high use of electricity as it is one of the sources of energy in urban areas. The electrification rate would also increase due to the migration of people from rural to urban because access to electrical energy is better in urban areas than rural. This would also affect the consumption of electrical energy.

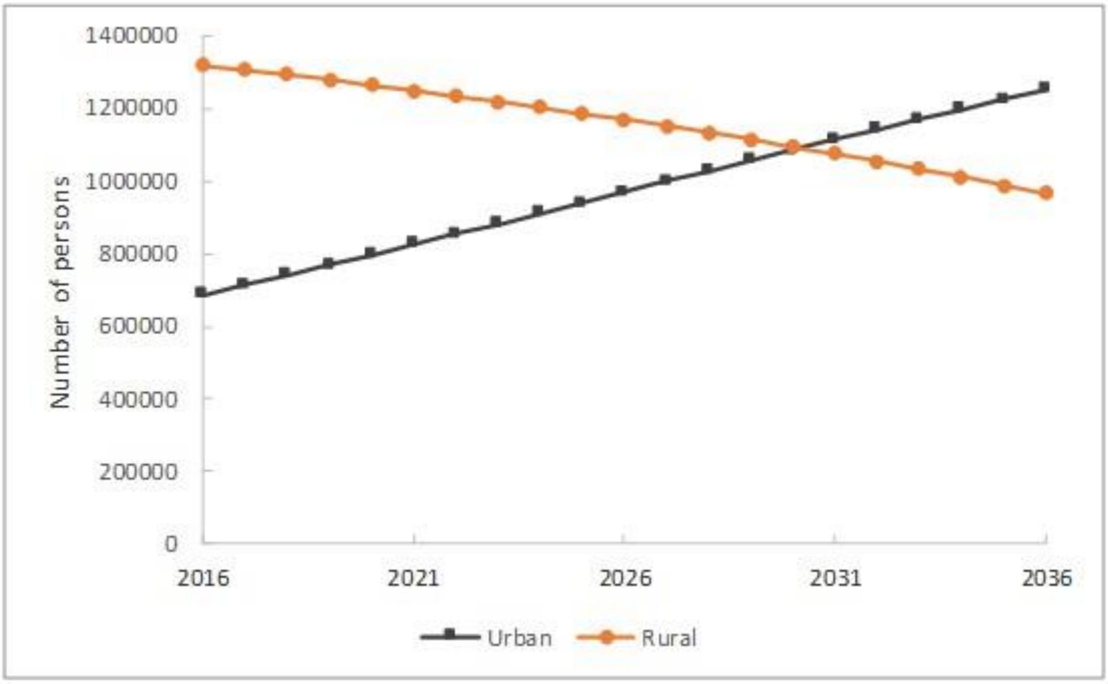

Figure 10 Lesotho Population Migration Projection

3.8.3 Electricity Demand Growth

Table 6 contains the trend of the growth in the use of electricity over the past 9 years (2008 to 2017) and the highest observed growth rate was 8.2% in 2010 and the lowest is -4.8% in 2014. The average growth rate of these 9 years was 4.3%. This trend of electricity consumption was used to predict future electrical energy consumption; the average 4.3% is assumed to represent the BAU scenario in this study. The LE consumption is achieved by calculating the average of

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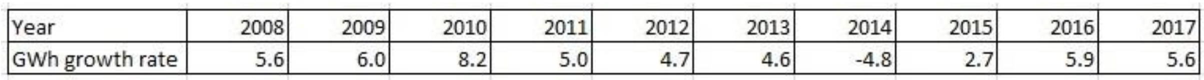
[4] See Lesotho Bureau of Statistics' Population Projection Report 2019

the five low-energy growth values and it yielded 2.4%. High Economy electricity consumption is taken as 6.3% which is calculated from the average of the five high-energy growth values shown in Table 6. HE is therefore taken as 6.3% from 2018 until 2030. It is anticipated that the economic growth would drop to 4.8%, as a result of the termination of the LHDA project which is expected to have an impact on the economic growth. These calculated growth rates are used to calculate the future growth in the consumption of electricity associated with the respective scenarios for Lesotho.

Table 10 annual energy growth



Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
GWh growth rate	5.6	6.0	8.2	5.0	4.7	4.6	-4.8	2.7	5.9	5.6

The introduction of a baseline tariff will also contribute to the consumption of electricity. Again, the electrification rate which is at 45% (at the time of this study) will increase due to initiative by the Ministry of Energy to introduce the Sustainable Energy for all (SEforAll) project to expand the rate of electrification by considering the renewable energies and the offgrid system. The SEforAll project would affect grid penetration and some of the electricity will be sourced from renewable energy. It is also anticipated that the installation of solar water heaters will increase due to initiatives like the sustainability program at the National University of Lesotho which intends to equip more people with applications of renewable energy technologies.

New initiatives such as the new developments in the mining sector like the expansion of the Mothae mine is expected to be connected to the grid and many other mining opportunities which are still under exploration. Similarly, the demand for electrification is anticipated for the development of the cannabis farms emerging as a potential market. In terms of the transport sector, it is also anticipated that the global growing market for electric cars would shift the use of fossil fuel for power vehicles to electricity since more cars would be charged at the service stations and homes.

Chapter 4 – Results and Discussions

4.1 Introduction

This part of the report presents the results of hourly forecasted electrical load, peak loads and energy consumption for LEC power grid. The results for base year were presented then the forecasted electrical load at an interval of five reference years and load profiles for the seasons. The forecasted results were calculated for three scenarios namely HE, LE and BAU. The LDC was presented to predict time duration at which maximum load occurs. The results in this study were validated by comparing the actual and calculated results. This study was compared with other studies of the similar nature to further validate the results. Lastly the possibility of electrical power deficit was presented to show what would happen if the power generation remain the same for the duration of the study period.

4.1 Load profiles

Figure 11 displays a one-year (2018) load profile for LEC. It was developed from the hourly load to determine the pattern of electrical load and the number of seasons in a year. It shows the different seasons of the year where the blue color, yellow color and grey color represents Summer 1, Winter and Summer 2 respectively. The load pattern for summer 1 and summer 2 were low and almost the identical while the system peak load was in winter.

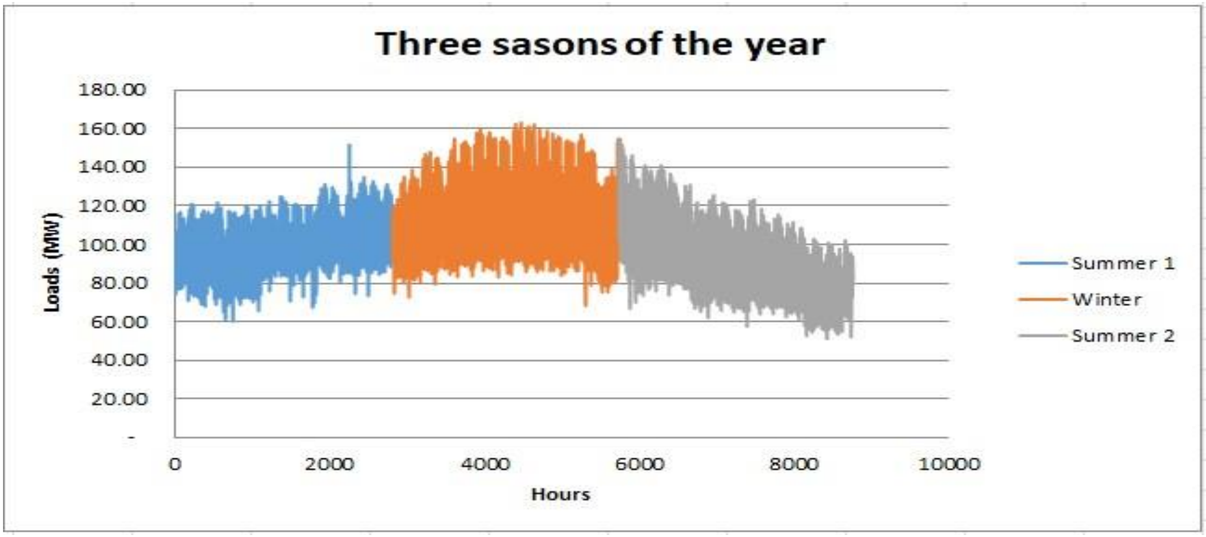
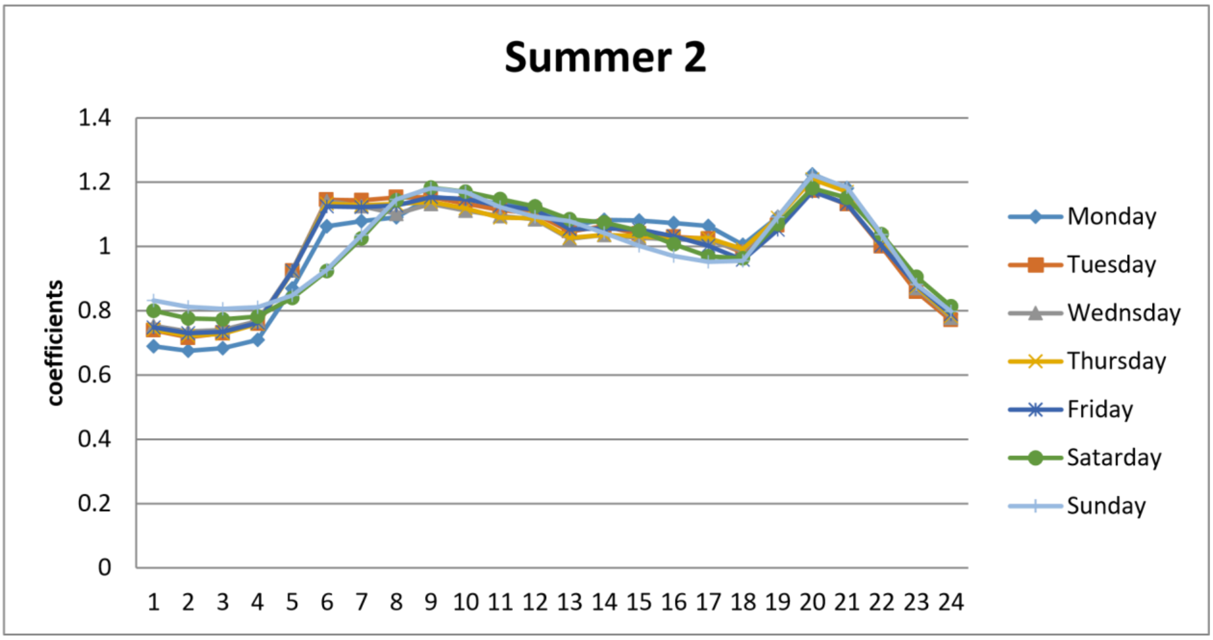


Figure 11 Load profile for LEC's 2018 data showing different seasons of the year

The difference in the load profiles of the various sectors was due to the nature of the applications that the electricity was used for. For example, the domestic peak load was in the morning and the evening when consumers were at home. For the industrial sector, the load profile was relatively constant throughout the day because some of the plants operate all day long. The services sector peak load was during the day because the offices are operational during the day and closed at night.

