



**ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING**

**LONG TERM DEMAND-FORECASTING AND GENERATION EXPANSION PLANNING OF THE ETHIOPIAN
ELECTRIC POWER (EEP)**

**A THESIS SUBMITTED TO ADDIS ABABA INSTITUTE OF TECHNOLOGY,
SCHOOL OF GRADUATE STUDIES, ADDIS ABABA UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN ELECTRICAL ENGINEERING
(ELECTRICAL POWER ENGINEERING)**

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APRIL, 2017**



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*Dedicated to every Ethiopian who longs for a day when a future-Ethiopia can boast of
uninterrupted power supply.*

In the memory of my grand-father, Hagi Abdurahman.

Acknowledgement

I am highly grateful to my advisor and instructor, Prof. NP. SINGH for his valuable guidance, insight, encouragement, and professional expertise during the course of this thesis work and to his efforts in conducting the two courses he has taught me. It is a blessing for me to be taught by such a qualified and experienced instructor.

Special thanks to the Ethiopian Electric Power staff members, who assisted me in collecting the data required for this thesis work.

I also would like to thank Mekele University for awarding me a chance to pursue this MSc study and all the AAIT and ECE staff members for facilitating every study and research requirements during my study.

My friends and colleagues Hassen, Messay, Eskedar, Muluken, Biadgilign and Tibebu, you guys deserve my gratitude for being there when I needed you during my study years. Deepest thanks to my family, Dad, Mom and my brother.

Glory be to Allah, whose good will brought me this far.

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Abstract

In the upcoming decade, Ethiopia is expected to experience high economic, Industrial and social growth. As a result, In addition to the growth of the existing electricity demands, the Ethiopian Electric Power (EEP) expects new customer demands from neighboring countries, from Irrigation & Transportation systems and New Industrial and manufacturing customers. Therefore, it is required that these new demands requested be considered during the generation expansion planning of the country. Moreover, it is also required to take into consideration of the uncertainty of the demand driving parameters such as the Gross Domestic Product (GDP) and Population growth of the country in order to make an accurate load forecasting.

This thesis, in addition to introducing the new demand requests into its forecast, it also applied a stochastic demand forecasting method to consider the uncertainty of the demand driving parameters of the GDP and Population growth of the country. In this stochastic method of demand forecasting two Scenarios, each having different forecasted GDP data are considered. The 1st Scenario considered a moderate GDP forecast, which was forecasted by the International Monetary Fund (IMF) until 2028. The 2nd Scenario considered the country's 2028 Target GDP data obtained from MOFED (Ministry of Finance and Economic Development). The historical population data of the country (until 2014) was collected from the Central Statistical Agency of Ethiopia and the United Nations. Based on these data the electricity demand forecast and Generation Expansion Planning (GEP) of the year 2028 is done for both the scenarios.

Using the Scenario-1 GDP data, a peak demand of 12,450 MW is estimated for the year 2028. While, in the 2nd Scenario a peak demand of 13,319 MW is estimated. Comparing the Generation Expansion Planning results of the 2 Scenarios, for the year 2028, it is recommended to construct the Scenario-2 selected plants of Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams with a total cost of \$3,190 million.

KEYWORDS: Demand Forecasting, Stochastic Forecast, Generation Expansion Planning, Optimization, Gross Domestic Product.

CHAPTER 1

INTRODUCTION

1.1 Background

Our day to day living is changing rapidly. From hunting and gathering to a fully computerized and automated era. Today we are living in an era where things we never imagined earlier have become our vital necessities. For example, light in those ages was to be got only from the sun for a limited part of the day. But now thanks to Thomas Alva Edison who by inventing electricity illuminated our world, it is possible to access electric light at any time of the day.

The social and economic development of any country is highly dependent in electricity. Recent statistics conducted in Africa indicates that; power shortages cut economic growth of the continent by 2-4 percent annually; the toxic fumes released by burning firewood and dung kill 600,000 people a year half of them children and Health clinics are unable to refrigerate life-saving vaccines and children are denied the light they need to study [1].

In addition to the requirement of availability of electric supply for a nation, there is also a need of un-interrupting and durable electricity supply capable of supplying its daily and seasonal changing demands with-out any failure excuses. Without such electricity adequacy and durability, businesses, homes and the society at large cannot function to their full capacity; Goods and services would cost more than they should if every business owner has to own private backup diesel generators; health care provision would be substandard and inadequate. Unreliable power supply undermines investment which results in higher unemployment rates. As a result, the electric power system of a country should be built in such a way that it would be capable of meeting the electricity demand of its citizens adequately and it should assure that every household and business office has access to adequate and durable power supply.

Ethiopia has many and different types of electrical energy sources to meet the power demand of its total 97 million people [1]. However, according to USAID (2015) only 25% of the population is connected to the grid [2]. Moreover, based on the countries estimated economic and demographic growth data and the countries policy of manufacturing sector expansion there is no doubt that the future electricity demand will exceed its existing generation capacity. Hence unless these demand growths are addressed in advance, power supply inadequacy might result in the near future.

In order to solve the country's problem of power supply inadequacy and lower-durability, a generation upgrade and expansion plan based on a demand forecast which took into consideration of the growth of all possible demand categories is

necessary. This means that more generating units should be added to the existing power plants or new power plants can be built at new locations in the nation's power grid to adequately supply the existing and forecasted demand.

1.2 Problem Statement

According to the World Bank (2015), Ethiopia experienced an average Gross Domestic Product (GDP) growth rate of 10.7% in the past decade, and according to the country's second growth and transformation plan (GTP II) the country plans to continue this trend for the next 10 years. The country also plans to self-suffice and export extra electricity of 12,075 GWh to neighboring countries by 2020 [3].

Moreover, in addition to the growth of the existing demands of the Domestic, Commercial and Industrial customers, there are new pending demand requests of rail way and irrigation system that are estimated to require 1,450 GWh and 2,900 GWh of electricity respectively by the year 2020 [3].

This thesis has looked through that, in Ethiopia, taking into consideration of the above explained new demand requests together with the uncertainty of its population, social and high GDP growth and the government's growth and transformation plans need to be included in the demand forecasting and generation expansion planning of the country in order for a much reliable and accurate planning to happen, and that is the motivation for the work presented in this thesis.

1.3 Study Objectives

The general objectives of this study are to make a long-term demand forecasting and develop a feasible model that solves the problems of generation expansion planning of the Ethiopian Electric Power (EEP) for the year 2028.

The specific objectives of the study include:

- To include every demand requests in forecasting the demand, including the demand requested by the Export, Transportation and Irrigation customers.
- To study and forecast the long term electricity demand of the Ethiopian Electric Power using the stochastic method.
- To make use of different data of the Gross Domestic Product (GDP) and Population number of the country to estimate its electricity demand.
- To develop a mathematical model and MATLAB codes for those revealed objectives and constraints in the generation expansion planning of the Ethiopian Electric Power (EEP).

1.4 Methodology

In this thesis, the demand forecast of the Ethiopian Electric Power (EEP) for the year 2028 is done using a Stochastic Method.

In this Stochastic Forecasting Method, the effects of the uncertainty of the *demand driving parameters* such as the GDP and the Population number of the country are considered, the historical data of these two driving parameters are correlated to the historical demand data using a software WEKA and by forecasting these two parameters till the year 2028 and by inserting them in the determined correlation, the future demand is estimated until the year 2028.

According to EEP (2015), there exist a total of 34 potential candidate plants proposed to be studied for a long-term planning. From these candidate plants a Generation Expansion Planning (GEP) was done to select the most optimum generating plants capable of supplying the 2028 forecasted demand adequately, at a minimum cost.

Optimization of the candidate plants is done by developing a mathematical model and applying the model to the 34 candidate plants using Matlab. This GEP is done for the demand forecasted using the Stochastic Method.

In pursuing this study, soft-wares such as the WEKA, Ms-Excel and Matlab; different literatures, text books, periodicals, websites and thesis papers were used and referred.

1.5 Chapters Overview

In Chapter 1 explanation of the background of the study, the problem statements, objectives of the study and a summary of the methodologies used in the study are briefed. In Chapter 2 an introduction of the Ethiopian Electric Power (EEP) is given. In this introduction, the generation and transmission capacity of the EEP, the total demand status and un-served demand of its customers is discussed. In Chapter 3 detail explanation of different categories of demand forecasting methods and that of the Generation Expansion Planning, detail models, steps and mathematical equations used in this study referring to the literatures reviewed are given to the reader. Chapter 4 first discusses the data used for the simulations and then gives the simulation results. The analysis of the results and discussions made based on the simulation results are also discussed in this chapter. In Chapter 5 it is given; the conclusions of the results, recommendations and proposals for future work in this area.

CHAPTER 2

ELECTRICITY IN ETHIOPIA AND THE ETHIOPIAN ELECTRIC POWER (EEP)

2.1 Introduction

Ethiopia is a land-locked country located in the horn of Africa. It is the second most populous country in the Sub-Saharan Africa having a total population of over 97 million people [1].

Ethiopia has registered impressive Gross Domestic Product (GDP) in recent years, ranging between 6% and 12% per year depending on the data sources. The World Bank (2015) and IMF (2015) forecast the country's average annual GDP growth at a rate of 7.7 % over the next ten years.

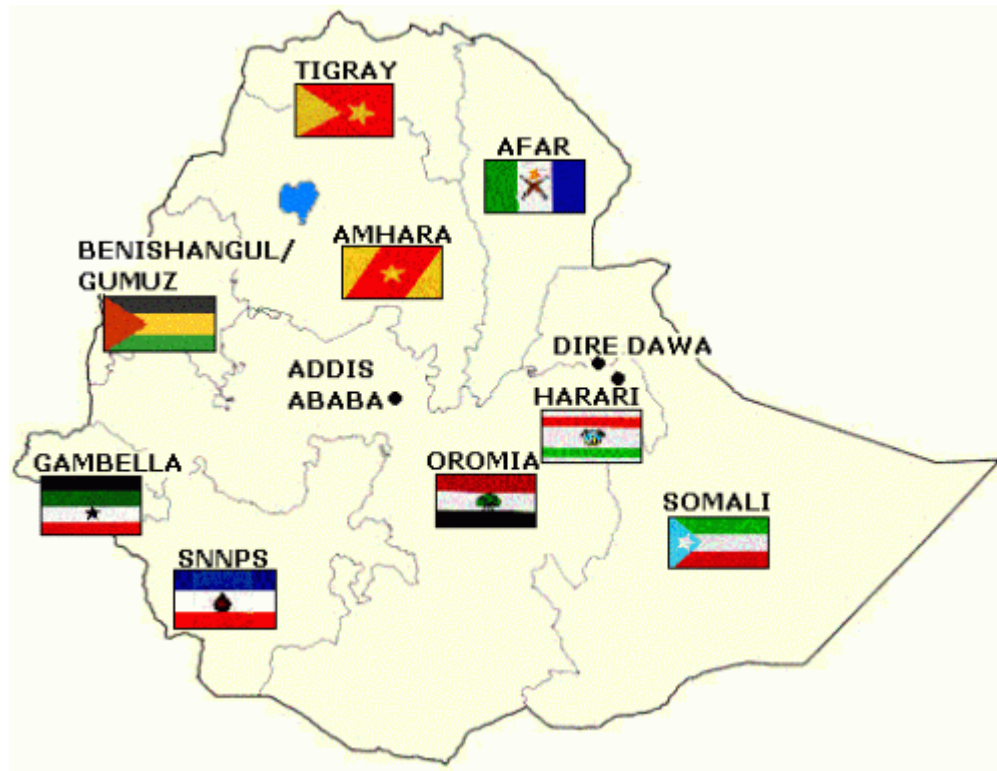


Fig. 1.1 Map of national regional states of Ethiopia

Despite its strong overall economic growth, Ethiopia remains one of the poorest countries in Africa. To address the remaining challenges, the government has created ambitious economic development targets. The country's ten-year (2010–2020) economic strategy, the Growth and Transformation Plan (GTPI and II), seeks

to achieve the Millennium Development Goals and middle-income status by 2025 [2].

