ELECTRICAL ENERGY GENERATION AND DEMAND FORECASTING OF BANGLADESH BY ECONOMETRIC MODELLING

by

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DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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APPROVAL

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ABSTRACT

Bangladesh is a developing country with large population of more than 145 million in a total area of 147,570 sq. km. Population is increasing exponentially but generation of power is not increasing accordingly. About 47% [1] of the country's population has access to electricity, which is very low compared to many developing countries of the world. And per capita electricity generation is 182 kWh per annum which is still among the lowest in the world. The principal economic factor driving the electrical energy generation and demand is the income of a nation's population which is typically reflected by GDP of the nation. GDP often indicates the growth of national economy. From the basic economic theory, everyone is quite familiar to the fact that an increase in income leads to higher purchasing power. Higher purchasing power drives an economic entity (An individual or an industry or a firm, etc.) to the consumption of more commodities. Therefore, the electricity demand and generation are expected to increase with the growth of economy. Based on these phenomena, the possible econometric models have been developed in this work for estimating, analysis and forecasting the electrical energy generation and demand served in Bangladesh by using 'Stata' software. 'Stata' is a data analysis and statistical software. It is a tool for researchers in applied economics. 'MINITAB' software is also used for time trend analysis. This research uses time series data and employs auto regressive econometric modeling technique for modeling and forecasting. In this study, no significant impact of price on electricity demand and generation has been found. Moreover, the forecast obtained from the research shows that the electricity demand and generation are increasing rapidly with the advancement of time. This research is forecasted that the electricity demand served in year 2020 will be 13,916 MW and the net energy generation in year 2020 will be 102,017 GWh.

List of Acronyms

ANN	Artificial Neural Network
APSCL	Ashuganj Power Station Company Limited
AR	Auto Regressive
BERC	Bangladesh Energy Regulatory Commission
BPDB	Bangladesh Power Development Board
CPI	Consumer Price Index
DESA	Dhaka Electric Supply Authority
DESCO	Dhaka Electric Supply Company Limited
DPDC	Dhaka Power Distribution Company Limited
EGCBL	Electricity Generation Company of Bangladesh Limited
GDP	Gross Domestic Product
IMF	International Monetary Fund
IPP	Independent Power Producer
LRM	Linear Regression Model
MAD	Mean Absolute Deviation
MAPE	Mean Absolute Percentage Error
MPEMR	Ministry of Power, Energy and Mineral Resources
MPSE	Mean Percentage Square Error
MSD	Mean Standard Deviation
MSE	Mean Square Error
NWPGCL	North West Power Generation Company Limited
NWZPDCL	North West Zone Power Distribution Company Limited
PBS	Palli Biddyut Samiti
PGCB	Power Grid Company of Bangladesh Limited
PSMP	Power System Master Plan
REB	Rural Electrification Board
RESET	Regression Equation Specification Error Test
RPCL	Rural Power Company Limited
SZPDCL	South Zone Power Distribution Company Limited
WAPDA	Water and Power Development Authority
WZPDCL	West Zone Power Distribution Company Limited

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Chapter 1

INTRODUCTION

1.0 Introduction

Bangladesh is a land of more than 145 million peoples. Only 47% of the population has access to electricity [1]. Therefore, there is a huge scope of load growth. Bangladesh still remains an agrarian country. Because of the rapid population growth, the amount of per capita cultivable land is dwindling very fast. In order to survive as a nation, and to prosper in the 21st century, Bangladesh will have to shift from an agrarian economy to an industrial economy. Consequently, the power generation will have to increase drastically to achieve that goal.

Electricity is a typical form of energy. Uses of this electrical energy are rapidly increasing day by day. In fact, now-a-day's electricity is the basic need of human life. Human civilization is tremendously advanced by versatile uses of electricity. For this reason, demand for electricity is integrated with all aspects of development. Electrification is associated with higher income and increased savings, less poverty, greater job opportunities, higher industrial and agricultural productivity, better health care, sanitation, improved educational opportunities and so on.

Electricity plays a crucial role in the socio-economic development of any country. It is considered as the driving force of all development activities. Electricity has a great positive impact on our national economy as well as on GDP (Gross Domestic Product) of the country. GDP is one of the important measures of the economic condition for a developing country. Bangladesh is going through a power crisis for a long time. Demand of power is high but supply is not adequate. This crisis is slowing the pace of our GDP growth rate. Currently, Bangladesh GDP growth rate is about 5.5% [1] which need to be increased to have a stable economy. As the economy is dependent upon educational, agricultural, industrial, commercial and other economic development, it directly and indirectly depends upon electricity supply. So Electrification of the country should be a priority.