Figure 12, Figure 13 and Figure **14** presents the daily load patterns for the different seasons of the year. The days of the week were represented from Monday to Sunday. The graph shows that the electricity load profile in Summer 1 is almost flat and the load is low between 01:00 and 04:00 and starts to increase at 05:00. The peak load is at 06:00 and in the evening the peak load is at 20:00 while the load starts to grow at 18:00 and drops at 21:00. It then continues to drop until it reaches the lowest value at midnight. The load is almost constant during the day and drops a little bit during the lunch break which is between 12:00 and 14:00. The load profile follows the same pattern for both the Winter season and Summer 2 and the peak load is reached in Winter on Monday, which is a working day, in the morning hours around 09:00. The graphs further show that Sunday is the lowest energy consuming day followed by Saturday which is just greater than Sunday in energy consumption and this is because on these days there are few commercial and industrial activities taking place. Of the working days, Tuesday, Wednesday and Thursday are the highest energy-consuming days because on these days, the commercial and industrial activities are fully operational.



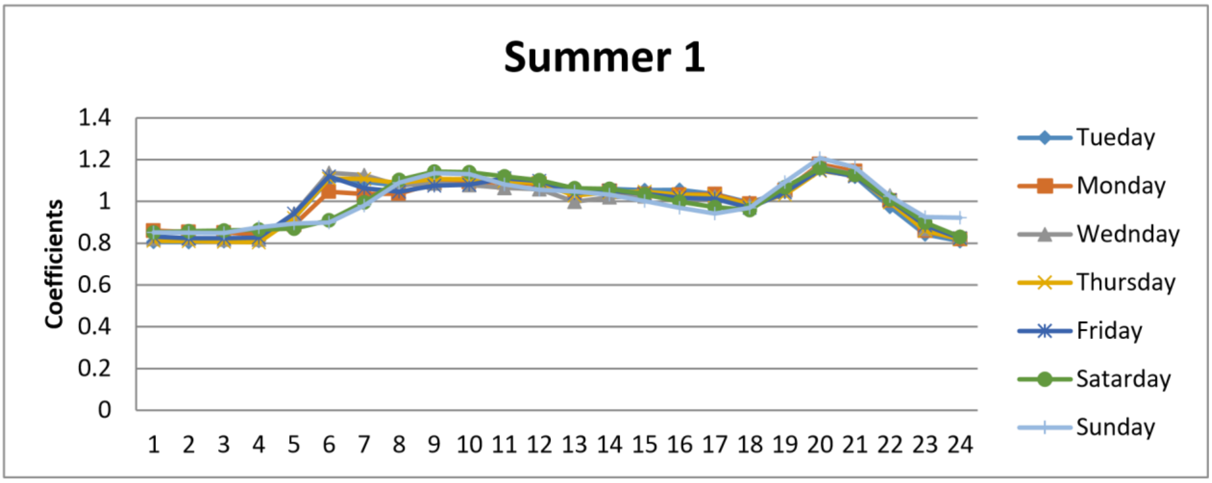


Figure 12 summer 1 base year load profile

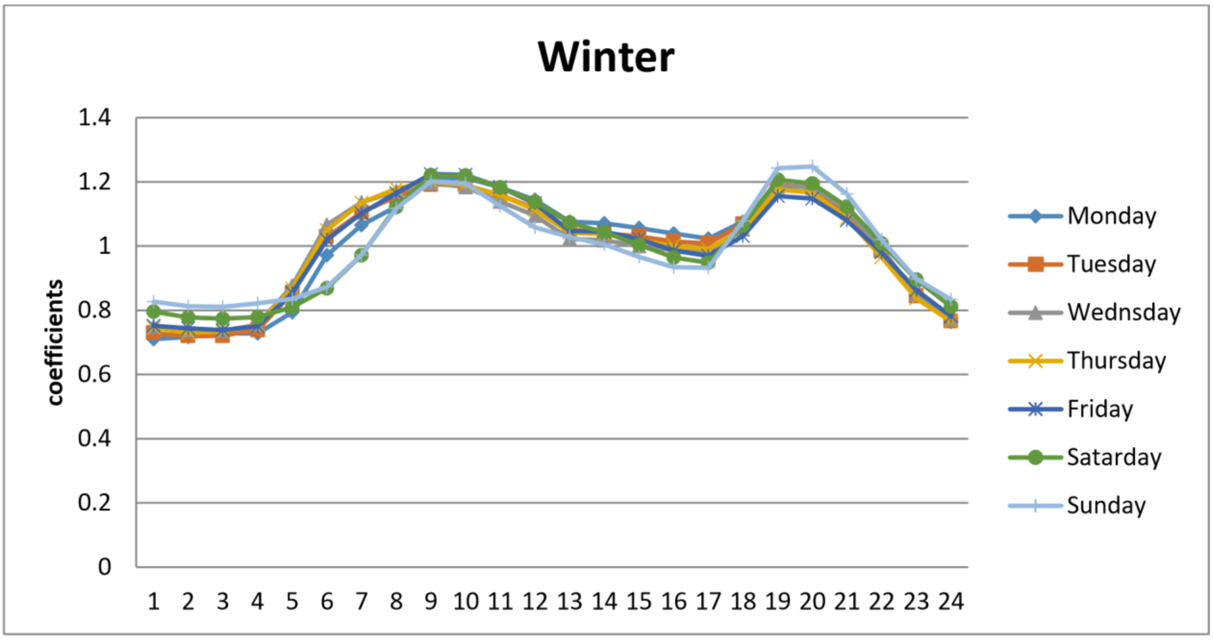


Figure 13 winter base year load profile

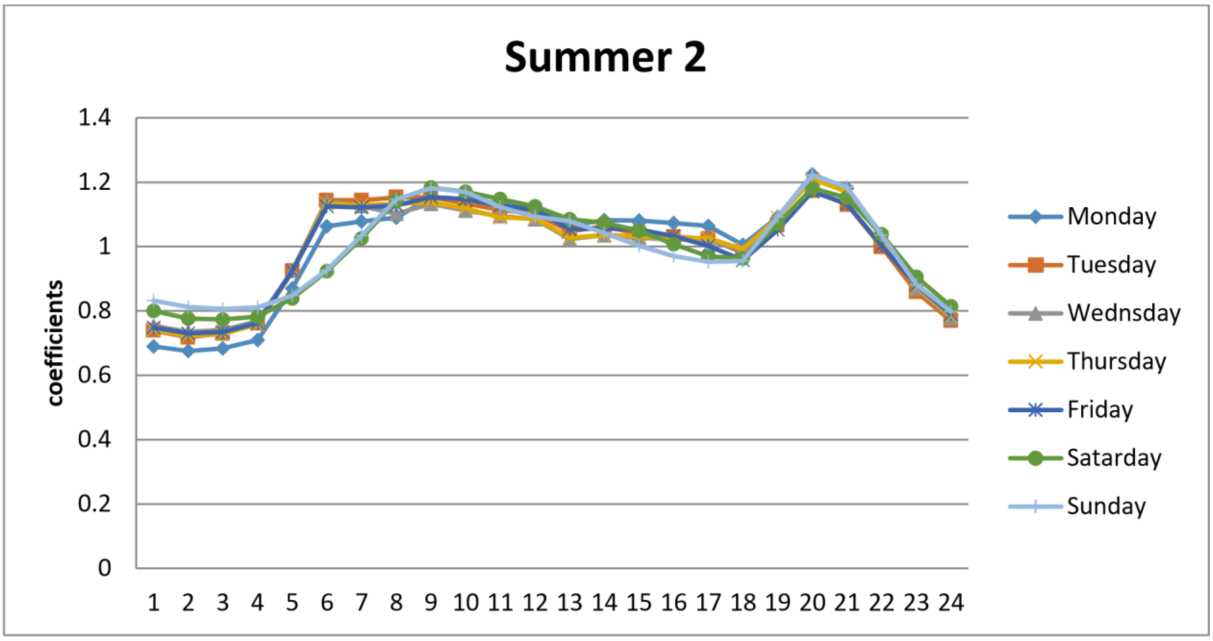


Figure 14 summer 2 base year load profile

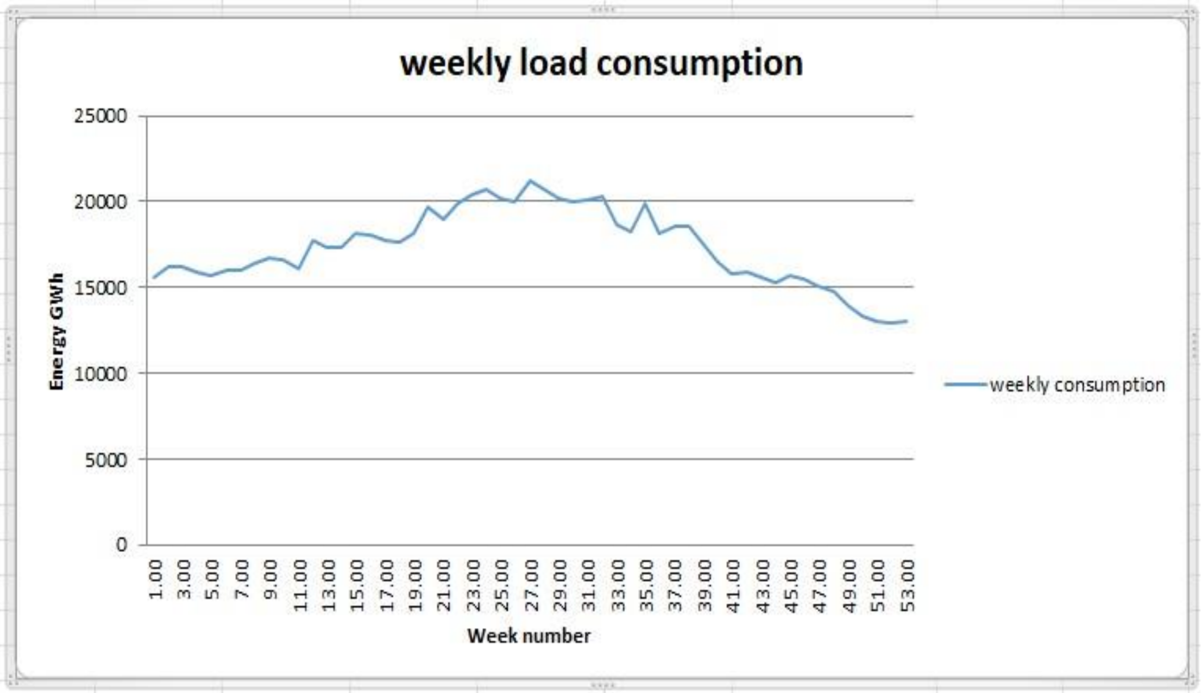


Figure 15 shows the weekly load profile of the base year in terms of energy consumption. It shows that the load was low from the first week of the year until week 19 when the load started to increase due to the advent of cold weather. The peak load occurred in week 27 which was in July, and, at week 37 which was in September, it dropped further to a lower value until it reached the minimum in week 53.