In the energy sector, the government's main stated objective is to use a carbon-neutral growth path way to improve the living conditions of its people. The GTP includes an aggressive energy policy framework designed to expand installed electricity capacity from approximately 2,000 MWs to 12,000 MWs, to build 132,000 km of new distribution lines and increase the number of customers from two million to six million by 2020. Renewable energy capacity, primarily hydro, and energy efficiency will play major roles in this growth by 2020 [2].

The Ethiopian electricity system is governed by a power utility having two corporate entities. These entities are the Ethiopian Electric Power (EEP) and the Ethiopian Electric Utility (EEU). The generation of the power and construction of new transmission lines are handled by the EEP while the later is tasked with managing the distribution, sales and operation of electricity in Ethiopia [4].

Overview of the country's current generation capacity, transmission coverage and its customers demand status are given in the following sections 2.2 to 2.4.

2.2 Generation System Capacity and Transmission System Coverage of the EEP

The Ethiopian Electric Power (EEP) has a total of 21 operating and 15 committed generating units [5]. The operating units are capable of generating a total of 4,372 MW of power (up more than 200% since 2008), out of which 90% of the power is generated by hydro units, 8% by wind, 0.3% by geothermal and 3.7% of the power is generated by diesel units [2]. Table 2.1 below shows the operating units and their current actual generation capacity [5] [2].

Table 2.1 Details of the Current Operating Units of the Ethiopian Electric Power (EEP)

No	Name of The Plant	Type of The Plant	Plant Capacity (MW)	Plant Factor
1	Koka	Hydro	43.2	29%
2	Tis Abay I	Hydro	12	81%
3	Awash II	Hydro	32	59%
4	Awash III	Hydro	32	59%
5	Fincha	Hydro	134	67%
6	Melka wakana	Hydro	153	41%
7	Aluto Langano	Geothermal	7.3	65%
8	Tis Abay II	Hydro	73	69%
9	Gilgel Gibe I	Hydro	184	51%
10	Awash 7killo	Diesel Oil	28	83%
11	Kaliti	Diesel Oil	11.2	83%
12	Dire Dawa	Diesel Oil	40	80%
13	Tekeze	Hydro	300	40%
14	Gilgel Gibe II	Hydro	420	52%
15	Tekeze	Hydro	300	49%
16	Sor	Hydro	5	49%
17	Fincha Amertinesh	Hydro	97	52%
18	Gilgel Gibe III	Hydro	1,870	72%
19	Adama 1	Wind park	51	55%
20	Ashegoda	Wind park	120	53%
21	Tana Beles	Hydro	460	34%

[Source: the USAID and EEP, 2015]

As shown in Table 2.1 above, the average Plant Factor (the ratio of the average power load of the plants to their rated capacity) of the power units is 58.2%. This low Plant Factor according to the Ethiopian Electric Power (2015) is due to faulty generators, lack of machine maintenance and generally, aging generators in the old power units.

Due to the utilities commitment to improve the power situation of the country, there are a number of projects under way to expand the generation system. Table 2.2 below shows the power plants under construction and under commissioning at the moment and expected to be connected to the grid between the years 2015 and 2020.

Table 2.2 Details of the EEP Plants Being Constructed and Under Commissioning

S. No	Name of the plant	Type of the plant	plant capacity (MW)	Status of the power plants
1	Grand Ethiopian Renaissance Dam (GERD)	Hydro	6400	Under Construction
3	Messobo/Harena	Wind park	51	Committed
4	Ayisha	Wind park	300	Committed
5	Gilgel Gibe V	Hydro	660	Under Construction
6	Debre Birhan	Wind park	100	Committed
7	Asela	Wind park	100	Committed
8	Adama II	Wind park	210	Committed
9	Genale Dawa III	Hydro	254	Committed
10	Genale Dawa VI	Hydro	246	Committed
11	ChemogaYeda I	Hydro	162	Committed
12	ChemogaYeda II	Hydro	118	Committed
13	Geba I	Hydro	215	Committed
14	Geba II	Hydro	157	Committed
15	Halele Warabesa-1	Hydro	440	Committed

[Source: the USAID and EEP 2015]

According to the Ethiopian Electric Utility (EEU) the Ethiopian transmission grid currently consists of 12,000 km of High Voltage (ranging between 35KV to 230KV) transmission line and 157,000 km of both Medium Voltage (ranging between 600V to 35KV) & Low Voltage (voltages up to 1 KV) distribution lines [5]. In the coming years EEU planned to connect Ethiopia and Kenya with a 500 KV HVDC transmission line, and a memorandum of understanding is signed to connect the grid with Tanzania, Rwanda, South Sudan, Yemen and a second line with Djibouti [5].

2.3 Electricity Demand

The Peak demand of the country which was 465 MW in 2004 grew by 17% per year and reached 1,262 MW by the year 2014 [6]. Factors contributing to this high demand growth rate include [6]:

- The countries High GDP growth which according to the government grew at an annual average rate of 10.7%.
- Expansion of the national grid to rural towns and villages, raising the electricity access of the country which was 15% in 2007 to 53% in 2014.
- Industrial consumption enhancement due to the high industrial development of the country.
- Household energy consumption in major towns shifted from wood-fuel and kerosene to electricity.

In the next years up to 2028, due to the factors given above and due to new demand requests from the new railway developments, new large irrigation developments, new industrial zones, large scale dwelling house expansion programs, universal electricity access expansion program and export consumers increment, the demand growth is expected to grow at a higher rate than it did in the last decade [5].

2.4 Un-Served Energy

Although Ethiopia has more than enough energy sources to meet the Energy demand of its people, and although Ethiopia has crafted ambitious energy targets, electricity access challenges remain. Over half of the population is located geographically close to the electricity grid, but actual interconnection rates are just 25% [2]. Per capital domestic electricity consumption is less than 100kWh per year [2]. Traditional biomass for house hold cooking also accounts for 89% of the total domestic energy consumption. Firms and companies also report outages and it is very common for homes and firms to have their own generation units [7].

CHAPTER 3

LOAD FORECASTING AND GENERATION EXPANSION PLANNING

3.1 Introduction

In this chapter reviews of different literatures regarding the Demand Forecasting and Generation Expansion Planning are discussed. Moreover, the procedures, steps and mathematical models of the methods that are selected and used in this thesis are explained.

3.2 Literature Review of Load Forecasting

The word 'Load' is a general term meaning either 'demand' or 'energy', where demand is the time rate of change of energy. The term forecast refers to projected load requirements determined using a systematic process of defining future loads in sufficient quantitative detail to permit important system expansion decisions to be made. Generally speaking, demand forecasting is a systematic procedure for quantitatively defining future loads [8].

Power demands may be classified as residential, commercial and industrial. Of these three broad classes of demands, residential and commercial demands have the most constant annual growth rate and the most seasonal fluctuations, while the Industrial demands are considered base demands that contain little weather dependent variations. These industrial demands tend to grow more in developing countries which have a higher rate of industrial growth [8].

Electrical load forecasting is vitally important for the electric industry of any country's economy. It has many applications including energy purchasing and generation, load switching, contract evaluation, and infrastructure development [9].

Power system expansion planning starts with a forecast of anticipated future demand requirements. Estimates of both demand and energy requirements using accurate methods are crucial to effective system planning [8].

Demand forecast can be divided into three categories: Short-Term Load Forecasts (STLF) which usually range from one hour to one week, Medium-Term Load Forecasts (MTLF) which ranges from a week to a year, and Long-Term Load Forecasts (LTLF) which ranges from a year to ten to fifteen years [9] [10]. There are different parameters affecting demand forecasting. The main parameters are listed as follows [10]:

- Time factors such as, Hours of the day (day or night), Day of the week (week day or weekend) and Time of the year (season).
- Weather conditions (temperature and humidity).
- Class of customers (residential, commercial, industrial, agricultural, public etc.)
- Special events (TV programs, public holidays, etc.)
- Population.
- Economic indicators (per capita income, Gross National Product (GNP), Gross Domestic Product (GDP), etc).
- Trends in using new technologies.
- Electricity price.

However, as we move towards longer time frames, the accuracies of some driving parameters drop. For instance, the forecast of energy prices for Short-Term Load Forecasts (STLF) is more accurate than that of Medium-Term Load Forecasts (MTLF). The same is true for weather forecast.

Due to inaccuracies involved in the long-term driving parameters, it is of common practice to perform Long-Term Load Forecasts (LTLF) using different scenarios (such as scenarios having different future GDPs and the population numbers) [9].

Different techniques of Long-Term Load Forecasting are suggested and discussed in different literatures such as, The End-use Modeling, Econometric Modeling, and the combinations of both models [8] [10]. Based on the End-Use Approach, descriptions of appliances used by customers, the sizes of the houses, the age of equipment, technology changes, customer behavior, and population dynamics are usually included in the statistical and simulation methods. While in the Econometric Modeling factors such as per capita incomes, employment levels and electricity prices are included. This model can also be used in combination with the End-use Approach [9].

According to Sullivan (1977) forecasting techniques are classified as Deterministic Method and Stochastic Method. The Deterministic Method involves fitting trend curves to basic historical data adjusted to reflect the growth trend itself. In this method a simple extrapolation of the historical demand is done and no attempt is made to account for random variations of different driving parameters, which results in a less accurate demand forecast. However, in the Stochastic Method the uncertainty of either one parameter or a set of parameters is considered, some of these parameters include the demographic growth such as the population number and the economic growth such as the Gross Domestic Product (GDP) of the country. In this method in order to clearly understand the interrelationship of the historical demand growth with that of the Gross domestic product (GDP) and Population number, the correlation of the system loads to the population number and the Gross domestic product (GDP) is done, and based on the forecasted GDP

and Population number of the country and using their correlations to the electricity demand, the future demand is estimated.

During load forecasting a question to ask may be, should peak demand be forecasted using forecasted energy and load factors, or should it be forecasted separately? This question was explained by Sullivan (1997) as “Two options are open to the researcher”. The researcher can estimate the energy, considered to be less difficult and obtain the demand forecast from it by using forecasted load factors. Advantages of using energy as the primary forecast and obtaining the peak demand forecast from it are that energy tends to be much less erratic, is considered a better trend growth indicator, and is readily related to demographic and economic factor, using energy data broken down into classes of services, areas etc [11].

The second option is that the forecaster can forecast the peak demand directly. The advantages claimed for separately forecasting the peak demand are that it is a more direct method and can be related directly to such weather variables as temperature [11].