The principal economic factor driving the electrical energy generation and demand is the income of a nation's population which is typically reflected by the Gross Domestic Product (GDP) of the nation. GDP often indicates the growth of national economy and industrialization. From the basic economic theory, everyone is quite familiar to the fact that an increase in income leads to higher purchasing power and more demand of industrial products. The industrial development of a country is a part of the total development program undertaken. The process of economic development brings many changes in the economy. The industrial development affects the traditional sectors and economic life of the peoples improves. Therefore, the electricity demand and generation are expected to increase with the growth of economy and industrialization.

1.1 Background of Bangladesh Power Sector

Dhaka, the capital city of Bangladesh is an old city. There is a public saying that Nawab of Dhaka installed a small generator in his residence "Ahsan Monjil" and started generating power at 5pm on 7th December 1901, which is considered as the introduction of electricity in Dhaka city. Later, in and around 1930, M/S. DEVCO, a subsidiary of M/S. Octavians Steel Company, developed electricity distribution system at 400V level under complete private ownership and brought that for public use. Most probably in the year 1933 a power generating station named "Dhanmondi Power House" was established and from there the electricity distribution to the public on commercial basis started [2].

After partition of Indo-Pak sub-continent, in the year 1947 when the British colonial rulers left, power generation and distribution of this part of the country were in the hands of some private companies. The power supply to then 17 districts was within the township in a limited way. The generation voltage was 400 volts. Power used to be supplied to most of the districts during night-time only. Only exception was Dhaka city where power used to be supplied by two 1500 kW generators and the generation voltage was 6600 volts and this was the highest distribution voltage. There were no long distance transmission lines. At that time other than some private companies, power was used to be generated by some isolated industries (tea, sugar, textiles) and railway workshops. Dhakeswari Cotton Mills, Pahartali Railway workshop, Saidpur Railway workshop and Sugar

Mills were amongst them. In aggregate the generation capacity of the country was 21 MW. The generation capacity of the power utility companies together was only 7 MW and there was no transmission system [3].

The Electricity Directorate was established in 1948 in order to plan and improve power supply situation of the country. In 1957 the Govt. took over the private owned companies in Dhaka and placed them under the Electricity Directorate for power generation and distribution. Considering the increasing demand of electricity and its importance in agriculture and industry, "Water and Power Development Authority" (WAPDA) was created to ensure the rapid development of electricity system at 1959. In 1960, Electricity Directorate was merged with WAPDA. The basic philosophy was to give more autonomy to an organization for the development of this basic infrastructure. At that time relatively higher capacity plants were built at Siddhirganj, Chittagong and Khulna (highest plant size was only 10 MW Steam Turbine at Siddirganj). At the same time Kaptai dam was under construction under Irrigation department. Unit size of Kaptai was 40 MW, which for that time was considered to be a large power plant. Side by side construction of Dhaka-Chittagong 132 kV transmission line was in progress. Construction of Kaptai dam and commissioning of Dhaka-Chittagong 132 kV transmission line in the year 1962 may be taken as milestone of power development of this country. During 1960 to 1970 the generation capacity rose from 88 MW to 475 MW, supplied largely by natural gas and oil fired, steam power and hydro plants [3-4].

Shortly after the creation of an independent Bangladesh, in 1972, the first Government of Bangladesh, in an effort to speed up the investment in the sector issued an Ordinance creating the Bangladesh Power Development Board (BPDB) as the successor organization of the power side of WAPDA. The Ordinance recognized the divergence of energy related issues in development. During 1972 to 1995, BPDB increased the generating capacity in the country to 2818 MW, and the length of its 230 and 132 kV transmission networks to 419 km and 2469 km. For the first time in December 1982, the eastern and western halves of the country were electrically connected through the commissioning of double circuit 230 kV transmission line across the Jamuna river energized at 132 kV between Ishurdi and Tongi called the first East-West Interconnector. Generation sources were diversified to include a 230 MW hydropower station at Kaptai on the Karnaphuli river and natural gas and imported fuel based, open and combined cycle power plants at different locations of Eastern and Western part of the country. The distribution networks of all major towns and cities had been linked through 230 kV and 132 kV inter-ties [4].

In order to intensify the pace of rural electrification, the Government issued as ordinance in 1977 establishing the Rural Electrification Board (REB), a semi-autonomous agency charged with the responsibility of planning, developing, financing and construction of rural distribution networks, promoting the establishment of Rural Electric Cooperatives (Palli Bidyut Samities), handing over the constructed rural networks to them, assisting the PBSs to operate and maintain the rural networks and monitoring their financial performance [5].