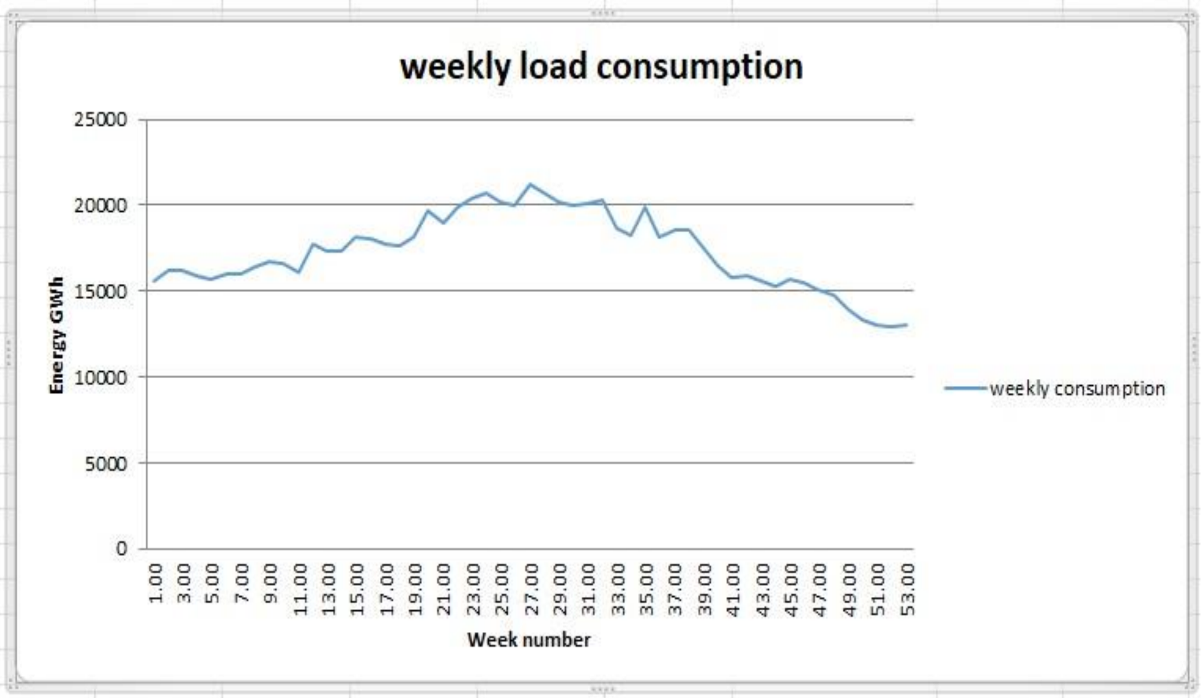


Figure 15 weekly load profile for base year

4.2 Modulation Coefficients

After analysing the raw data for 2018 load profile, equations (7), (8) and (9) were used to calculate weekly, daily and hourly coefficients. The coefficients were used to determine the future load pattern of the system load. The weekly coefficients calculated the variation of electrical load for 53 weeks and three seasons in a year. The daily coefficients calculated the varying electrical load for seven days of the week with different types of the days namely working days (Monday to Friday) weekend (Saturday and Sunday) and holyday. The hourly coefficients calculated the varying load patterns throughout the day for 24 hours, seven days of the week for 8760 hours of the year. All of these coefficients were used to predict the load profile of electrical load in the future 20 years.

4.2 Base year construction

The base year was constructed to validate the accuracy of the model where the calculated and electrical load and energy consumption results were compared. The actual peak load for 2018 was 162 MW while the calculated peak load was 166 MW. The percentage deviation of calculated to actual was 2% which was within the acceptable range of 5% [14]. The maximum energy purchased in 2018 was 891 GWh while the calculated result was 940.78 where the deviation of calculated results to actual was 5% [14].

Figure **16** depicts the calculated load profile of the Base Year, 2018. The blue color shows the results for the Summer 1 season, the black color for the results of Winter where the system reached the peak. The Green color was used to distinguish the results for Summer 2 which was the season with the lowest energy consumption. The range of the load profile was for one year (8760 hours) showing the hourly load profile.

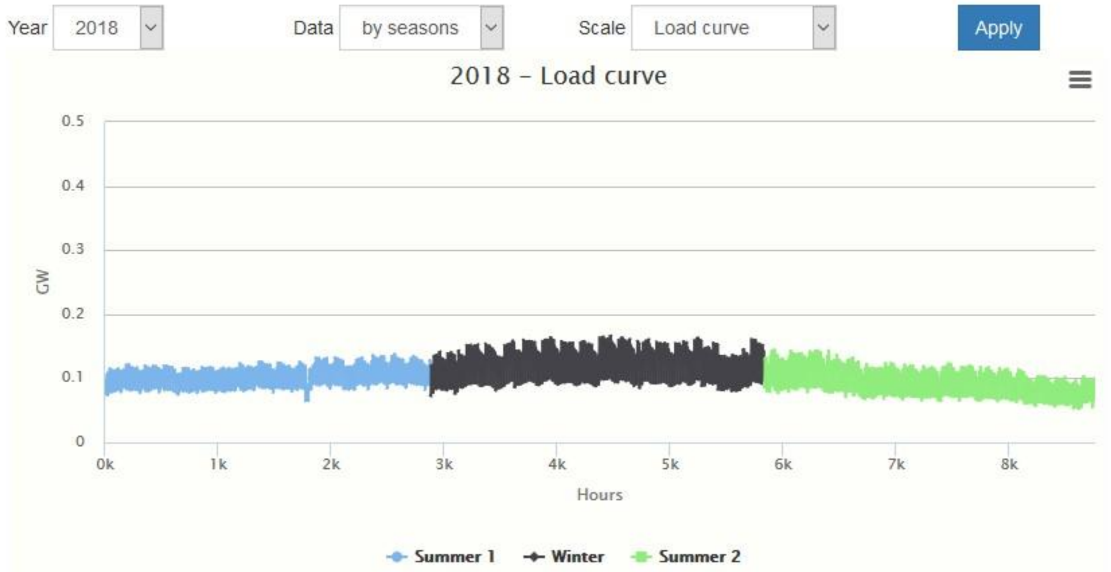


Figure 16 season load profile for 2018

Figure **17** and Figure **18** illustrate the Load Duration Curves which show the variation of the loads in the descending order, starting with the peak loads and ranging to the lowest load of the system in the year 2018. Figure **17** shows the Normalized Load Duration Curve which presents both the time duration and the peak load in percentage form. According to Figure **17**, for example, the Peak Load of the system was equal or above 75% of system peak load for 20% of the available time of the year. Again, Figure **17** showed the base load of 2018 to be 52.24 MW. Figure **18** shows Load Duration Curve, with time presented in actual hours, and the actual load for three seasons of the year where the peak load was 166 MW. The season with the highest peak was winter.

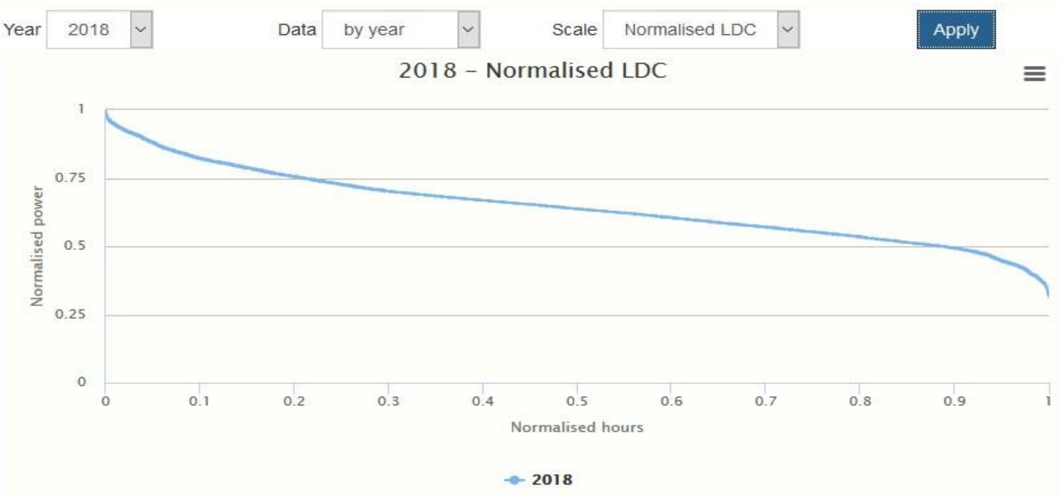


Figure 17 Normalised Load Duration curve 2018

Figure 18 Load Duration For 2018 by Seasons

4.3 Model Validation Results

The comparison was made of the actual and the calculated results for the previous nine years (2009 to 2018). This comparison was performed to evaluate the accuracy of the MAED-EL approach. The purpose was to validate the results by comparing the actuals with the results calculated by MAED-EL. Table **11** and Figure **19** show the actual results and the calculated results for the Peak Loads of the LEC's grid. The Peak Loads of the electricity for the period of the nine years (2009 to 2018) were compared (i.e. actual results vs. calculated results). The deviation of the calculated results from actual results varied from 4% to -5% as shown in Table **11** and Figure **19**. The average deviation was 1%.

Table 11 Validation of Peak Loads from 2009 to 2018

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Actual Loa	116	121	125.95	128.68	143	144.12	154.2	161	154	162
Calculatec	116.32	121.01	125.91	130.73	135.94	141.48	147.18	152.8	159.38	165.34
% differer	0%	0%	0%	2%	-5%	-2%	-5%	-5%	3%	2%

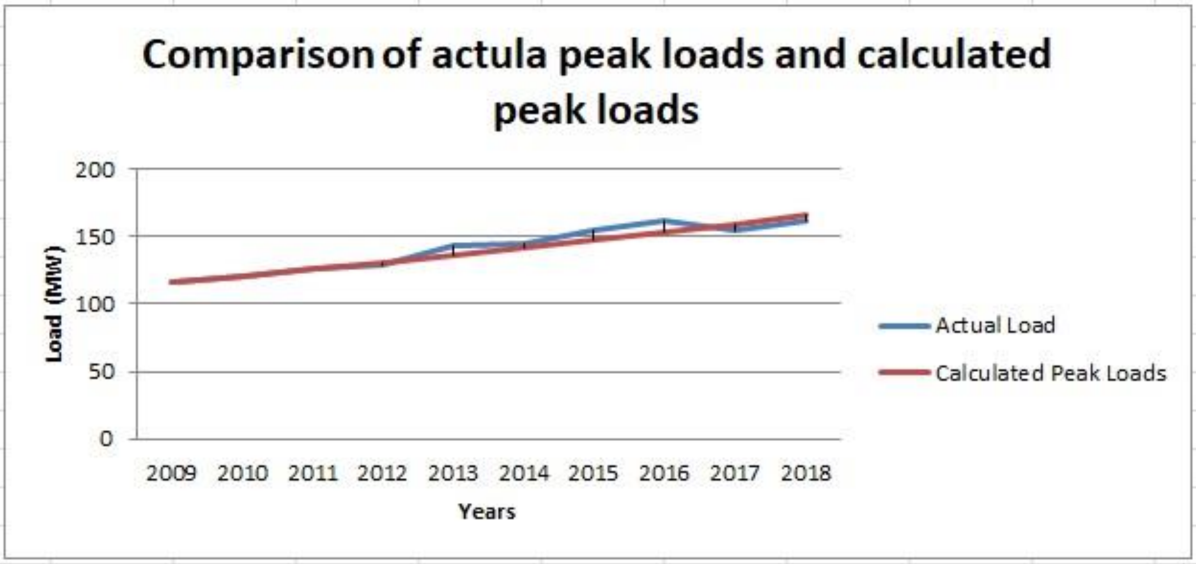


Figure 19 Validation of Peak Loads from 2009 to 2017

Table 12 and Figure **20** show the trends of actual energy consumed from 2009 to 2018 as compared to the calculated energy over the same period of 9 years. The deviations of the calculated result to actual fluctuated from 5% to -4% as presented in **Table** 12 and Figure **20**. The average deviation for this period of 9 years is 1%, which is less that the allowable. This means that the model would produce accurate results and that, decision-makers can reliably use its forecasts to plan for the future electrical energy expansion.