In Ethiopia since a negligibly small weather variations exist in it's 'thirteen months sun shining' climate [12], it is not necessary to relate the electricity demand to the temperature variation. Rather, it is necessary to relate the electricity demand to the variable demographic and economic factors. Therefore, in this thesis the first option of forecasting the energy demand (by relating it to the variable demographic and economic factors) is forecasted first and from the forecasted energy the peak demand is obtained using equation 3.1(given in section 3.2.1).

In this thesis a special focus is given to the Long Term Load Forecasting (LTLF) of the EEP for the years 2015 to 2028. This demand is estimated using the stochastic method. In this method different scenarios are considered and decision is made. This Stochastic method is further explained in the next section (section 3.2.1).

3.2.1 Stochastic Method

In Stochastic Method, unlike the Deterministic Method discussed in the previous section 3.2, one parameter or a set of parameters are uncertain. This means that, unlike the Deterministic method, in this Method forecast isn't carried out on an expectation [13] [14] rather the effect of the uncertain parameters is taken into consideration.

This Method relates system demands to various demographic and economic factors and enables the forecaster to understand clearly the interrelationship between load growth patterns and the demographic and economic factors [10]. Typical economic factors and demographic factors include the country's Gross

Domestic Product (GDP) and its Population number. The steps/procedures followed to stochastically forecast the 2015 to 2028 demands are given as follows:

1. Data collection:

The Historical data of such as the Gross domestic product (GDP), the Population number, the Energy Sales of the country for the past 10 years (up to 2014) and new pending electricity demand requests of the Export, Industrial and Irrigation sectors for the future years until 2028 were collected from different firms (These data are given in section 4.2.1).

2. Parameter Forecast (Forecast of the GDP and Population number):

In order to include the effects of the un-certainty of the two driving parameters (the GDP and Population number) on the Energy Forecast, the forecast of the future GDP and the future Population number of Ethiopia was required.

Therefore, in this step, the forecast of the GDP and the Population number until the year 2028 is done.

3. Correlation of the historical energy sales data to the GDP and the Population number:

Based on the historical and forecasted data of the GDP and Population number and based on the historical energy sales data, the correlation between the GDP and the Population number versus the Energy Sales of each of the existing customer categories (Domestic, Commercial and Industrial sectors) is determined.

The manual determination of these correlations is not an easy job and time consuming. Hence, it requires the aid of a computer application to get a better accuracy and a short execution time.

In this thesis the software used to determine the correlation is a data-mining software WEKA. (further explanation of WEKA is given in Appendix C and reference [15]).

Moreover, in this step the *Total Energy Forecast* of the existing demand categories is calculated by adopting EEP's historical data of transmission loss of 16% and adding it to the sum of the forecasted *Total Energy Sales* of the Domestic, Commercial and Industrial electricity demands.

4. Considering pending demand Requests:

Since there are pending demand requests and new demand categories expected to emerge in the next ten years, in this step to get the *Total Energy Forecast* of the years 2015 to 2028, the *Total Energy Forecast* of the existing demand categories forecasted in Step 3 above is added to the new pending demand requests and estimated energy sales of the new Demand categories.

5. Peak Demand Forecast:

To obtain the peak demand forecast, the Total Energy Forecast calculated in step 4 above is converted to the Peak demand forecast (using equation 3.1 given below) by considering the utilities 2012 to 2014 average load factor of 57%.

$$Peak\ Demand = \frac{Energy\ Demand}{Load\ Factor * 8.76} \quad (3.1)$$

Where:

Peak Demand : is the annual Peak Demand in MW.

Energy Demand : Total Annual Energy Demand in GWh.

Load Factor: is the ratio of actual Energy used in a year to the possible Energy that could have been used in a year.

Steps 1 to 5 discussed above are applied for two scenarios having different GDP data as given in section 4.2.

3.3 Literature Review of the Generation Expansion Planning (GEP)

Generation Expansion Planning (GEP) is the problem of determining *when, what* and *where* the generation plants are required so that the loads are adequately supplied for a foreseen future time. Therefore Generation Expansion Planning is an optimization problem in which the aim is to determine the new generation plants in terms of when to be available, what type and capacity they should be and where to allocate so that an objective function is optimized and various constraints are met [7]. Its objective is usually to determine a minimum cost strategy for long-range expansion of the generation systems adequate to supply the load forecast within a set of technical, economic and political constraints [7].

GEP may be of static type in which the solution is found only for a specified stage (typically a year) or a dynamic type, in which, the solution is found for several stages in a specified period [7].

3.3.1 Optimization of the Generation Expansion Planning

Optimization means finding "best available" values of some objective function given a defined domain, including a variety of different types of objective functions and different types of domains [8].

In optimization theory, a given function often called the *objective function* is to be minimized subject to a set of constraints. The controllable variables of the optimization problem are called *optimization* or *decision variables* [16]. Generally speaking, a standard optimization problem can be expressed as follows [10]:

$$\begin{aligned} & \text{Min}_x C(x) && \text{Subjected to} \\ & f(x) = 0 && \& & g(x) \leq 0 \end{aligned} \quad (3.2)$$

Where:

X : the decision variable,

C(x) : is the objective function

f(x) = 0 : is the equality constraint and

g(x) ≤ 0 : is the inequality constraint.

If the function C(x) and the decision variable x are linear functions, then the optimization problem is referred to as a linear programming problem. If any of the element of x is an integer variable, then the problem becomes an integer linear problem [10].

Optimization techniques can be of a mathematical or heuristic technique. Out of these two techniques the mathematical optimization technique is usually used in power system literatures [10]. This technique usually formulates the problem in a mathematical representation.

In Generation Expansion Planning the application of the optimization technique helps in determining the optimum generating units (having the least investment and capital cost) provided that these selected units are capable of supplying the demand adequately.

In this thesis, the optimization model used in the Generation Expansion Planning (GEP) is the standard optimization model given in equation 3.2 above and its objective function and constraints are explained as follows:

3.3.1.1. Objective Function

The objective function is to minimize the sum of generation investment cost, operating costs, fuel cost and a penalty cost λ for the un-served energy. The addition of the penalty cost λ is done to ensure that the optimization result is not a global optimum i.e. one that satisfies the highest demand, but rather should be able to pay the penalty of the un-served demand.

Hence, the Total Cost to be minimized can be described as:

$$C_{total} = C_{inv} + C_{O\&M} + C_{Fuel} + \lambda \quad (3.3)$$

Where:

C_{total} - The total cost to be minimized

C_{inv} - The investment cost

$C_{O\&M}$ - The operation and maintenance cost

C_{fuel} - The fuel cost

λ - Penalty cost of un-served demand

In this study a total of 34 candidate units were considered. The specifications of each units such as their investment costs, operation and maintenance costs, life times and fuel costs are given in Table A1 of Appendix A. These costs are briefly discussed as follows:

1. Investment Cost (C_{inv}):

This term represents the cost of a power plant, in terms of \$/MW. The total investment cost is the product of this value with the power plant capacity.

$$C_{inv} = \sum_{i=1}^{Ng} (C_{inv_i} PG_i) \quad (3.4)$$

Where:

C_{inv} - Total Investment cost in \$/MW

C_{inv_i} - The cost in \$/MW for candidate unit i

PG_i - The capacity of candidate unit i (MW)

Ng - The total number of candidate units considered

2. Fuel Cost (C_{fuel}):

The fuel cost of a plant is, in fact, dependent on its production level (i.e. $f(PG_t)$). In other words, the cost varies with the production level. For simplicity, however, the cost (\$/MW) is considered to be fixed here. Total cost is calculated from the product of this value and the capacity of the unit.

$$C_{fuel} = \sum_{i=1}^{Ng} (C_{fuel_i} PG_i) \quad (3.5)$$

Where:

C_{fuel} - Total fuel cost in \$/MW.

C_{fuel_i} - The fuel cost in \$/MW for candidate unit i.

PG_i - The capacity of candidate unit i (MW).

Ng - The number of candidate units considered (in this study, $Ng = 34$).

3. The Operation and Maintenance Cost ($C_{O\&M}$):

Operation and Maintenance (O & M) is the process required for the proper operation of power plants, defined in terms of the number of days per year. Two cost parameters are also normally defined for maintenance.

- A fixed term, independent of energy production (in terms of \$/MW); the total value is calculated from the product of this value times the plant capacity times 12 (12 months).
- A variable term, defined in terms of \$/MWh. Note that the total variable cost is affected by the period of maintenance, as during these days, the plant does not generate any power.

$$C_{O\&M} = \sum_{i=1}^{Ng} (C_{o\&m_i} PG_i) \quad (3.6)$$

Where:

$C_{O\&M}$ - Total operation and maintenance cost in \$/MW

$C_{O\&M_i}$ - The fixed term of the operation and maintenance cost in \$/MW for candidate unit i

PG_i - The capacity of candidate unit i (MW).

Ng - The number of candidate units considered

4. The Cost of un-served Energy (λ):

Based on the existing diesel generators electricity price, a cost of \$0.02 per KW was considered to be the maximum cost of electricity when calculating the penalty cost of the un-served demand. This penalty of the Un-served Energy was calculated using the following equation:

$$\lambda = 0.02 * u_E \quad (3.7)$$

Where:

λ - Cost of the Un-served Energy (\$)

U_E - Total Un-served Energy (KWh)

3.3.1.2. Constraint:

The generation capacity should be sufficient in meeting the demand of the required future year T. (In this study the Generation Expansion planning was done for the year 2028). Hence the Generation Constraint can be expressed as given in the following equation (3.8):

$$\left(1 + (Res_t/100)\right) PL_t \leq \sum_{i=1}^{Ng} (PG_i + P_{Gt}) \quad (3.8)$$

Where:

$(Res_t/100)$ – The required reserve capacity in year t

PL_t - The demand in year t.

Ng - The number of the candidate units considered.

PG_i - The capacity of candidate unit i (MW).

P_{Gt} - The capacity available due to existing units in year t.

The above discussed models of the objective function and constrains were written and run in Matlab . This Matlab code has many purposes such as, calculating the total cost required for the construction of each candidate plants (details of the candidate plants is given in Table A1 of Appendix A), calculating the total capacity of each of the group of plants selected for expansion and comparing it to the forecasted peak demand, suggesting the best group of plants for expansion (based on the plant's capacity and cost of expansion). Detail explanation of the Matlab code is given in Appendix B.

3.3.2. Assumptions, *Simplifications and Considerations*

In the Generation Expansion Planning of this thesis the following assumption were taken:

- The existing plants (both the operating and committed plants given in Tables 2.1 and 2.2 chapter 2) as built-in. Or it is assumed that all the committed plants given in Table 2.2 will be built and be operating before the year 2028. Therefore, the GEP in this thesis is done based on the specifications of the candidate plants (given in Appendix A) but not based on the already committed plants, as they are assumed to be operating before 2028.
- During the calculation of the expansion cost of the candidate plants, an annual interest rate of 7.5% was considered. This was based on the loan interest rate of the Commercial Bank of Ethiopia [17].

CHAPTER 4

SIMULATION STUDIES AND ANALYSIS OF RESULTS

4.1 Introduction

In this chapter the data collected and the demand forecasting results obtained by following the procedures given in section 3.2.1 are discussed in detail. Moreover, the simulation result of the Generation Expansion Planning done based on the forecasted demand is discussed in section 4.3 of this chapter.

4.2 Demand Forecasting

In this section the data collected from different firms and the demand forecast of the country until the year 2028 is discussed.