Table 12 Validation of Energy Consumption from 2009 to 2017

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Actual energy (GWh)	654	717	725	757	800	786	804	886	892	891
Calculated energy (GWh)	656.62	682.89	710.2	738.61	768.16	798.88	830.84	864.07	898.64	934.58
% difference	0%	-5%	-2%	-2%	-4%	2%	3%	-2%	1%	5%

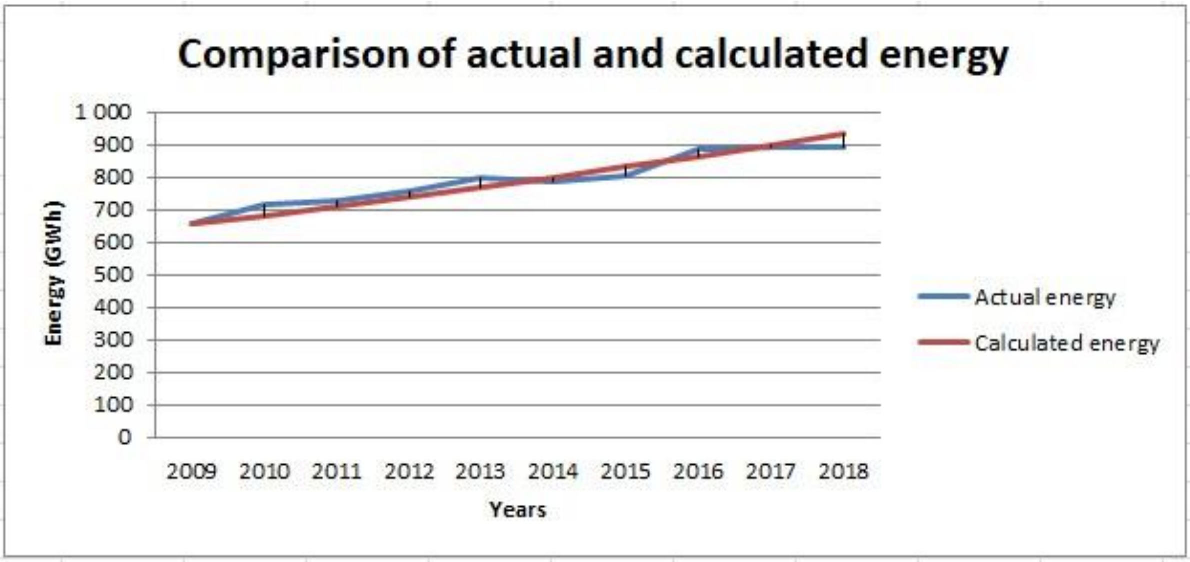


Figure 20 Validation of Maximum Energy from 2009 to 2017

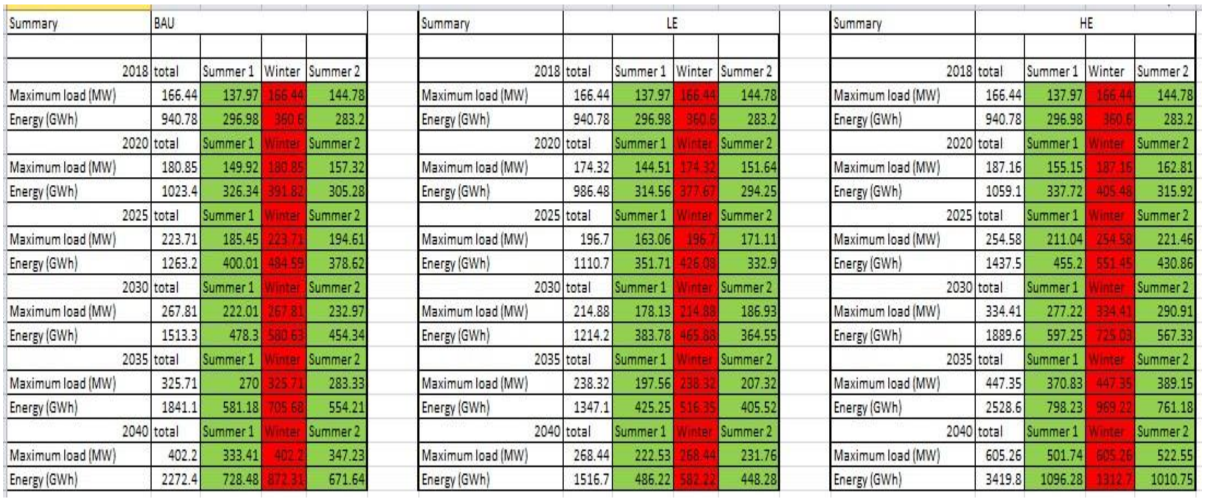
4.3 Construction of future hourly load profile

The base load was first constructed, when the results for the base load were satisfactory i.e within the range of 5% deviation when comparing the calculated to actual results. The hourly electrical load was forecasted from 2020 to 2040 at an interval of five. Three scenarios, HE, LE and BAU were projected. Three seasons of the year (Summer 1, Winter and Sumer 2) were considered. The peak load was in winter and the season with lowest electrical energy consumption was summer 1.

4.3.1 Projected Peak Demand and Energy consumption

Table **13** shows the results for future LEC peak loads, anticipated maximum energy consumption for different seasons of the year; the green color highlights the summer seasons and the red color highlights winter. The Peak Load of the system for each reference year was in the winter season as shown in Table **13**. The winter electricity consumption was high because of the cold weather which called for the use of more electricity for space heating. The consumption was low in the summer seasons because the ambient temperature was moderate.

Table 13 Summary of the Seasons' Peak Loads



Summary	BAU			
2018	total	Summer 1	Winter	Summer 2
Maximum load (MW)	166.44	137.97	166.44	144.78
Energy (GWh)	940.78	296.98	360.6	283.2
2020	total	Summer 1	Winter	Summer 2
Maximum load (MW)	180.85	149.92	180.85	157.32
Energy (GWh)	1023.4	326.34	391.82	305.28
2025	total	Summer 1	Winter	Summer 2
Maximum load (MW)	223.71	185.45	223.71	194.61
Energy (GWh)	1263.2	400.01	484.59	378.62
2030	total	Summer 1	Winter	Summer 2
Maximum load (MW)	267.81	222.01	267.81	232.97
Energy (GWh)	1513.3	478.3	580.63	454.34
2035	total	Summer 1	Winter	Summer 2
Maximum load (MW)	325.71	270	325.71	283.33
Energy (GWh)	1841.1	581.18	705.68	554.21
2040	total	Summer 1	Winter	Summer 2
Maximum load (MW)	402.2	333.41	402.2	347.23
Energy (GWh)	2272.4	728.48	872.31	671.64

Summary	LE			
2018	total	Summer 1	Winter	Summer 2
Maximum load (MW)	166.44	137.97	166.44	144.78
Energy (GWh)	940.78	296.98	360.6	283.2
2020	total	Summer 1	Winter	Summer 2
Maximum load (MW)	174.32	144.51	174.32	151.64
Energy (GWh)	986.48	314.56	377.67	294.25
2025	total	Summer 1	Winter	Summer 2
Maximum load (MW)	196.7	163.06	196.7	171.11
Energy (GWh)	1110.7	351.71	426.08	332.9
2030	total	Summer 1	Winter	Summer 2
Maximum load (MW)	214.88	178.13	214.88	186.93
Energy (GWh)	1214.2	383.78	465.88	364.55
2035	total	Summer 1	Winter	Summer 2
Maximum load (MW)	238.32	197.56	238.32	207.32
Energy (GWh)	1347.1	425.25	516.35	405.52
2040	total	Summer 1	Winter	Summer 2
Maximum load (MW)	268.44	222.53	268.44	231.76
Energy (GWh)	1516.7	486.22	582.22	448.28

Summary	HE			
2018	total	Summer 1	Winter	Summer 2
Maximum load (MW)	166.44	137.97	166.44	144.78
Energy (GWh)	940.78	296.98	360.6	283.2
2020	total	Summer 1	Winter	Summer 2
Maximum load (MW)	187.16	155.15	187.16	162.81
Energy (GWh)	1059.1	337.72	405.48	315.92
2025	total	Summer 1	Winter	Summer 2
Maximum load (MW)	254.58	211.04	254.58	221.46
Energy (GWh)	1437.5	455.2	551.45	430.86
2030	total	Summer 1	Winter	Summer 2
Maximum load (MW)	334.41	277.22	334.41	290.91
Energy (GWh)	1889.6	597.25	725.03	567.33
2035	total	Summer 1	Winter	Summer 2
Maximum load (MW)	447.35	370.83	447.35	389.15
Energy (GWh)	2528.6	798.23	969.22	761.18
2040	total	Summer 1	Winter	Summer 2
Maximum load (MW)	605.26	501.74	605.26	522.55
Energy (GWh)	3419.8	1096.28	1312.7	1010.75

The calculation of the long-term hourly load curve projections of electrical energy and peak loads for Lesotho indicates that from 2018 to 2040 the Peak Load will grow from 166 MW in 2018 to 605.26 MW (for HE), 402.2 MW (for BAU), and 268.44 MW (for LE) in 2040. Figure **21** shows the final Peak Loads for each reference year (2020,2025,2030,2035 and 2040) for all scenarios, HE,LE and BAU. The calculated results indicate that the Peak Load is expected to grow by 269% (HE Scenario), 142% (BAU Scenario) and 62% (LE scenario) from 2018 to 2040.