4.2.1 Data collection:

The historical energy sales data, data of new demand requests (requested by the new Irrigation sector, Industrial and Export sector), the historical and forecasted data of the Gross Domestic Product (GDP) and Population number of the country are collected from different firms and are given in sections 4.2.1.1 to 4.2.1.3 as follows:

4.2.1.1. Data of the Energy Sales and New Demand Requests

The historical energy sales data of the Domestic, Commercial and Industrial sectors until the year 2014 were collected from the utility (EEP) as given in Table 4.1 below:

Table 4.1 Historical Energy Sales Data of the Utility

Year	Annual Energy Sales Data (GWh)				Transmission Loss(%)	Total Generated Energy (GWh)
	Domestic	Commercial and Street Light	Industrial	Total Energy Sales		
2004	552	557	826	1935	20%	2,322
2005	730.6	556.96	803.19	2090.75	19%	2,488
2006	795.7	617.65	988.83	2402.18	17%	2,811
2007	1060.31	752.27	977.83	2790.41	16%	3,237
2008	1029.32	774.27	1139.65	2943.24	16%	3,414
2009	1178.1	760.41	1187.94	3126.45	16%	3,627
2010	1256	876	1289	3421	16%	3,968
2011	1442	884	1498	3824	16%	4,436
2012	1650	1090.3	1804.9	4545.2	16%	5,272
2013	1919.5	1253.5	2017.5	5190.5	16%	6,021
2014	2053.8	1291.43	2089.59	5434.82	16%	6,304

(Source: the Ethiopian Electric Power (EEP,2015))

As can be seen from the previous Table 4.1, the 2004 total energy generated was 2,322 GWh. Applying equation (3.1), this gives that a peak demand of 465 MW was experienced in the year 2004. This peak demand grew into 1,288 MW by the year 2014.

Table 4.2 Pending Energy Request of the New Irrigation, Transportation and Export sectors.

Year	Transport Sector Requested Energy (Gwh)	New Irrigation System Requested Energy (Gwh)	Pending Export Energy Request (GWh)	Total Energy Request (GWh)
2015	904	2,038	----	2,942
2016	1,050	2,373	-----	3,423
2017	1,197	2,708	8366	12,271
2018	1,343	3,043	8366	12,752
2019	1,489	3,378	9680	14,547
2020	1,636	3,713	12075	17,424
2021	1,782	4,048	16017	21,847
2022	1,928	4,383	21387	27,698
2023	2,075	4,718	25329	32,122
2024	2,221	5,053	26643	33,917
2025	2,367	5,388	30585	38,340
2026	2,514	5,723	32332	40,569
2027	2,646	6,044	34119	42,809
2028	2,778	6,365	35906	45,049

(Source: the Ethiopian Electric Power (EEP, 2015)

From the data of the pending demand requests given Table 4.2 above it is observed that for the year 2028 an energy supply of 2,778 GWh is requested by the new Transportation sector. While for the same year 6,365 GWh of energy is requested by the new irrigation system and 35,906 GWh of energy is requested by the Export customers.

4.2.1.2. GDP Data

The historical and forecasted Gross Domestic Product (GDP) data of the country were collected from the Ethiopian Ministry of Finance and Economic Development (MOFED) and the International Monetary Fund (IMF). The IMF forecasted a moderate GDP growth at an annual average rate of 7.7% [18]. While, the MOFED, considered the government's 2nd Growth and Transformation Plan (GTPII), which targets the GDP growth at an annual average rate of 11%. The historical and forecasted GDP data of both firms are given in Tables 4.3 and 4.4 below:

Table 4.3. Historical GDP data of the IMF and MOFED

Year	IMF GDP data (Million Birr)	MOFED GDP data (Million Birr)
2004	Not Available	86,691
2005	Not Available	92,499
2006	Not Available	99,899
2007	Not Available	107,891
2008	Not Available	116,523
2009	107,500	125,844
2010	116,960	136,793
2011	128,656	148,694
2012	137,192	161,630
2013	158,078	175,692
2014	203,178	190,977

(Source: (IMF, 2015): (MOFED, 2015))

Comparing the historical GDP data of the above Table 4.3, it can be seen that starting from the year 2011 the Gross Domestic Product (GDP) of the country has grown at a higher rate in the IMF data than in the MOFED's data. Hence, for 2014 a historical GDP of 203,178 million Birr is recorded by the IMF while 190,977 million Birr is recorded by the MOFED.

Table 4.4. Forecasted GDP data of the IMF and MOFED

Year	IMF forecasted GDP (Million Birr)	MOFED forecasted GDP (Million Birr)
2015	218,823	211,985
2016	235,672	235,303
2017	253,819	261,186
2018	273,363	289,917
2019	294,412	321,807
2020	317,082	357,206
2021	341,497	396,499
2022	367,792	440,114
2023	396,112	488,526
2024	426,613	542,264
2025	459,462	601,913
2026	494,840	668,124
2027	532,943	741,617
2028	573,979	823,195

(Sources: (IMF, 2015): (MOFED, 2015))

Similarly, From the forecasted GDP data given in table 4.4 above it is indicated that a 2028 GDP of 823 billion Birr is targeted by the MOFED data . While it is estimated by the IMF that 574 billion Birr will be the GDP of the country by 2028.

4.2.1.3. Population Data

The historical and forecasted data of the Population number of Ethiopia was collected from the Central Statistical Agency (CSA) of Ethiopia and the United Nations (2015) as shown in Tables 4.5 and 4.6 below:

Table 4.5. CSA Historical and Forecasted Population data of Ethiopia

Historical Population Data		Forecasted Population Data	
Year	Population Number/1000	Year	Population Number/1000
2004	68,085	2015	90,562
2005	69,924	2016	92,917
2006	71,812	2017	95,332
2007	73,750	2018	97,811
2008	75,668	2019	100,354
2009	77,635	2020	102,963
2010	79,654	2021	105,637
2011	81,725	2022	108,387
2012	83,850	2023	111,205
2013	86,030	2024	114,096
2014	88,267	2025	117,062
		2026	120,107
		2027	123,229
		2028	130,622

(Source: the Central Statistical Agency (CSA) of Ethiopia, 2015)

From Table 4.5 above according to the Central Statistical Agency of Ethiopia, the Population number of the country will have a 2.8% annual growth rate until the year 2028, and will reach 130,622 million by the year 2028.

However, according to a United Nations (2015) data, if the prevailing fertility rate of Ethiopia continues and mortality declines as would be expected under normal conditions, it is estimated that the Population of Ethiopia may grow at a rate of 3% or more a year during the next decade [19]. The United Nations population forecast is given in Table 4.6 below:

Table 4.6 UN Forecasted Population number of Ethiopia

Year	Population Number/1000
2015	91,003
2016	93,369
2017	95,796
2018	98,287
2019	100,843
2020	103,465
2021	106,152
2022	108,915
2023	111,747
2024	114,652
2025	117,633
2026	120,692
2027	123,829
2028	131,259

(Source: the United Nations, 2015)

From Table 4.6 above it can be observed that for the year 2028, the UN forecasted the population number of Ethiopia to be 131.2 million. Comparing this 2028 forecast with that of the CSA population forecast given in Table 4.5 (which is 130.6 million), only a difference of population of less than 1million is observed. Therefore, since this is a negligibly small difference in population number, the CSA data given in Table 4.5 is considered during the energy forecast of this thesis.

However, since there is a significant difference between the IMF forecasted GDP (given in Table 4.3) and MOFED's target GDP data (given in Table 4.4), both of these two GDP data are considered during the demand forecast of this thesis. Hence, the demand forecast is done using two different scenarios. The 1st scenario forecasts the demand based on the IMF's GDP data while the 2nd scenario forecasts the demand based on the MOFED's GDP data. The procedures followed and results obtained in these two scenarios are given in sections 4.2.2 and 4.2.3 as follows:

4.2.2. Scenario-1 (IMF GDP Scenario):

In this scenario the demand is estimated using the IMF's historical and forecasted GDP data (given in Table 4.3) and the historical and forecasted Population number data given in Table 4.5. The procedures followed and results obtained are given in sections 4.2.2.1 to 4.2.2.3 as follows:

4.2.2.1. Correlation of the historical Energy sales data to the GDP and the Population number:

The correlation between the historical Domestic Energy Sales and the historical GDP and Population number is obtained using WEKA as follows:

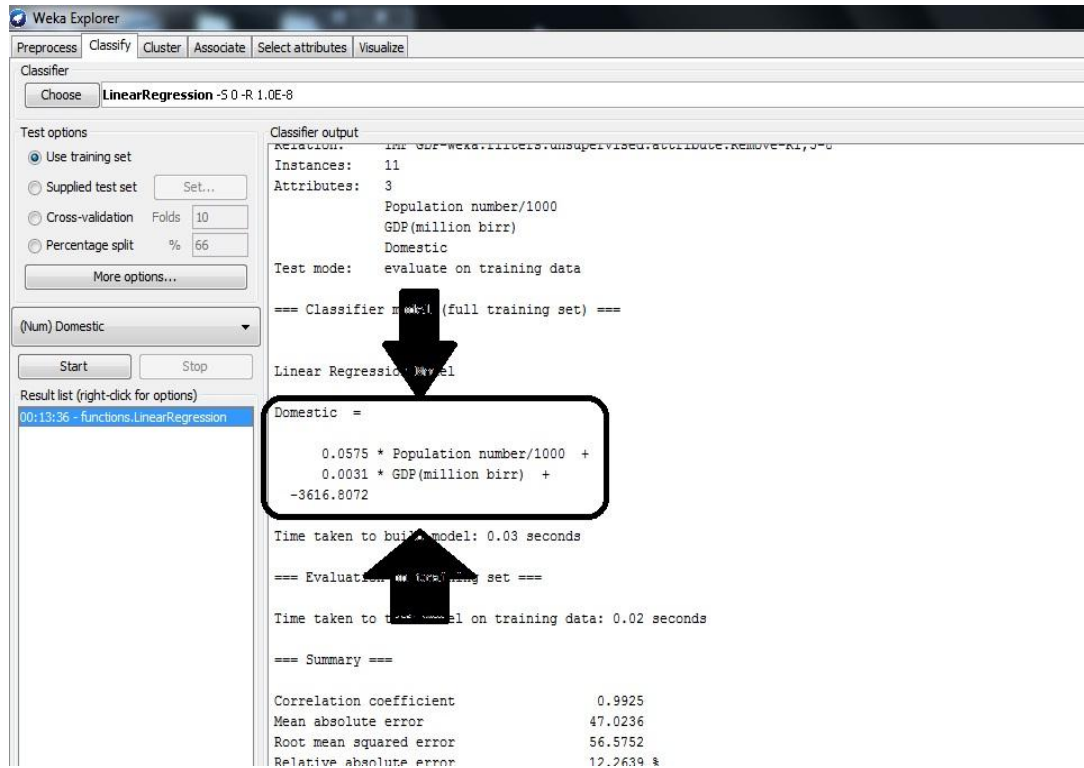


Figure 4.1 Screenshot of the WEKA result of the correlation between the Domestic Energy Sales and the GDP and Population number.