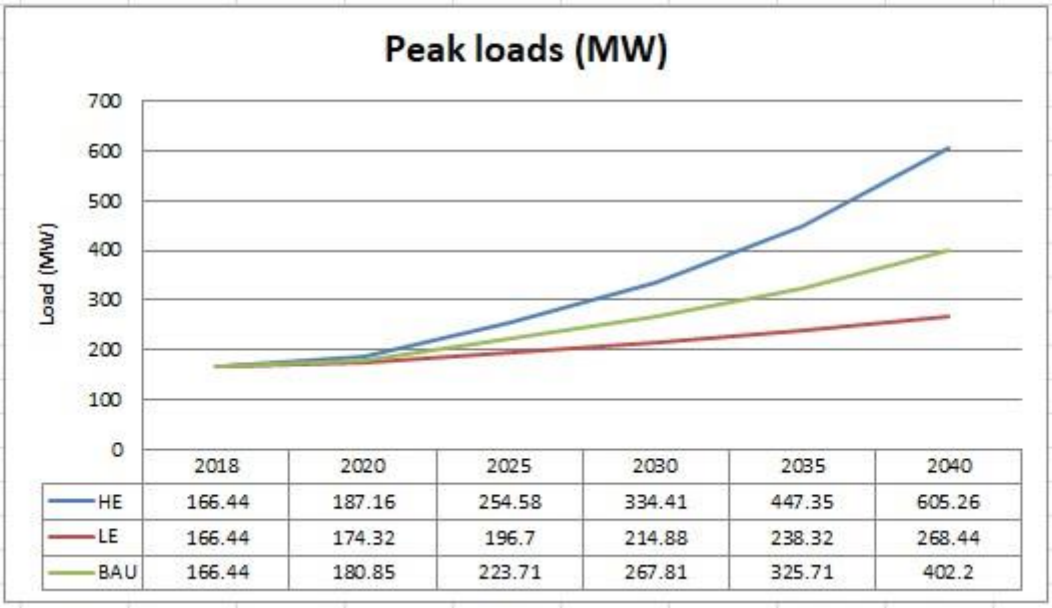
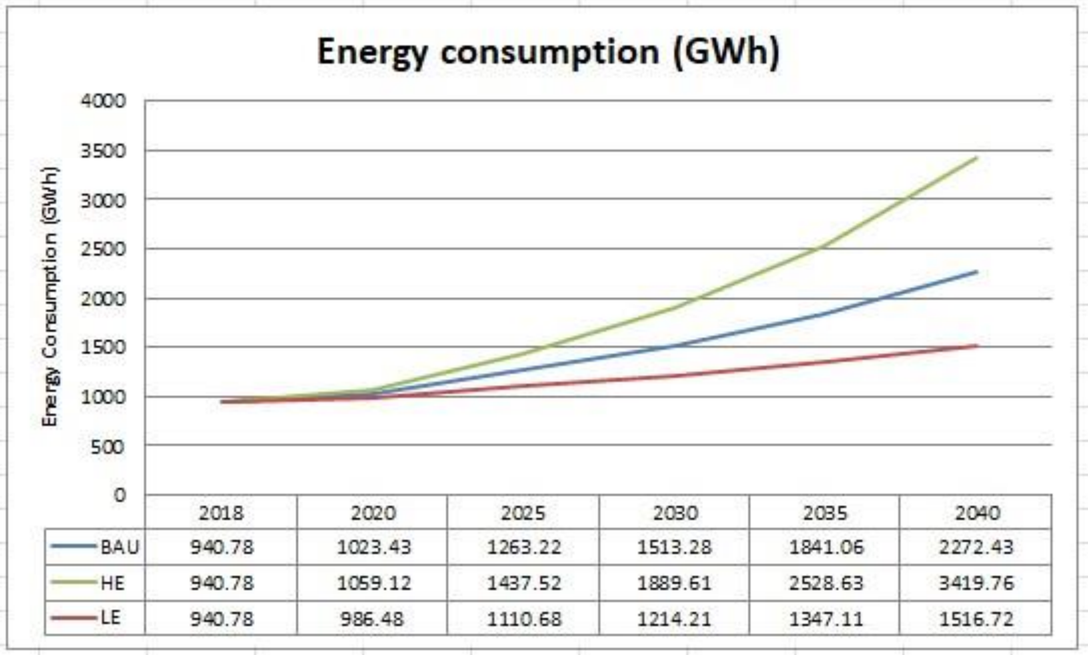


Figure 21 Peak loads for the Different Scenarios

4.4.2 Projected Energy Consumption

Figure **22** shows the predicted energy consumption for all reference years during the study period. If the economic growth was high, the anticipated highest energy consumed annually was predicted to increase from 940 GWh in 2018 to reach 3457.36 GWh in 2040. The forecasted energy consumption for the low economic growth rate (LE) scenario will be 1516.72 GWh, and for BAU the anticipated energy consumption will be 2272.43 GWh. The calculated results of this study indicated that the energy consumption was expected to grow from the base of the study to the end by 268%, 142% and 61% for HE, BAU and LE, respectively.



	2018	2020	2025	2030	2035	2040
BAU	940.78	1023.43	1263.22	1513.28	1841.06	2272.43
HE	940.78	1059.12	1437.52	1889.61	2528.63	3419.76
LE	940.78	986.48	1110.68	1214.21	1347.11	1516.72

Figure 22 Projected Energy Consumption Under Different Scenarios

4.4.3 Projected electrical Load

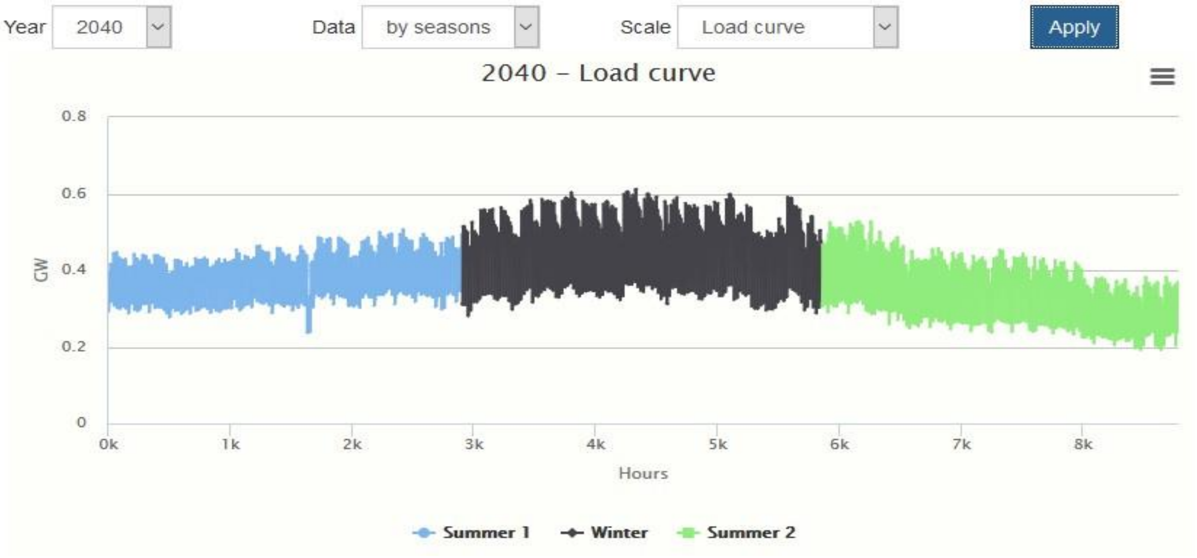
Figure 24 and Figure **24** shows the load profile as forecasted from 2020 to 2040 where, under the HE scenario conditions, Peak Load was assumed to increase from 166 MW in 2018 to 187.16 in 2020 the projected to 605.26 MW in 2040. Again, this graph shows the load profile by seasons of the year. The load profile shows that the electrical load was low from the first hour of the year to about 2888 hours which is at end of March and start growing gradually

Year 2020

Data by seasons

Scale Load curve

Figure 23 seasonal hourly load profile for 2020



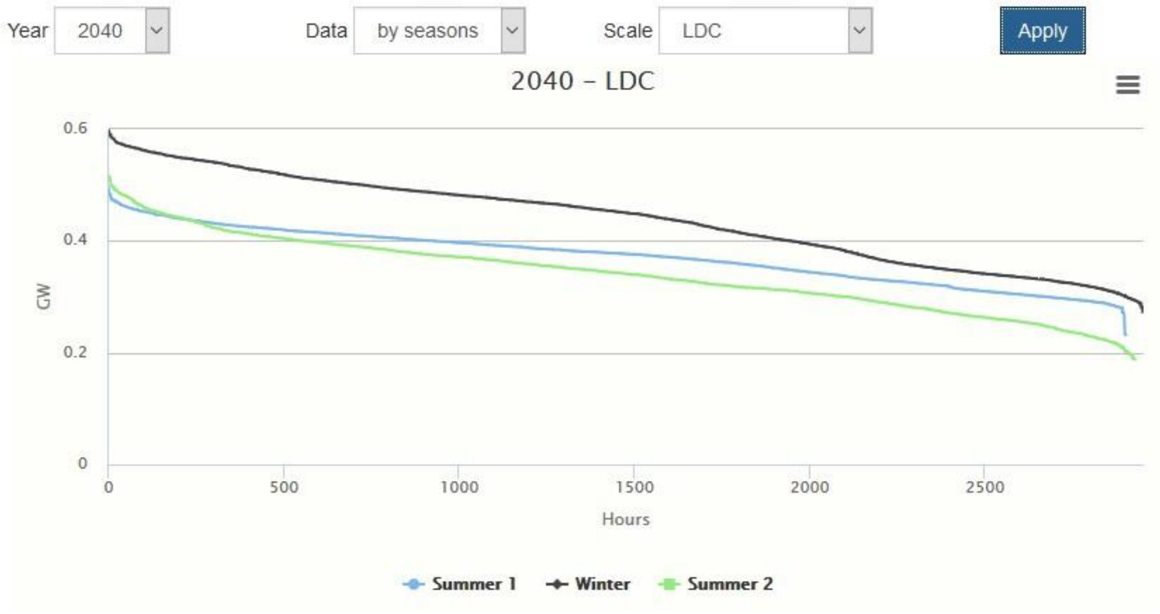
Year 2040

Data by seasons

Scale Load curve

Figure 24 Seasonal hourly Load Profile for 2040

Figure **25** is the Load Duration Curve with the actual values showing the growth of the peak load in 2040 respectively, under HE scenario. It is shows the seasons of the year with the black color representing the peak load in winter. Summer 2 is the season with the lowest electrical energy peak.



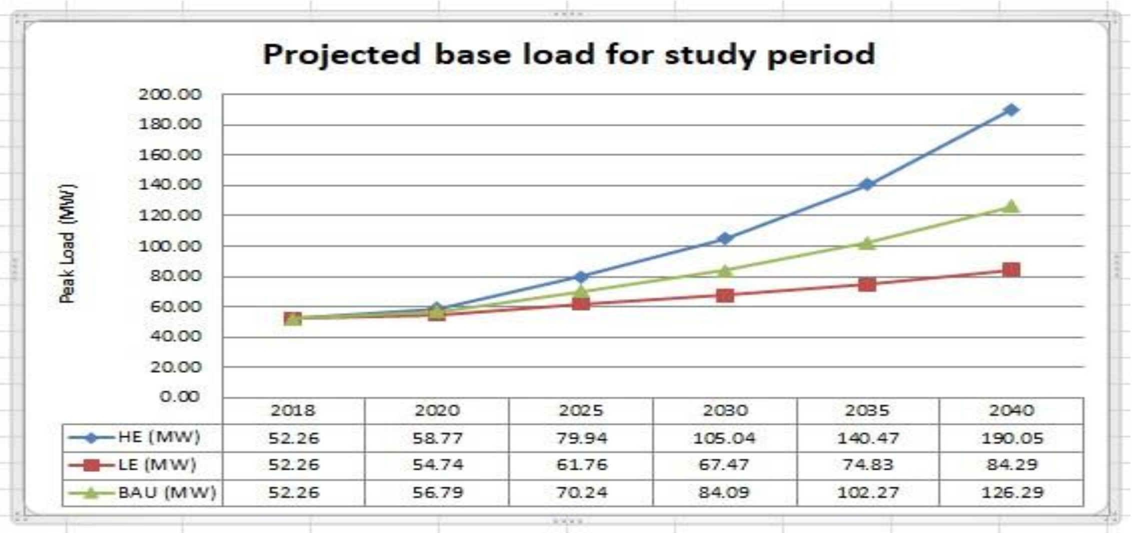
Year 2040

Data by seasons

Scale LDC

Figure 25 Load duration curve 2040 under HE scenario

Figure 26 illustrates the growth of LEC base load for from the base year for the duration of the study period which is 20 year. The growth is presented from 2020 to 2040 for all three scenarios (HE, BAU and LE). All reference (2020, 2025, 2030, 2035 and 2040 base loads were forecasted. The base load in the base year of scenario was 52.26 MW and predicted to reach the maximum of 190.05 MW for HE, 84.29 MW for LE and 126.29 BAU by the end of the study period.