As shown in Figure 4.3 above the equation relating the Domestic electricity demand to the population and GDP of the country is :

$$\text{Domestic Energy Sales} = 0.0031 * \text{GDP} + 0.0575 * \text{Pop.} - 3616.807 \quad (4.1)$$

Where:

Domestic Energy Sales: The utility's annual energy sales for the Domestic consumer In GWh.

Pop. : The total divided by 1000 of the country's population number during the year when the energy was sold/is to be sold to the domestic consumer.

GDP : The million Birr Gross Domestic Product of the country during the year when the energy was sold/is to be sold to the domestic consumer.

Similarly for the Commercial and Industrial Energy Sales the correlations given in equations 4.2 & 4.3 below were obtained using WEKA:

$$\text{Commercial Energy Sales} = 0.0027 * \text{GDP} + 0.0253 * \text{Pop} - 1443.2 \quad (4.2)$$

Where Commercial Energy Sales : is the utility's annual energy sales for the Commercial consumer (GWh).

Pop. : is the total divided by 1000 of the country's population number during the year when the energy was sold/is to be sold to the domestic consumer.

GDP: the Gross Domestic Product (million Birr) of the country during the year when the energy was sold/is to be sold to the commercial consumer.

$$\text{Industrial Energy Sales} = 0.0037 * \text{GDP} + 0.0506 * \text{Pop} - 3062.8 \quad (4.3)$$

Where:

Industrial Energy Sales: is the utility's annual energy sales for the Industrial consumer (GWh).

Pop : is the total divided by 1000 of the country's population number during the year when the energy was sold/is to be sold to the domestic consumer.

GDP : the Gross Domestic Product (million Birr) of the country during the year when the energy was sold/is to be sold to the Industrial consumer.

In equations 4.1 to 4.3 above it is shown how the energy sales of the Domestic, Commercial and Industrial customers of the utility are related to the Population number and the GDP.

By inserting the IMF forecasted GDP (given in Table 4.3) and the Population number (given in Table 4.5) into the 3 equations, it is determine how much energy Sales of the Domestic, Commercial and Industrial customers there will be for the years 2015 to 2028. The result obtained is given in Table 4.7 below.

Table 4.7 Scenario-1: Forecasted Energy sales of the Domestic, Commercial and Industrial customers.

Year	Domestic Energy Sales Forecast (GWh)	Commercial Energy Sales Forecast (GWh)	Industrial Energy Sales Forecast (GWh)	Total Energy Sales Forecast (GWh)	Total Energy Forecast (including Transmission loss) (GWh)
2015	2,269	1,439	2,329	6,037	7,003
2016	2,457	1,544	2,511	6,511	7,553
2017	2,652	1,654	2,700	7,006	8,127
2018	2,855	1,770	2,898	7,522	8,726
2019	3,066	1,891	3,104	8,061	9,351
2020	3,287	2,018	3,320	8,625	10,005
2021	3,516	2,152	3,546	9,213	10,688
2022	3,756	2,292	3,782	9,830	11,403
2023	4,005	2,440	4,030	10,475	12,151
2024	4,266	2,595	4,289	11,150	12,935
2025	4,539	2,759	4,561	11,858	13,755
2026	4,823	2,932	4,846	12,600	14,617
2027	5,121	3,113	5,144	13,379	15,520
2028	5,673	3,411	5,670	14,755	17,116

In Table 4.7 above it is estimated that by the year 2028 energy demand of 5,673 GWh is required by the Domestic customers, this energy demand has increased by an annual average rate of 26% from its 2015 energy sales. Similarly, for the other demand categories, it is estimated that for the year 2028 a 3,411GWh and 5,670 GWh of energy will be required by the Commercial and Industrial customers respectively. From the last column of the above table the Total Energy Forecast was calculated by considering a transmission loss of 16% of the Total Energy Sales. This was based on the historical transmission loss data collected from the utility.

4.2.2.2. Consideration of New Demand Requests:

The summation of the new energy request of the Export, Irrigation and Transportation sectors (given in Table 4.2) to that of the total Energy Forecast of the existing demand categories (given in Table 4.7 above) is done as given in Table 4.8 below.

Table 4.8 Total Energy forecast of the years 2015 to 2028:

Year	Total Energy Forecast of the Existing Demand Categories (GWh)	Total Pending Energy Request (GWh)	Total Energy Forecast (GWh)
2015	7,003	2,942	9,945
2016	7,553	3,423	10,976
2017	8,127	12,271	20,398
2018	8,726	12,752	21,478
2019	9,351	14,547	23,898
2020	10,005	17,424	27,429
2021	10,688	21,847	32,535
2022	11,403	27,698	39,101
2023	12,151	32,122	44,273
2024	12,935	33,917	46,852
2025	13,755	38,340	52,095
2026	14,617	40,569	55,186
2027	15,520	42,809	58,329
2028	17,116	45,049	62,165

4.2.2.3. Peak Demand Forecast:

The Total Energy Forecast calculated in Table 4.8 above is converted to the Peak Demand Forecast by considering the utilities 2012 to 2014 (three years) average load factor of 57% and using equation 3.1 as given in Table 4.9 below:

Table 4.9 Energy and Peak Demand Forecasts of the years 2015 to 2028.

Year	Total Energy (Gwh)	Peak Demand (MW)
2015	9,945	1,992
2016	10,976	2,198
2017	20,398	4,085
2018	21,478	4,301
2019	23,898	4,786
2020	27,429	5,493
2021	32,535	6,516
2022	39,101	7,831
2023	44,273	8,867
2024	46,852	9,383
2025	52,095	10,433
2026	55,186	11,052
2027	58,329	11,682
2028	62,165	12,450

From Table 4.9 above based on the IMF GDP data (scenario-1) it is estimated that a Peak Demand of 1,992 MW is required by the year 2015, this estimated demand will increase by an annual average rate of 37.5% and will reach 12,450 MW by the year 2028.

4.2.3. Scenario-2 (Target GDP scenario):

In this scenario it is taken into consideration of the MOFED's Target GDP data (given in Table 4.4) and the historical and forecasted Population number data (given in Table 4.5). The procedures followed in forecasting the demand are given in sections 4.2.3.1 to 4.2.3.3 as follows:

4.2.3.1. Correlation of the historical Energy sales data to the GDP and Population number:

Based on the historical and forecasted data of the GDP and Population number and based on the historical energy sales data, the correlation between the GDP and the Population number versus Energy Sales of each of the existing customer categories (Domestic, Commercial and Industrial) is determined using WEKA.

The correlation between the historical Domestic Energy Sales and the historical GDP and Population growth is obtained as follows:

$$\text{Domestic Energy Sales} = 0.0138 * \text{GDP} - 572.096 \quad (4.4)$$

Where:

Domestic Energy Sales: Is the utility's annual energy sales for the Domestic consumer (GWh).
GDP: the Gross Domestic Product (million Birr) of the country during the year when the energy was sold/is to be sold to the Domestic consumer.

Similarly for the Commercial and Industrial Energy Sales the correlations given in equations 4.3 & 4.4 below were obtained using WEKA:

$$\text{Commercial Energy Sales} = 0.0374 * \text{Pop.} - 2058.2151 \quad (4.5)$$

Where:

Commercial Energy Sales : is the utility's annual energy sales for the Commercial customer (GWh).

Pop. : is the total divided by 1000 of the country's population number during the year when the energy was sold/is to be sold to the Commercial consumer.

$$\text{Industrial Energy Sales} = 0.0673 * \text{Pop.} - 3909.9166 \quad (4.6)$$

Where:

Industrial Energy Sales: is the utility's annual energy sales for the Industrial consumer (GWh).

Pop. : is the total divided by 1000 of the country's population number during the year when the energy was sold/is to be sold to the Industrial consumer.

In the equations 4.4 to 4.6 above it is shown how the energy sales of the Domestic, Commercial and Industrial customers of the utility are related to the historical Population number and GDP Data.

In equation 4.4 it is shown that the Domestic energy sales is related to the GDP with a coefficient of 0.0138 while the coefficient relating it to the Population number is zero, this is due to the negligibly small effect of the population change on the Domestic Energy sales compared to the effect of the GDP growth. Similarly, From Equation 4.5 the Commercial customers demand is correlated with the population number with a coefficient of 0.0374 while the Industrial customers demand is related with the population number with a coefficient of 0.0673 (Equation 4.6).

by substituting the MOFED forecasted GDP (given in Table 4.4) and the CSA Population number (given in Table 4.5) into the equations 4.4 to 4.6, it is determine how much energy demands of the Domestic, Commercial and Industrial customers there will be for the years 2015 to 2028. These results are given in Table 4.10 below.

Table 4.10 Scenario-2: Forecasted Energy sales of the Domestic, Commercial and Industrial customers

Year	Domestic Energy Sales Forecast (GWh)	Commercial Energy Sales Forecast (GWh)	Industrial Energy Sales Forecast (GWh)	Total Energy Sales Forecast (GWh)	Total Energy Forecast (including Transmission loss) (GWh)
2015	2,353	1,329	2,185	5,867	6,806
2016	2,675	1,417	2,343	6,435	7,465
2017	3,032	1,507	2,506	7,045	8,173
2018	3,429	1,600	2,673	7,701	8,934
2019	3,869	1,695	2,844	8,408	9,753
2020	4,357	1,793	3,019	9,169	10,637
2021	4,900	1,893	3,199	9,992	11,590
2022	5,501	1,995	3,385	10,881	12,622
2023	6,170	2,101	3,574	11,845	13,740
2024	6,911	2,209	3,769	12,889	14,951
2025	7,734	2,320	3,968	14,023	16,266
2026	8,648	2,434	4,173	15,255	17,696
2027	9,662	2,551	4,383	16,596	19,252
2028	10,788	2,827	4,881	18,496	21,455

From Table 4.10 above it can be observed that by the year 2028 energy demand of 10,788 GWh is expected by the Domestic customers, this energy demand has increased by 3.58% from its 2015 demand. Similarly, for the other demand categories, it is estimated that for the year 2028 energy of 2,827 GWh and 4,881 GWh will be required by the Commercial and Industrial customers respectively. As shown in the above table, the *Total Energy Forecast* was calculated by considering a transmission loss of 16% of the *Total Energy Sales*. This was based on the historical transmission loss data collected from the EEP.

4.2.3.2. Consideration of New Demand Requests:

The summation of the new energy request of the Export, Irrigation and Transportation sectors (given in Table 4.2) to that of the total Energy Forecast of the existing demand categories (given in Table 4.10 above) is done as given in Table 4.11 below.

Table 4.11 Scenario-2: Total Energy forecast of the years 2015 to 2028:

Year	Total Energy Forecast of the Existing Demand Categories (GWh)	Total New Energy Requests (GWh)	Total Energy Forecast (GWh)
2015	6,806	2,942	9,748
2016	7,465	3,423	10,888
2017	8,173	12,271	20,444
2018	8,934	12,752	21,686
2019	9,753	14,547	24,300
2020	10,637	17,424	28,061
2021	11,590	21,847	33,437
2022	12,622	27,698	40,320
2023	13,740	32,122	45,862
2024	14,951	33,917	48,868
2025	16,266	38,340	54,606
2026	17,696	40,569	58,265
2027	19,252	42,809	62,061
2028	21,455	45,049	66,504

4.2.3.3. Peak Demand Forecast:

The Total Energy Forecast calculated in Table 4.11 above is converted to the Peak Demand Forecast by using equation 3.1 and considering the utilities three years average load factor of 57%. The result is given in Table 4.12 below:

Table 4.12 Scenario-2: Energy and Peak Demand Forecasts of the years 2015 to 2028.