	2018	2020	2025	2030	2035	2040
HE (MW)	52.26	58.77	79.94	105.04	140.47	190.05
LE (MW)	52.26	54.74	61.76	67.47	74.83	84.29
BAU (MW)	52.26	56.79	70.24	84.09	102.27	126.29

Figure 26 base loads

Figure 27,Figure 28,Figure 29 show the LDC for HE, BAU and LE scenarios. They illustrate the growth of the LDC from the base year for all reference year ranging from the first hourly of first day of the year to the last hour of the last of the year which makes 8760 hours in year for common year and 8764 for Leap year that MAED-EL considers when calculating. The LDC for different years are arranged in order their peak load and base load starting from bottom with the lowest peak load at the bottom of the graph to the highest peak per each scenario.

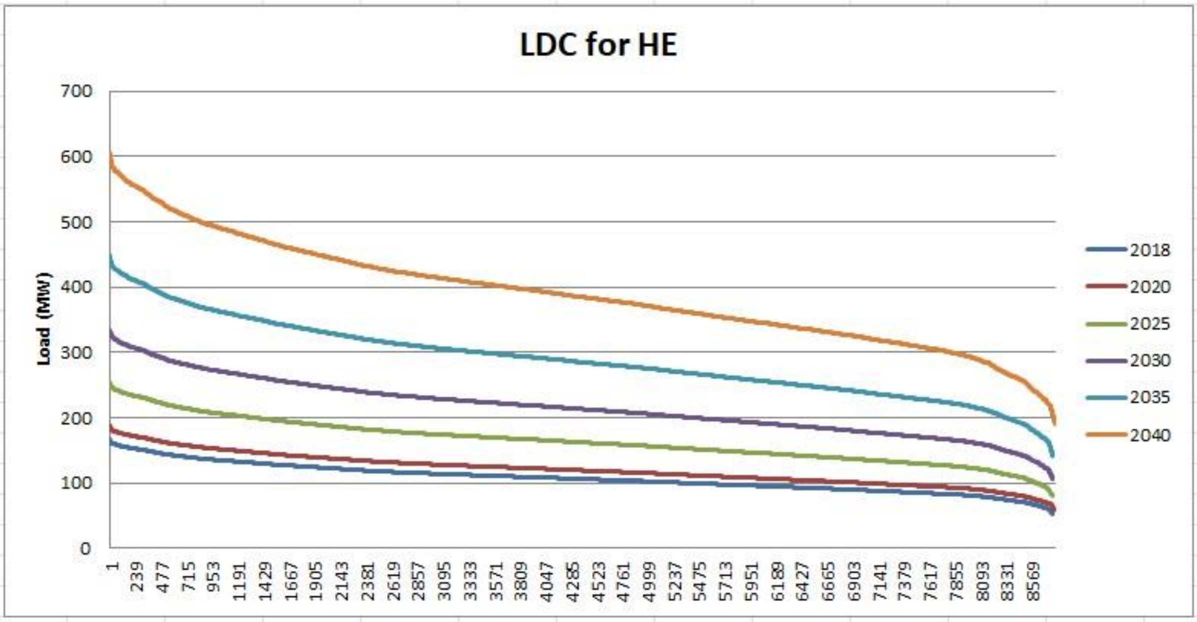


Figure 27 LDC for HE

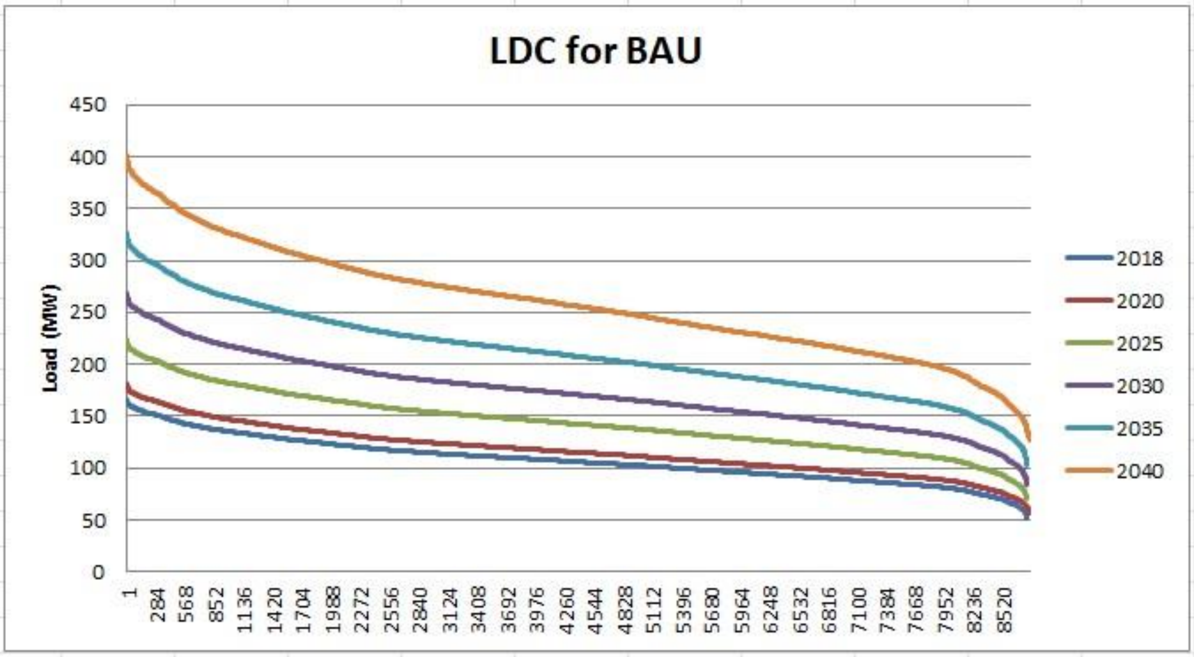


Figure 28 LDC for BAU

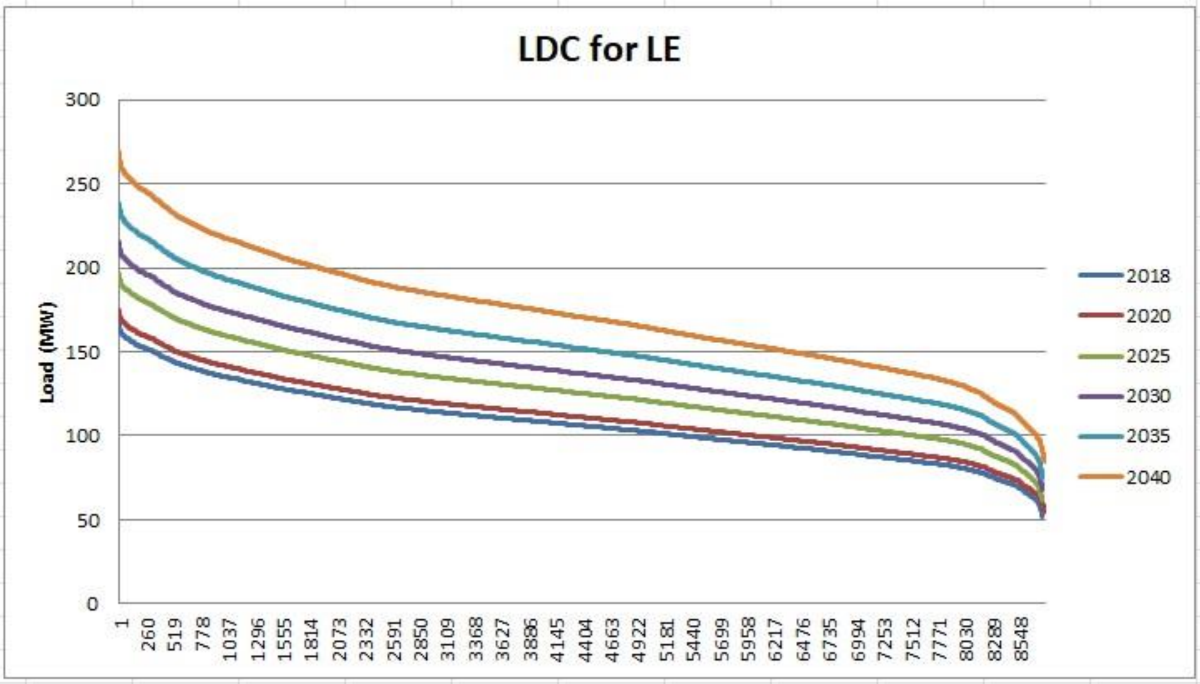


Figure 29 LDC for LE

Figure 30 the pattern for all sectors (industries, services and households) where industrial had high load followed by households and lastly the service. This was because most of energy was consumed in the mining and industrial textile factories. The load has not shifted because

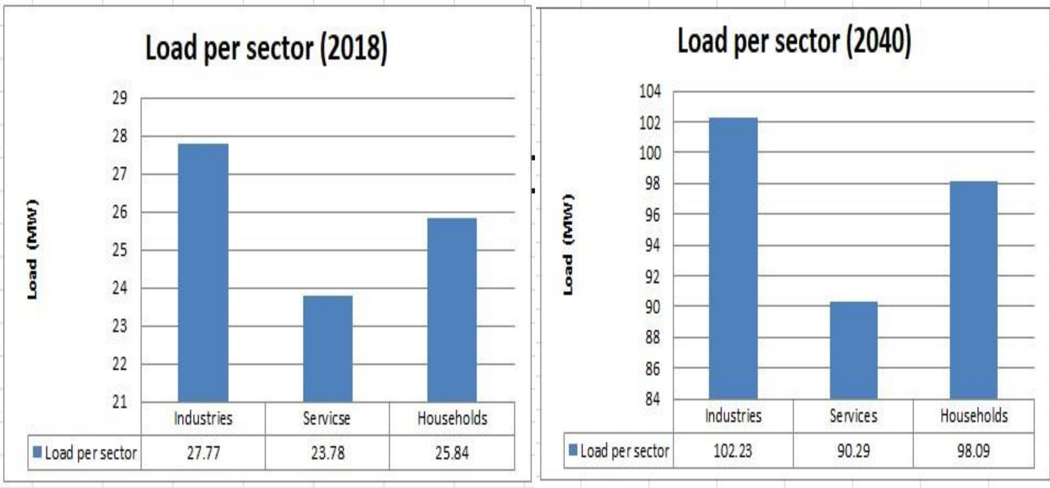
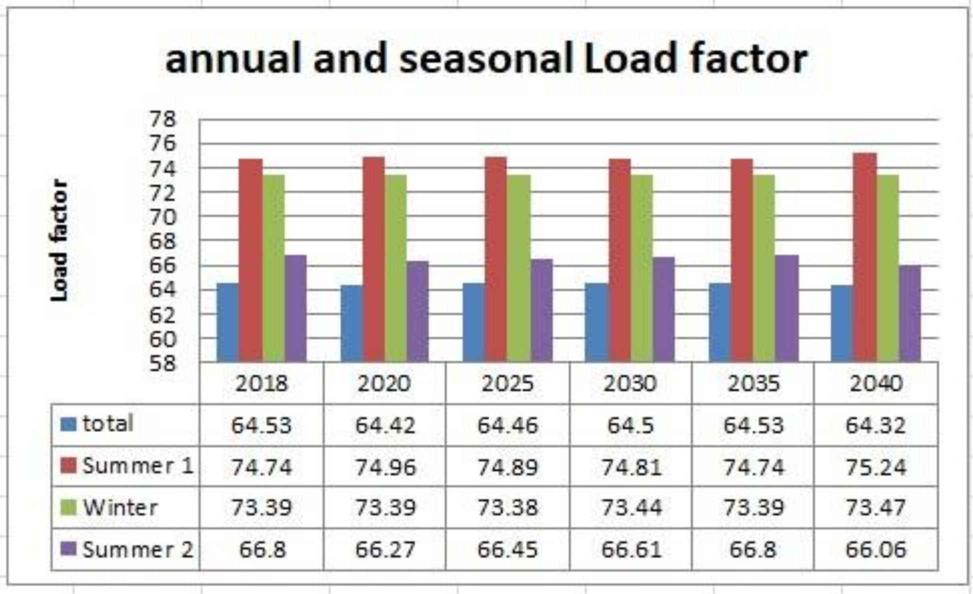


Figure 30 (a) 2018 load per sector (b) 2040 load per sector

4.4.4 Projected Load Factors

Figure **31** shows the results of forecasted Load Factors for all seasonal of the year with values for base year and all reference years. There is slight change in the load factor because shifting of load has not been performed in this study, MAED-EL was only used to predicts the hourly load curves. As far as the forecasts for the seasons are concerned, the load factor for Summer 1 shows a slight improvement in the load factor, viz. 74.74 % in 2018 to 75.24% by 2040.