Year	Total Energy (Gwh)	Peak Demand (MW)
2015	9,748	1,952
2016	10,888	2,181
2017	20,444	4,094
2018	21,686	4,343
2019	24,300	4,867
2020	28,061	5,620
2021	33,437	6,697
2022	40,320	8,075
2023	45,862	9,185
2024	48,868	9,787
2025	54,606	10,936
2026	58,265	11,669
2027	62,061	12,429
2028	66,504	13,319

From Table 4.12 above, it can be observed that in Scenario-2 a Peak Demand of 1,952 MW is estimated for the year 2015, this electricity demand will increase by an annual average rate of 41.5% and will reach 13,319 MW by the year 2028.

4.2.4 Result Analysis of the Forecasted Loads

The demands forecasted in scenario-1 and Scenario-2 can be summarized as given in Chart 4.1 below:

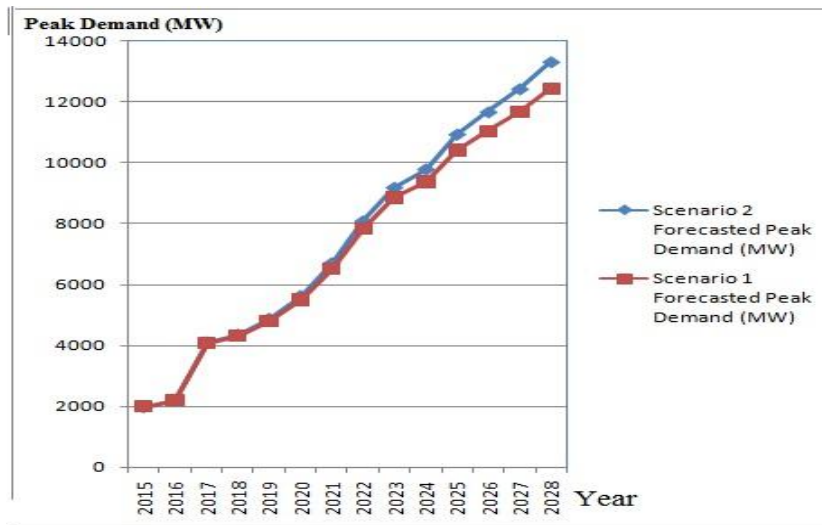


Chart 4.1 Demands Forecasted using Scenario-1 and Scenario-2

As can be seen from the Chart above, for the years following 2017 the demand forecasted in Scenario-1 increases at an annual average rate of 37.5% and reaches 12,450 MW by the year 2028, this is 870 MW less compared to the 2028 Scenario-2 Peak demand forecast which is 13,319 MW by the year 2028.

For a similar Population data the effect of the GDP variation in the forecasted demand of the two scenarios is shown in Chart 4.2 below:

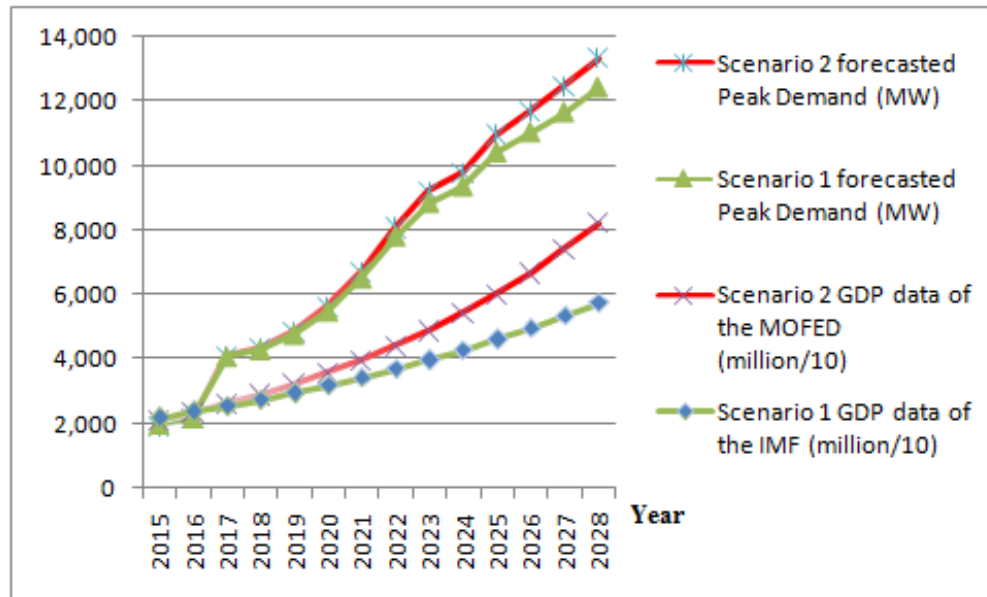


Chart 4.2 Scenario-1 and Scenario-2 Forecasted Demands Versus the GDP data used

As shown in Chart 4.2 above, for a similar Population forecast data of the Central Statistical Agency (CSA) different data of the GDP forecast was considered in scenario-1 and Scenario-2. In Scenario-2 a higher GDP data of the MOFED was considered and as can be seen from the Chart, this resulted in a higher demand forecast, while in Scenario-1 a lesser GDP forecast of the IMF was considered which resulted in a lower peak demand forecast.

4.3 Generation Expansion Planning (GEP)

Based on the equations/models of the objective function and constrains described in section 3.3 a Matlab code was developed (given in Appendix B). Using this Matlab code the Generation Expansion Planning or selection of plants to supply the 2028 scenario-1 and Scenario-2 forecasted demand is done.

For each of the 2 scenarios, different cases of selected plants were considered and a *case-based decision analysis* is done to select the group of plants capable of supplying the 2028 forecasted demands, with a minimum possible expansion and operation costs. The cases considered, their results and detail analysis is discussed in sections 4.3.1 and 4.3.2 as follows:

4.3.1 Generation Expansion Planning Based on the Scenario-1 Forecasted Demand.

Based on the 2028 Scenario-1 forecasted demand (given in section 4.2.1.), three different cases of selected plants were obtained using Matlab, these cases are given in Table 4.13 below.

Table 4.13 Scenario-1: Plants selected for the 2028 Scenario-1 forecasted demand

Considered Cases	Names Of The Selected Candidate Plants	Total Capacity Of the Selected Plants (MW)	Excess capacity of the selected plants (MW)	Total Expansion Cost (Million USD)
Case 1	Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi, Tams	7,407	1,383	3,190
Case 2	Gibe IV, UpperMandeya, Karadobi, Tams	6,472	448	2,850
Case 3	Beko-Abo, Upper-Mandeya, Karadobi, Tams	5,935	-89	2,540

From Table 4.13 above, for the year 2028, from the result of Case 1, a construction of the hydro plants Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams is selected and these plants require a total expansion cost of \$3.19 billion. When these plants are connected to the grid (added to the existing operating plants), the power system will have an excess capacity of 1,383 MW than the Scenario-1 forecasted demand of 12,450 MW.

From Case 2 of this table, it is shown that the hydro plants: Gibe IV, Upper-Mandeya, Karadobi and Tams are suggested. When these plants are connected to the grid, the power system will have an excess capacity of 448 MW than the scenario-1 forecasted demand of the year 2028. The total cost required for the construction of these plants is \$2.85 billion.

Similarly, from Case 3 of Table 4.13, the plants Beko-Abo, Upper-Mandeya, Karadobi and Tams are suggested and require a total expansion cost of \$2.54 billion. When these plants are connected to the grid, the power system will have 89 MW of capacity less than the scenario-1 forecasted demand of 12,450 MW.

From these 3 Cases, for the year 2028, the plants selected in Case 3 may results in un-served demand of 89 MW. This un-served demand is high enough to be neglected since it might result in power outages during peak hours. Hence, the plants selected in Case 3 are not recommended.

From Cases 1 and 2, since the addition of the capacity of the plants of Case 2 can sufficiently supply the 2028 forecasted demand of 12,450 MW and since they have less expansion cost of \$2.85 billion than a cost of \$3.19 billion required by the plants in Case 1, the plants in Case 2 are recommended for expansion.

Therefore, for the 2028 Scenario-1 forecasted demand, the hydro plants Gibe IV, Upper-Mandeya, Karadobi and Tams having a total capacity of 6,472 MW are suggested for construction.

4.3.2 Generation Expansion Planning (GEP) based on the Scenario-2 Forecasted Demand

Based on the Scenario-2 forecasted demands (given in section 4.2.2.), two different cases of selected plants were obtained using Matlab, these cases are given in Table 4.14 below.

Table 4.14 Scenario-2: Plants selected for the Scenario-2 Forecasted Demand

Considered Cases	Names Of The Selected Candidate Plants	Total Capacity Of the Selected Plants (MW)	Excess capacity of the selected plants (MW)	Total Expansion Cost (Million USD)
Case 1	Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi, Tams	7,407	514	3,190
Case 2	Gibe IV, UpperMandeya, Karadobi and Tams	6,472	-420	2,850

From Table 4.14 above, for the year 2028, from the results of Case 1, a construction of the hydro plants Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams is selected and these plants require a total expansion cost of \$3.19 billion and when these plants are connected to the grid (added to the existing operating plants), the power system will have a capacity of 514 MW more than the 2028 Scenario-2 forecasted demand of 13,319 MW.

From Case 2 of this table, the plants Gibe IV, Upper-Mandeya, Karadobi and Tams are selected. These plants require a total Expansion cost of \$2.85 billion. When these plants are connected to the grid (added to the existing operating plants), the power system will have a lesser capacity of 420 MW than the 2028 Scenario-2 forecasted demand of 13,319 MW.

From these 2 Cases, the addition of the plants selected in Case 2 may result in a shortage of 420 MW to supply the 2028 Scenario-2 forecasted demand of 13,319 MW. This un-served demand is high enough to be neglected, as it may result in frequent power outages. Hence, the plants selected in Case 2 are not recommended for expansion. However, since the plants selected in Case 1 can sufficiently supply the forecasted demand of 13,319 MW, a construction of the case 1 plants (Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams) having a total capacity of 6,472 MW is suggested for the year 2028.

4.3.3 Summary and Comparison of the Plants Selected in Scenario-1 and Scenario-2

The summary of the plants selected for the scenario-1 and Scenario-2 forecasted demands and the total expansion cost required for each scenario is given in Table 4.15 below:

Table 4.15 Summary of the plants selected for the Scenario-1 and Scenario-2 forecasted demands

	Selected Plants					Total Cost (Million \$)	Total Capacity (MW)
Scenario-1	Gibe IV	Upper Mendaya	Karadobi	Tams		2,850	6,472
Scenario-2	Beko- Abo	Gibe IV	Upper Mendaya	Karadobi	Tams	3,190	7,407

From Table 4.15 above, it is observed from the GEP of the Scenario-1 and Scenario-2 forecasted demands that: for the Scenario-1 only 4 plants of: Gibe IV, Upper-Mandeya, Karadobi and Tams are required. While for Scenario-2 five plants of Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams are required. As a result, the expansion for Scenario-2 requires a cost of \$340 million more than the cost required for the expansion of the plants selected in Scenario-1.

However, although the Scenario-1 selected plants have a \$340 million lesser expansion cost than the Scenario-2 selected plants, it can be observed that; if the Target GDP of the government (GTP II) succeeds (or if the Scenario-2 forecasted demand takes place) and if only the plants selected for Scenario-1 are constructed, it is likely that a capacity shortage of 869 MW will occur by the year 2028. Therefore, in order to minimize this possible risk of capacity shortage, it is recommended to construct the Scenario-2 selected plants of Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams with additional cost of \$340 million than the Scenario-1 selected plants.

CHAPTER 5

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

5.1 Conclusions

In this thesis, we have applied a stochastic method of demand forecasting to tackle the uncertainty of the load driving parameters such as, the Gross Domestic product (GDP) and the Population number of Ethiopia. The future GDP of the country was forecasted by different firms in different ways and different results were obtained. The GDP data used in this study was obtained from two firms; the Ministry of Finance and Economic Developments (MOFED) and the International Monetary Fund (IMF). These two GDP data were selected as a basis to consider 2 scenarios of the electricity demand forecast. The 1st scenario was based on the data of the IMF which made a moderate GDP forecast. While, the 2nd scenario was based on the MOFED's higher Target GDP (this MOFED data is based on the government's second Growth and Transformation Plan (GTPII)).

From the two Scenario results presented in sections 4.2.2 and 4.2.3 it is observed that for the year 2020 a peak demand of 5,493 MW is estimated in Scenario-1, this forecast is 126 MW more than the Scenario-2 forecasted demand of the same year. This difference of the two forecasts increase and reaches 869 MW by the year 2028. This higher demand forecast of the Scenario-2 is due to the fact that, Scenario-2 has considered the government's Target GDP data, which is higher than the IMF's Scenario-1 GDP data.

The Generation Expansion Planning (GEP) is done for the year 2028 and was done based on the demands forecasted using both Scenarios. From the Matlab results of the GEP, for the scenario-1 forecasted demand, only 4 plants: Gibe IV, Upper-Mandeya, Karadobi and Tams are selected. The expansion cost required for these plants is \$2,850 million. While, for the Target GDP Scenario (Scenario-2) 5 plants of: Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams are selected. The total cost required for the expansion of these plants is \$3,190 million.

From the plants selected in Scenario-1 and Scenario-2 it can be observed that although the Scenario-1 selected plants have \$340 million lesser cost than the Scenario-2 selected plants, a risk of un-served demand of 869 MW might occur if only the Scenario-1 selected plants are constructed and if the Scenario-2 forecasted demand takes place (which would happen if the Target GDP of the government's GTPII succeeds). Therefore, in order to minimize this possible risk, it is recommended to construct the Scenario-2 selected plants of Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams for the year 2028.

5.2 Recommendations

Based on the results obtained in chapter 4, the country's electricity demand is expected to reach a peak demand of 13,319 MW by the year 2028. Hence, to adequately supply this demand, the Ethiopian Electric Power (EEP) is recommended to construct the Beko-Abo, Gibe IV, Upper-Mandeya, Karadobi and Tams having a total capacity of 7,407 MW.

Furthermore, based on the experience obtained during the study, the following suggestions are given:

- Collecting of the data required to conduct this study was one tough stage, for the reason that, the data was not easily available online or even with the EEP due to confidentiality issues. So it is recommended that a better mechanism of supplying data for research purposes be available in the firm.
- Unlike the Matlab codes used in this study there are more accurate market available generation planning packages such as the WASP, but these software were difficult to find in the university. hence it is recommended for the university to make available for the researchers/ students to access latest softwares or such packages easily.

5.3 Suggestions for future work

The study carried out in this thesis is a study on modeling the uncertainties in expansion planning of the Ethiopian power system. The work has also included creating a model of the system that can be improved with accurate data. Other improvements on the methods used and ideas on further studies are given as follows:

- Extend the Generation Expansion planning carried out in this study by including the Transmission systems Expansion Planning (TSEP).
- Apply Artificial Neural Network (ANN) to forecast the long term demand with a better accuracy.

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Appendix A: Specifications of the proposed generating plants

The specifications of the various generating plants for the proposed GEP are given in Table A1 below:

Table A1. list and specifications of the candidate generating Plants

No	Name Of The Plant	Type Of The Plant	Plant Capacity (MW)	Plant Factor	Investment Cost (\$/Kw)	Fuel Cost	Life time (Year)	O &M Cost (\$/kwyr)
1	Abaya	Geothermal	100	0.8	3075	0	30	30
2	Abu Samuel	Hydro	6	0.29	3536.8	0	70	53
3	Addis Abeba	Solar	100	0.19	1800	0	25	25
4	Aleltu East	Hydro	189	0.48	5433.2	0	70	53
5	Aleltu West	Hydro	265	0.45	6022.7	0	70	53
6	Baro 1 + Baro 2	Hydro	645	0.46	3340.2	0	70	53
7	Beko Abo	Hydro	935	0.8	1820.5	0	70	53
8	Birbir R	Hydro	467	0.66	3427.1	0	70	53
9	Border Ethiopia-Kenya	Solar	100	0.17	1800	0	25	25
10	Border Ethiopia-Somalia	Solar	100	0.19	1800	0	25	25
11	Corbetti	Geothermal	75	0.8	3075	0	30	30
12	Dofan	Geothermal	60	0.8	3075	0	30	30
13	Genale 5	Hydro	100	0.65	3870.6	0	70	53
14	Genale 6	Hydro	246	0.71	3226.3	0	70	53
15	Genji	Hydro	214	0.48	1246.3	0	70	53
16	Gibe 5TH	Hydro	660	0.34	2210.5	0	70	53
17	Gibe IV	Hydro	1472	0.46	2210.5	0	70	53
18	Gojeb	Hydro	150	0.42	4741.4	0	70	53
19	Jijiga	Solar	100	0.23	1800	0	25	25
20	Karadobi	Hydro	1600	0.56	2173.5	0	70	53
21	Lower Dabus	Hydro	250	0.29	4504.7	0	70	53
22	Lower Didessa	Hydro	550	0.20	1463.5	0	70	53
23	Mekele	Solar	100	0.23	1800	0	25	25
24	Tams	Hydro	1700	0.38	2478.7	0	70	53
25	Tendaho	Geothermal	100	0.8	3075	0	30	30
27	Tulu Moya L	Geothermal	40	0.8	3075	0	30	30
28	Upper Dabus	Hydro	326	0.51	2601.6	0	70	53
29	Upper Mendaya	Hydro	1700	0.57	1934.8	0	70	53
30	Wabishebele	Hydro	88	0.89	12637.6	0	70	53
31	Werabesa + Halele	Hydro	436	0.51	2743.4	0	70	53
32	Yayu	Coal	100	0.68	1567	5.76	30	43
33	Yeda 1 + Yeda 2	Hydro	280	0.44	2604.5	0	70	53

(Source: EEP (Ethiopian Electric Power,2014)

Appendix B: Matlab codes of the Generation Expansion Planning

Selection of the optimum generating units for the Generation Expansion Planning is done using a code written in Matlab. This code is developed in such a way that it should be capable of reading and accessing data written in excel format and it is made to have a user interface to accept input and display required outputs and final results.

The required excel document contains the data of both the candidate units and the forecasted demand data in different sheets. The candidate units sheet contains a column data of Name of the plants , plant capacity (MW) ,Plant factor, investment cost(\$/Kw), fuel cost, lifetime (year) and operation & maintenance cost (\$/kwyear). The forecasted demand sheet contains column data of the year of the forecasted load, amount of the Forecasted load (MW), reserve %, interest rate and Existing capacity (MW).

Once the excel data are ready and fully available the Matlab code follows the following steps for the optimization of the generating units.

1. It accepts the required future year (2028) of the generation expansion from the user, and access the corresponding forecasted demand (in MW) from the linked excel document.
2. It calculates the required energy in GWh from the data in step 1, by considering a load factor of 0.7, and including transmission loses and required reserves.
3. From the 34 candidate plants listed in table 3.3. a screening of 10 best candidate plants (both in terms of least operation cost and higher Energy capacity) is done.
4. The selection of these candidate plants is done by considering the excel candidate data of the candidate plants capacity, Plant factor, investment cost, fuel cost, lifetime and operation & maintenance cost.
5. Based on the magnitude of the Energy required (calculated in step 2), a possible combination of different candidate plants among the 10 candidate plants selected in step 3 is done. This step can be simply illustrated by the following example:

Example: Let's assume we have 3 candidate plants and want to select which capacity combination of these plants best satisfies our demand, the possible combination of these 3 plants are listed as follows:

Table B1: Possible combinations of 3 candidate Plants

	Plant 1	Plant 2	Plant 3
Combination 1	0	0	1
Combination 2	0	1	0
Combination 3	0	1	1
Combination 4	1	0	0
Combination 5	1	0	1
Combination 6	1	1	0
Combination 7	1	1	1

From the table above a total of $2^3 - 1 = 7$ possible combinations are available, the candidate plants with '1' are selected in that combination while '0' are not. i.e. only candidate plant 3 is selected in combination 1 while all of the candidate plants are selected in combination 7.

For each combinations a calculation of the total expansion cost and capacity of the selected candidate plants can be made and which combination of plants can best supply our forecasted demand can be selected.

In a similar way to the above example, in our case a possible combinations of 10 candidate plants (a total of $2^{10} - 1 = 1023$) combinations is generated and a calculation of the total expansion cost and supply capacity is made.

Based on the total capital cost and energy capacity of each plant combinations, selection of the best combination is made, and the result is displayed to the user. The display includes the names of the selected candidate plants, the total expansion cost required by the plants, their total capacity and their shortage or excess capacity (if any). The Matlab code written is given as follows:

```

clear
clc
%% Required Input data
%% Required load nodes data:
candidate_data = xlsread('SgepS.xlsx', 'Candidate-data');
sizecanddata = size(candidate_data);
rowcanddata = sizecanddata(1);
colcanddata = sizecanddata(2);
%% Required loads data:
Add_Data = xlsread('SgepS.xlsx', 'Add-data');
[num,txt,row]= xlsread('SgepS.xlsx', 'Candidate-data');
sizeadddata = size(Add_Data);
rowadddata = sizeadddata(1);
coladddata = sizeadddata(2);
%% Data retrieval from candidate-units exell sheet
Capaci_Gen = zeros(rowcanddata,1);
No_Gen = zeros(rowcanddata,1);
Invest_Gen = zeros(rowcanddata,1);
Life_Gen = zeros(rowcanddata,1);
FuelCost_Gen = zeros(rowcanddata,1);
O_MCost_Gen = zeros(rowcanddata,1);
Plantfactor = zeros(rowcanddata,1);
for i=1:1:rowcanddata
Capaci_Gen(i) = candidate_data(i,4); % Capacity type plants
No_Gen(i) = candidate_data(i,1); % Generator type number
% Investment cost type plants:
Invest_Gen(i) = candidate_data(i,8)*1000;
Life_Gen(i) = candidate_data(i,13); % Life type plants
FuelCost_Gen(i) = candidate_data(i,12); % Fuel cost type plants
% Operation and maintenance cost type plants:
O_MCost_Gen(i) = candidate_data(i,14)*1000;
%Name of the candidate plants
Name{i}= raw{i+1,2};
%consideration of the plant factor
Plantfactor(i)= candidate_data(i,6);

fprintf('candidate name is:%s \n',Name{1});
if isnan(Name{i})
fprintf('Input argument "Name of candidate" determining \n');
fprintf('Name of candidate.\n');
error('"Name of candidate" of plant number %2i is empty or undefined
hence must be determined.',i);
end
sprintf('text datas %s',raw(2,2));

if isnan(Capaci_Gen(i))
fprintf('Input argument "Capaci_Gen" determining');
fprintf(' capacity type plants.\n');
error('"Capaci_Gen" of plant number %4i is empty or undefined hence must
be determined.',i);
end

if isnan(Invest_Gen(i))
fprintf('Input argument "Invest_Gen" determining');
fprintf(' investment cost type plants.\n');