There is also a slight improvement in Winter (73.39% to 73.47%). For Summer 2 the forecasted load factor drops and the peak load is predicted to be much higher in Summer 2 than the average peak load in that season.



	2018	2020	2025	2030	2035	2040
🟦 total	64.53	64.42	64.46	64.5	64.53	64.32
🟥 Summer 1	74.74	74.96	74.89	74.81	74.74	75.24
🟩 Winter	73.39	73.39	73.38	73.44	73.39	73.47
🟪 Summer 2	66.8	66.27	66.45	66.61	66.8	66.06

Figure 31 Annual and Seasonal Load Factors

4.5 Comparing the current study with other studies

The results produced from this study were compared to the results of similar studies of the electrical energy in Lesotho. This involves comparing the projected results produced by this study to the results produced by the other studies based on similar reference years and scenarios.

4.5.1 Senatla et al PLEXOS Results

A study reported by Senatla in 2018 [22] used ARIMA, to project the Peak Load and Maximum Energy Consumption for two scenarios, BAU and HE. The projection ranged from 2015 to 2045 at intervals of 10 years and five-year intervals from 2045 to 2050. Two of the years targeted in the Senatla study, coincided with years in this study, viz. 2025 and 2035. The Peak Load and Energy Projection resulting from the study conducted by Senatla covering 2015 to 2050 showed that the peak load in 2035 on BAU would be 363 MW [22] while in this study it was predicted that the peak load under BAU in 2035 would be 325.71 MW. Similarly, the calculated energy consumption was forecasted by Senatla to grow to 1291 GWh in 2035 and the calculated energy consumption in 2035 to grow to 1841.06 GWh.

Table **14** shows the comparison between this study's calculated peak load results and the results from Senatla' study.

The differences in the results produced by the two studies were caused by the fact that the growth rate assumed for the Senatla study was 3% from 2015 to 2025 and 2% thereafter to

2050. On the other hand, the growth rate used in this study was the trends of the (actual) electrical energy growth rate of 2009 to 2017 which was 3%. In this study the data used for energy growth rate was from 2009 to 2017 and the growth rate for BAU was 4.3% as shown above in

Table 10. In the Senatla study, the growth rate used for Load Projection for HE was 3% from 2015 to 2025 and then 5% until 2050 but in this study, the growth rate for HE was 6.3% from 2018 until 2030 when it was anticipated that the economic growth would drop to 4.8% in 2030, caused by the end of the LHDA project which would impact the economic growth.

Table 14 Comparison of Lesotho's Peak Load Projection by Senatla with the calculated results

	Senatla	Current study
Peak Load (MW) for HE (2025)	232	255
Peak load (MW) for HE (2035)	357	450
Peak Load (MW) for BAU (2025)	254	223.71
Peak load (MW) for BAU (2035)	363	325.71

Table 15 Comparison of Lesotho's Maximum Energy Projection by Senatla with the Calculated Results Produced by this Study

	Senatla	Current study
Peak Load (GWh) for HE (2025)	1345	1442.85
Peak load (GWh) for HE (2035)	2230	2547.29
Peak Load (GWh) for BAU (2025)	1057	1263.22
Peak load (GWh) for BAU (2035)	1291	1841.86

4.5.1 MRC Group’s MAED-EL Results

Figure **32** and Figure **33** show the calculated results produced by the MRC Group of Companies for energy growth from 2015 to 2030 using MAED-EL. The MRC Study considered three scenarios namely BAU, LE and HE. Figure 32 depicts the energy demands, by scenario, from 2015 to 2030. When the forecasts of the MRC Study were compared to those produced in this study, it was found that the energy projection for the HE scenario by the MRC Study was 1600 GWh in 2030, as compared to 1896.61 GWh in 2030 projected by this study. The Peak Load Demand calculated by the MRC Group came to 310 MW in 2030, while in this study the Peak Load Demand was estimated to be 334.41 MW. The differences in the results produced by this study and those of the MRC group are the result of MRC’s use of the following growth rates: 4% for BAU, 5.68% for HE, and 2.19% for LE which were the average GDP growth rates for the 19 years ranging from 2000 to 2018. In this study, on the other hand, the electrical energy growth rates used are from 2009 to 2017 and they were

4.3%, 6.3% and 1.8% for BAU, LE and HE respectively.

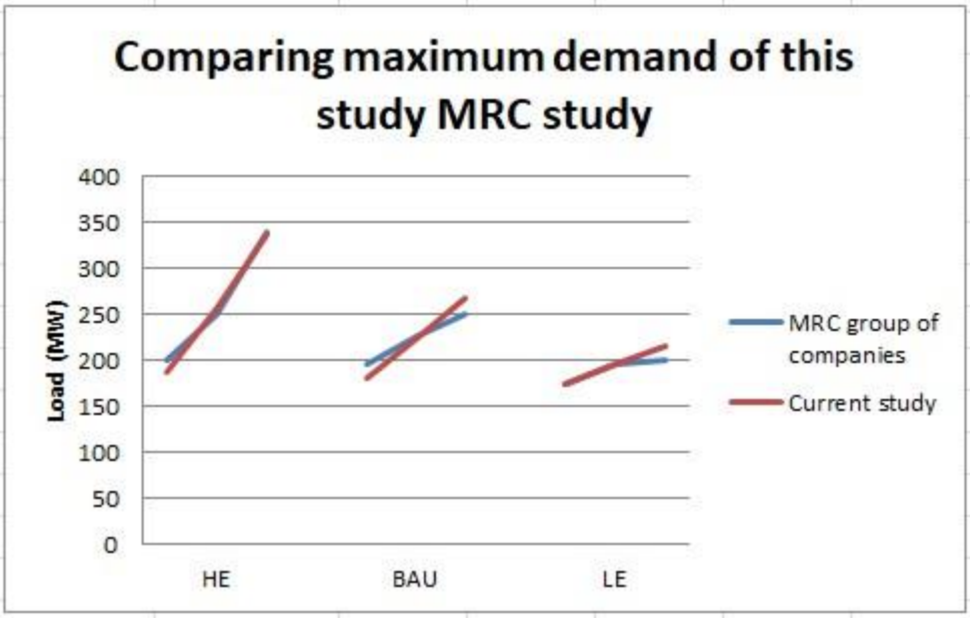


Figure 32 Scenario Peak Loads

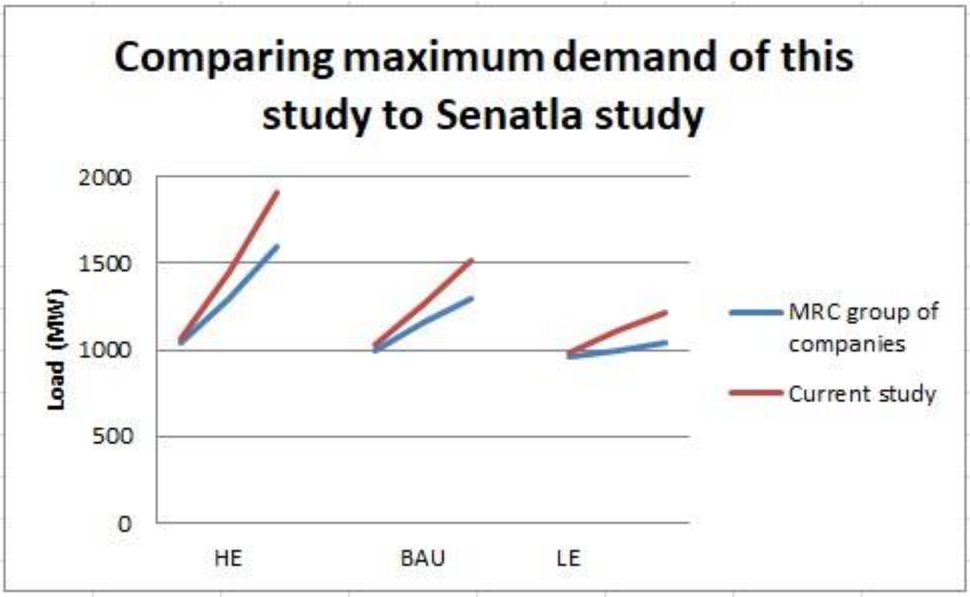


Figure 33 Scenario Maximum Energy

4.6 Implications of the study findings on national load and energy deficit

Figure **34** shows the forecasted growth of the Peak Load of the excess load for the period 2018 to 2040 which increased the generation deficit. The red color shows the anticipated load deficit if the 2018 generation was to remain the same by assuming that Muela remained constant at 72 MW (blue color). The red color shows the growth of the future electrical peak load which would be in turn, the result of electrical load that could not be met by the current power generation capacity in Lesotho if power generation remained constant for the duration of the study period. The Excess Peak Loads forecasted for all scenarios from 94.44 in 2018 to 115.16 MW, 108.85 MW and 102.32 MW in 2020 for HE, BAU and LE then, increase to 330.1 MW, 196.44 MW and 539.92 MW for BAU, LE and HE respectively in 2040.