```

```
error("Invest_Gen" of plant number %4i is empty or undefined hence must
be determined.',i);
end
if isnan(Life_Gen(i))
fprintf('Input argument "Life_Gen" determining');
fprintf(' life type plants.\n');
error("Life_Gen"of plant number %4i is empty or undefined hence must be
determined.',i);
end
if isnan(FuelCost_Gen(i))
fprintf('Input argument "FuelCost_Gen" determining');
fprintf('fuel cost type plants.\n');
error("FuelCost_Gen" of plant number %4i is empty or undefined hence
must be determined.',i);
end
if isnan(O_MCost_Gen(i))
fprintf('Input argument "O_MCost_Gen" determining');
fprintf(' operation and maintenance cost type plants.\n');
error("O_MCost_Gen"of plant number %4i is empty or undefined hence must
be determined.',i);
end
if (Capaci_Gen(i)==0)
fprintf('Input argument "Capaci_Gen" determining');
fprintf(' capacity type plants.\n');
error("Capaci_Gen" of plant number %4i is empty or undefined hence must
be determined.',i);
end
if (Life_Gen(i)==0)
fprintf('Input argument "Life_Gen" determining');
fprintf(' life type plants.\n');
error("Life_Gen" of plant number %4i is empty or undefined hence must be
determined.',i);
end
end
%celldisp(raw(7,2))
%% additional Data retrieval from add-data sheet
Year = zeros(100,1);
Load = zeros(100,1);
Reserv = zeros(50,1);

for i=1:1:rowadddata

Year(i) = Add_Data(i,1);
Load(i) = Add_Data(i,2); % Maximum network load (MW)
Reserv(i) = Add_Data(i,3)/100; % Reserve ratio
% Coefficient of annual interest:
Interest_rate = Add_Data(1,4)/100;
Exist_Cap = Add_Data(1,5)*0.595*8.76; % Capacity of existing plants in
Gwh
% Existing power plants, fuel costs:
Exist_FuelCost = Add_Data(i,6);

if (Year(i) == 0)
fprintf('Input argument "Year" determining');
fprintf('The year number.\n');
error("Year" should not be zero');
```

```
end
if (Load(i)==0)
fprintf('Input argument "Load" determining');
fprintf(' maximum network load(MW).\n');
error('"Load" should not be zero');
end
if (Reserv(i)<0)

fprintf('Input argument "Reserv" determining');
fprintf(' reserve ratio.\n');
error('"Reserv" should not be less than zero');
end
if (Interest_rate<=0)
fprintf('Input argument "Interest_rate" determining');
fprintf(' coefficient of annual interest.\n');
error('"Interest_rate" should not be less than or equal to zero');
end
if isnan(Year(i))
fprintf('Input argument "Year" determining');
fprintf(' The Year number.\n');
error('the "year number" of row %li is empty or undefined hence must be
determined.',i);
end
if isnan(Load(i))
fprintf('Input argument "Load" determining');
fprintf(' maximum network load(MW).\n');
error('"Load" of year number %4i is empty or undefined hence must be
determined.',Add_Data(i,1));
end
if isnan(Reserv(i))
fprintf('Input argument "Reserv" determining');
fprintf(' reserve ratio.\n');
error('"Reserv" of year number %4i is empty or undefined hence must be
determined.',Add_Data(i,1));
end
if isnan(Interest_rate)
fprintf('Input argument "Interest_rate" determining');
fprintf(' coefficient of annual interest.\n');
error('"Interest_rate" of year number %4i is empty or undefined hence
must be determined.',Add_Data(i,1));
end
if isnan(Add_Data(1,5))
fprintf('Input argument "Exist_Cap" determining');
fprintf(' capacity of existing plants.\n');
error('"Exist_Cap" is undefined and must be determined.');
```

```
end

if isnan(Add_Data(1,6))
fprintf('Input argument "Exist_FuelCost" determining');
fprintf(' existing power plants, fuel costs.\n');
error('"Exist_FuelCost" is undefined & must be determined');
```

```
end
end

%calculation of the cost and sorting minimum costs
A = zeros(rowcanddata,6);
```

```

Cost = zeros(rowcanddata,1);
CostpMW = zeros(rowcanddata,1);
rank = zeros(rowcanddata,1);
B = (1+Interest_rate);
A_P = zeros(rowcanddata,6);
Energy_Gen = zeros(rowcanddata,6);
N1 = zeros(rowcanddata,6);
l=0;
for i=1:1:rowcanddata
    if Capaci_Gen(i)>=400

        A_P(i) = (B^Life_Gen(i))*Interest_rate;
        A_P(i) = A_P(i)/(B^Life_Gen(i)-1);
        Energy_Gen(i)= (Capaci_Gen(i)*Plantfactor(i)* 8760)/1000; %plant
        factor is the ratio of the gen. load and the max capa. of the gen unit
        Cost(i) =
        Capaci_Gen(i)*(Invest_Gen(i)*A_P(i)+O_MCost_Gen(i))+FuelCost_Gen(i)*Energy
        y_Gen(i); %Calculation of the cost of each candidate units
        CostpMW(i) = Cost(i);
        %      fprintf('CostpMW %3i \n',CostpMW(i));
        l=l+1;
        A(l,1)= i;%rank

        A(l,2)= Capaci_Gen(i);
        A(l,3)= CostpMW(i);%
        A(l,4)= Energy_Gen(i);
        A(l,5) = Plantfactor(i);
        A(l,6)= Cost(i);
        Namec{l} = raw{i+1,2};
        fprintf('--- %3i \n ',A(l,3));
    end
end
for i=1:1:l

    B(i,1)= i;%rank
    B(i,2)= A(i,2);
    B(i,3)= A(i,3);%
    B(i,4)= A(i,4);
    B(i,5) = A(i,5);
    B(i,6)= A(i,6);
    NameB{i} = Namec{i};
end

AA = sortrows(B,3);%sorting the units according to their costperMW.

for i=1:1:l
    for j=1:1:l % to display the name the candidate unit
        if AA(j,1)==i
            NameBB{j} = NameB{i};
        end
    end
end
for i=1:1:l

```

```

fprintf('sorted %3i %3s %3i \n ', i, NameBB{i}, AA(i, 3));
end

fprintf('please Enter the required year number:\n(hint: it should be
between the years %3i and %3i)\n', Year(10), Year(13));
Yearkb = input('required year:');
fprintf('please Enter the required number of plants to be expanded: \n');
numofunits = input('required num of plants:');
% clc

for i=1:1:rowadddata
    if (Yearkb < Year(10) || Yearkb > Year(13))
        clc
        fprintf('please Enter a year number between the years %3i and %3i
\n', Year(10), Year(13));
        Yearkb = input('required year:');
    end
    if numofunits > 10
        numofunits = 10;
    end
    if numofunits <= 0
        clc
        fprintf('please Enter a required number of units greater than
zero');
        numofunits = input('required num of units:');
    end
    if (Yearkb < Year(7)) && Yearkb >= Year(1)
        clc
        fprintf('the expansion planning for this year is done and is
under commissioning\n');
        fprintf('please Enter a year number between the years %3i and
%3i\n', Year(10), Year(13));
        Yearkb = input('required year:');
    end
    if (Yearkb ~= Year(i) && Yearkb > Year(10) && Yearkb < Year(13))
        continue;
    end
    if (Yearkb == Year(i))
        Loadkb = (Load(i) * (1 + Reserv(i))) * 8.76 * 0.57; %considering a
load factor of 0.8
        Loadkb = Loadkb - Exist_Cap;

        LEnergy = Loadkb; % energy required for the optimum load
    end
end

for i=1:(2^numofunits)
    b = fi(i, 0, 10, 0);
    Tcost = 0;
    Eenergy = 0;
    for j=1:numofunits
        c(j) = bitget(b, fi(j));
        d(j) = dec2bin(c(j));
        ch(j) = bin2dec(d(j));
    end
end

```

```

        if ch(j)==1
            NameBBB{i,j}=NameBB{j};

        end
        if ch(j)==0
            NameBBB{i,j}=0;
        end

        Tcost= Tcost+ AA(j,6)* ch(j); %AA(j,6)is the cost of
energy of gen. j
        Eenergy= Eenergy+ AA(j,4)* ch(j); %AA(j,4)is the energy
of generator i
        end
        totalcost(i) = Tcost;
        totalenergy(i) = Eenergy;
    end
    LMW = LEnergy/8.76/0.8;
    fprintf('\n energy required = %3i GWh power required = %3i MW
\n',LEnergy,LMW);

%calculation of ENS
for i=1:1:(2^numofunits-1)
    Ens(i) =totalenergy(i) - LEnergy;
    PNS(i)= (Ens(i)/(8.76));%Excess MW capacity of the plants
    if Ens(i)<0
        totalcost(i)= totalcost(i)- (Ens(i)*228000);%addition of the Ens and
excess energy cost to the total cost 1$/
    end
    if Ens(i)>=0
        totalcost(i)= totalcost(i);
    end
end

for i=1:(2^numofunits-1)

    BB(i,1) = i;
    BB(i,2) = totalcost(i);
    BB(i,3) = totalenergy(i);
    BB(i,4)= Ens(i);
    BB(i,5) = PNS(i);

end

CC = sortrows(BB,-3);
%sorted according to their total energy the highest the first
for i=1:1:(2^numofunits-1)
    for k=1:1:(2^numofunits-1)

        if CC(k,1)==i
            for j=1:1:numofunits
                Namecc{k,j} = NameBBB{i,j};

            end
        end
    end
end
end

```

```
end

for i=1:1:(2^numofunits-1)

    fprintf('-----\n');
    fprintf(' %3i. \n',i);
    fprintf('candidate units---> ');
    for j=1:1:numofunits
        fprintf(' %3i. %3s ',j,Namecc{i,j});
    end
    fprintf('\n Total cost = %3i$           Excess
Capacity of the units(i)= %3iMW   \n',CC(i,2),CC(i,5));
    fprintf('\n-----\n');

end
```

Appendix C: Waikato Environment and Knowledge Analysis (WEKA)

Waikato Environment and knowledge analysis (WEKA) is a popular suit of machine learning software. In this thesis, we have used this software to in the demand forecasting part to determine the correlation between the historical energy sales and the demand driving parameters (such as the GDP and Population number of the country).



Figure C1: WEKA (Waikato Environment and knowledge analysis)

Among other softwares this thesis selected this software for the following advantages:

- It is freely available under the General Public License.
 - It's Portability: since it is fully implemented in the java programming language, thus runs on almost any modern computers.
 - It has a comprehensive collection of data preprocessing and modeling technique.
 - It has a better ease of use due to its graphical user interface.
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