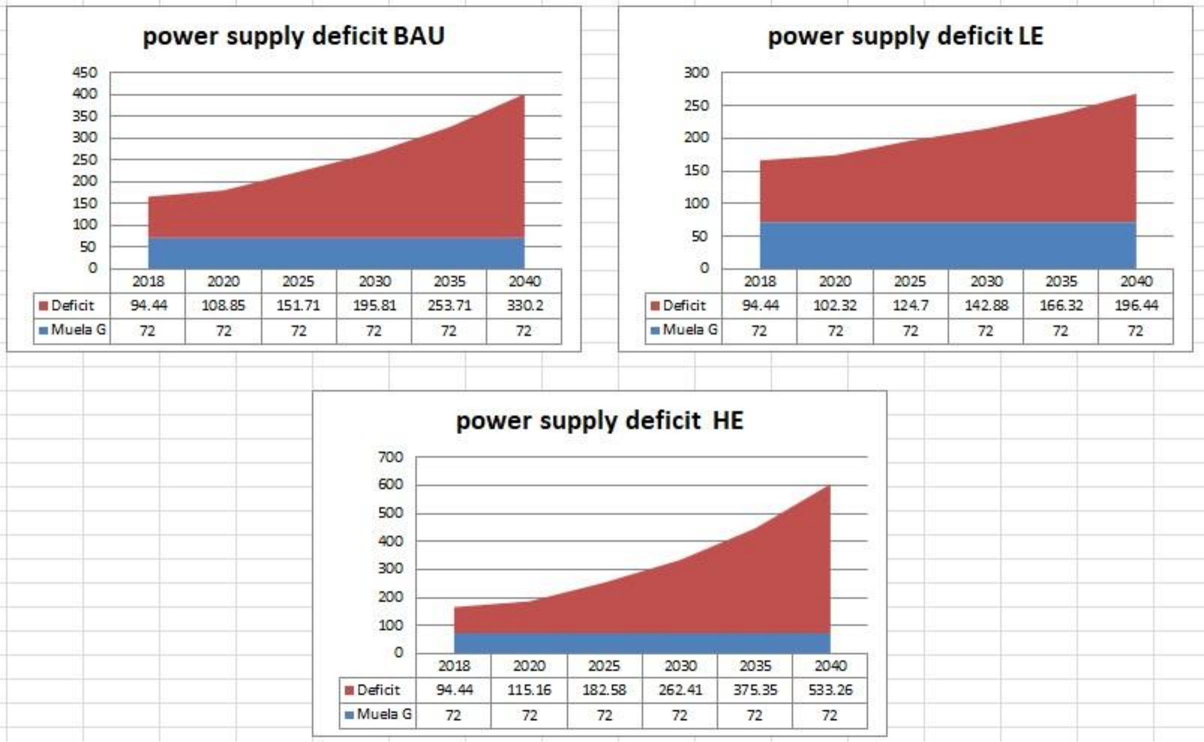


Figure 34 growth of power supply deficit to meet peak load

Figure **35** depicts the similar growth in energy consumption for the study period under all the scenarios. The blue color is used to show the 515 GWh Muela generation level and the red color is used to show the growing energy consumption that the growing electrical energy that the plant need to generate in order to meet the demand. The energy consumption deficit will grow from 415.32 GWh in 2018 to 543.66 GWh, 507.97 GWh,471 GWh for HE,BAU and LE in 2020 then to 1756.97 GWh, 1001.26 GWh and 2904.3 GWh by 2040 (in the cases of BAU, LE and HE, respectively) if the local power generation remains the same during the whole study period.

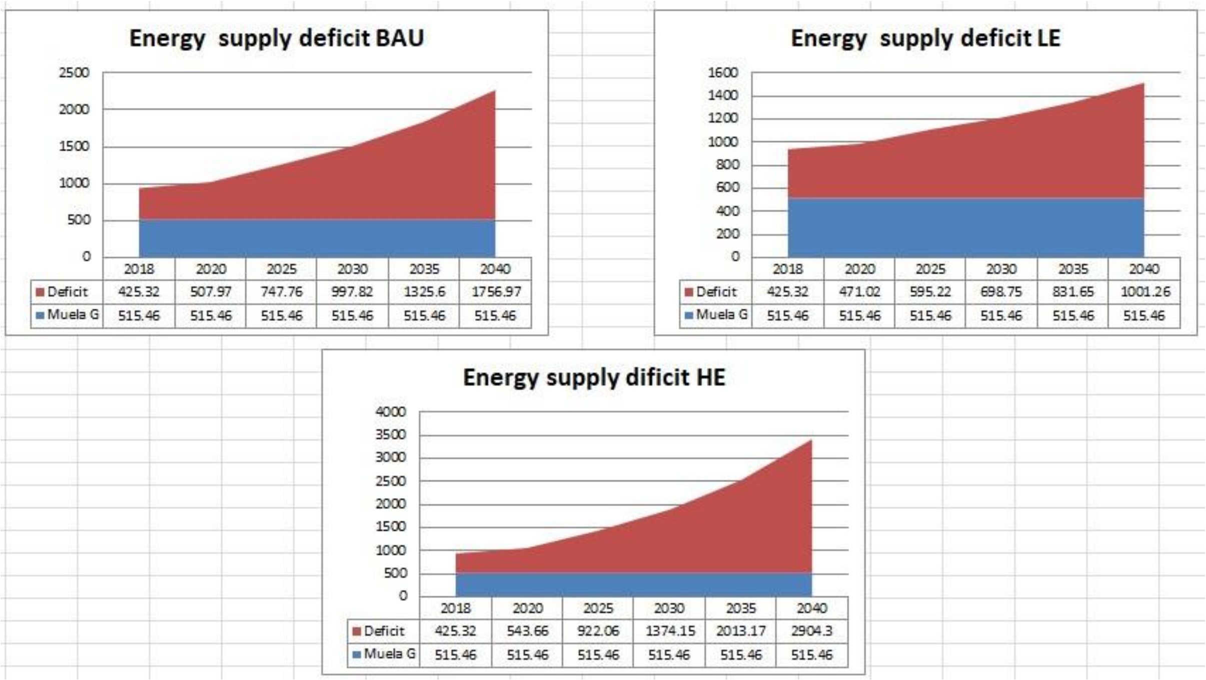


Figure 35 growth Energy supply deficit

Chapter 5 – Conclusions and Recommendations

5.1 Conclusions

The results obtained in this study predicted that the Peak Load would grow from 166 MW in 2018 to 187.16 MW, 180.85 MW and 174.32 MW for HE, BAU and LE respectively in 2020 then, projected to 605.26 MW, 402.2 MW and 268.44 MW for HE, BAU and LE respectively, in 2040. The consumption of energy would increase from 940 GWh in 2018, to 1023.43 GWh, 1059.12 GWh and 986.48 GWh in 2020 for HE, BAU and LE respectively then, projected to 3419.76 MW, 2272.43 MW, and 1516.72 MW in 2040, for HE, BAU and LE scenarios respectively. This growth in the Peak Load Demand and Energy increase would translate to the growth of 265% and 264% respectively from 2018 to 2040 in the case of the HE scenario.

The Base Load would also grow from 52.26 MW in 2018 to 58.77 MW, 56.79 MW and 54.74 MW in 2020 for HE, BAU and LE, then, projected to 190.05 MW, 126.29 MW and 84.29 MW in 2040 for HE, BAU and LE scenarios respectively. The power deficit expected to meet Peak Loads for all scenarios in 2018 was 94.44 and forecasted to be 115.16 MW, 108.85 MW and 102.32 MW in 2020 for HE, BAU and LE then, increase to 330.1 MW, 196.44 MW and 539.92 MW for BAU, LE and HE respectively in 2040. The energy consumption deficit in 2018 was 415.32 GWh and predicted to be 543.66 GWh, 507.97 GWh,471 GWh for HE,BAU and LE in 2020 then to 1756.97 GWh, 1001.26 GWh and 2904.3 GWh by 2040 (in the cases of BAU, LE and HE, respectively) if the local power generation remains the same during the whole study period. This means that if the current power generation capacity remains the same it would not meet the Base Load demand by 2040.

The results indicated that the high energy consumption occurred on the working days while the low energy consumption happened on weekends. It would appear that this phenomenon occurred because on working days the electrical energy was consumed by all sectors while on weekends, electricity was utilized by the households and some of the industries and services, but on a lower scale. It was found that the Industrial Sector was the heaviest energy consuming sector, followed by the Household then Service sectors. The high electricity consumption by the Industry sector was attributed to the huge electricity demand of clients such as the mines and textiles for the operations of their plants. The lower energy consumption by the Household and Services Sectors was attributed to low the electrification rate (at about 45%), which caused their low levels of consumption.

The results of the study also confirmed that the Peak Load occurred in Winter Season (around July) when the temperatures were at their lowest levels in Lesotho: typically ranging from 3^0C in the Lowlands to -13^0C in the Highlands. Therefore, more electrical energy was consumed for the air conditioning (e.g. heating) by the industries, services and households. The Load Factor was predicted to range from 64.53% in 2018 to 64.32% by 2040. This was attributed to the estimated Peak Load growing at a higher rate than the annual average load.

The challenges in this study was the availability of data like information for long term GDP forecasting in Lesotho covering the period being studied. The population growth was also projected until 2036 only, i.e. four years shorter than the term of this study. There was also a shortage of disaggregated data regarding the electrical energy consumption because the statistical meters which were used by the LEC to measure were only installed at substations where the different utilizations of the LEC's clients were aggregated from one feeder panel in the absence of individual feeder panels for each client or each sector (Industrial, Household, and Services). The electricity losses of the transmission and distribution power network were not divided such that the losses of each network could be determined separately.

To address these challenges, the past trends in the electricity consumption and GDP growth were used to predict the future electricity consumption when the impact of the big projects like LHDA Phase 2 was examined since they made significant contributions to the growth of both the GDP and the consumption of electricity. The Sectors were used as the "clients" as the input to MAED-EL. The categories of the LEC's customers were grouped according to the type of tariff used. The 12% total losses of electrical energy of transmission and distribution were distributed at 5% and 7% each per network component respectively.

The results produced by this study should inform the LEC's management about the future electrical energy demands in the country. It should assist Management to make well-informed decisions to source funds for upgrading the existing electrical infrastructure well in advance since the acquisition of enough capital for constructing transmission lines and power stations is usually a lengthy and arduous process. Also, the steps to be taken to acquire suitable land involve lengthy actions such as environmental impact analyses, geotechnical studies and feasibility studies, before the development of the power system's infrastructure commences. The output of this study should also be of benefit to the country by attracting investors in the energy sector, and, more particularly, those in renewable energy because they will be aware of the electrical energy demand deficits from 2020 to 2040 hence the required levels of power generation. They should also know the future Peak Loads of the seasons and their Base Loads and their hourly loads. This information should also assist in the designing and construction of power plants and generator units of the proper size, able to meet the load demands adequately on the different types of day and the three seasons of the year.

5.2 Recommendations

Based on the findings of this study, it is recommended that the system peak load be reduced which should improve the load factor and result in a lower cost per unit (kWh). This can make electricity more affordable and reduce the cost of constructing huge power plants to handle the peak load demand. This could be achieved through the distribution of the peak load by distributing the electricity consumption load of the larger energy-consuming clients in such a way they do not reach their peak loads at the same time.

It is recommended that LEC needed to plan for a new power plant that would be able to meet the energy requirements in the future since failure to do so could lead to load shedding if not addressed in advance. In short, the LEC would need to upgrade the existing power system infrastructure to accommodate the growing load. The records of the electrical energy losses should be divided into two categories, transmission network, and distribution network so that the losses for each could be studied separately.

Furthermore, the disaggregated consumption data of the different clients should be made known so that the LEC is informed of the load patterns of the different clients and it can predict the distinctive future load profiles of the different consumer categories. It is further recommended that more studies of this nature be conducted to analyze the load growth for each main substation because the growth of each substation or Load Centre differed from the others (being it urban, peri-urban or rural).

Again, studies of this nature should be conducted periodically because the factors which affect the consumption of electrical energy were seen to be fluctuating and they could impact the predictions of the study. Such factors could be, for example, the results of the occurrence of epidemic diseases that could impact population growth or a civil war that could displace people and impact the growth of the economy.

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