In 1990, another ordinance was issued, which was subsequently enacted as an Act transferring the 132 kV, 33 kV Transmission and distribution system in the Greater Dhaka Area including the Metropolitan City to a newly created Government agency called the Dhaka Electric Supply Authority (DESA). This was done to lessen the administrative burden on BPDB’s management by relieving it of the burden of managing about 50 percent of the energy distribution in the country. Later, government created a new subsidiary named Dhaka Electric Supply Company Ltd. (DESCO) in 1997 and provided the responsibility of electricity distribution in Mirpur, Gulshan, Baridhara and Uttara area of Dhaka. Dhaka Power Distribution Company Limited (DPDC), owned by the Government of the People's Republic of Bangladesh, was registered on 25 October, 2005 under the Companies Act, 1994. The company was created as a part of the Power Sector Reform Program by converted from DESA. At present, DPDC's operating area is confined to Dhaka Mega City area (except Mirpur, Gulshan, Uttara & its adjoining area) and Tongi & Naryangonj Municipal areas, Fatulla, Pagla, Nandalalpur, Enayetnagar, Dharmanagar & Kashipur, East Muktarpur and Shiddhirgonj area [2 & 4].

Power Grid Company of Bangladesh Ltd. (PGCB) was created under the restructuring process of Power Sector in Bangladesh with the objective of bringing about commercial environment including increase in efficiency, establishment of accountability and dynamism in accomplishing its objectives. PGCB was established on the 21st November, 1996 as a fully BPDB owned company. It was entrusted with the responsibility to own the national power grid; to operate and expand the same with efficiency. Pursuant to Government decision to transfer transmission assets to PGCB from Bangladesh Power Development Board (BPDB) and Dhaka Electric Supply Authority (DESA), PGCB completed taking over of all the transmission assets on 31st December 2002 since then, PGCB is operating those efficiently and effectively [6].

Bangladesh power demand was much higher than the supply, so the necessity was felt to generate more power. Government owned power plants were not enough to fulfill the power demand. But additional generation capacity required huge investment so government thought about mobilizing finance by attracting private sector in power generation and more importantly to increase power supply to alleviate the shortage. Bangladesh Government formulated "Private Sector Power Generation Policy of Bangladesh" and adopted in 1996. Under the Private Sector Power Generation Policy, so far 1907 MW power plants have been established and under operation [1].

In 1996, the independent power producers (IPP) started coming to generate power. Later small power producers (SPP) came in power market to generate power and to serve those areas which were not electrified. SPPs own generation plant of 10 MW to 30 MW. But some remote areas and isolated islands are still not covered by national grid because of the maintenance of the National Grid and transportation of fuel is very highly expensive, difficult and risky. This areas are being Electrifying with renewable energy. REB has taken initiatives to use Solar Photovoltaic Systems (Solar PV) for producing electricity. For the first time in Bangladesh BPDB implemented a pilot Project of 0.09 MW capacity of the Grid Connected Wind Energy (GCWE). BPDB also established a Wind Resource Assessment Station (WRAS) in Cox's-Bazar. BPDB also implemented an excellent Solar PV electrification project in the Chittagong Hill tracts [7].

The government is committed to implement reform program for the overall improvement in the power sector. A number of reform programmes has been taken up for implementation for improvement of management efficiency in generation, transmission and distribution. Some of them have already been implemented. The implementation status is highlighted below:

- Ashuganj Power Station has been converted into Ashuganj Power Station Company Ltd. (APSCL) in 1996.

- Electricity Generation Company of Bangladesh (EGCB) Ltd. was incorporated with Registrar of joint stock companies on February 16, 2004 to produce and sale of Electricity. It has already taken over the Siddhirganj 210 MW power Station. A number of Power Plant projects like Siddirganj 2x120 MW, Siddirganj 2x150 MW and Haripur 360 MW power Plant will be taken over by EGCB.

- West Zone Power Distribution Company Ltd. (WZPDCL) was established and incorporated as a public limited Company on 4th November 2002 to oversee the distribution system of Barisal and Khulna Zone.

- North West Zone Power Distribution Company Ltd. (NWZPDCL) is formed and Board of directors and Managements are recruited to run it efficiently. It will oversee the distribution activities of Rajshahi and Rangpur Zone.

- North West Zone Power Generation Company Ltd. (NWPGCL) has been formed in 2007. It will implement the Khulna 150 MW peaking, Sirajganj 150 MW Peaking Power Plant and Bheramara 360 MW Power plant projects.

- South Zone Power Distribution Company Ltd. (SZPDCL) is registered in 2008 as a distribution Company to run the distribution activities of Chittagong and Comilla Zone.

- Formation of North East Zone Power distribution Company Ltd. (NEZPDCL) is in progress. It will look after the distribution activities of Mymensingh and Sylhet zone.

- Bangladesh Power Development Board will be converted in to a Holding Company under the Company's Act 1994. Foreign consultants have already submitted the final report for proper implementation of Holding Company [8].

1.2 The Organization of Bangladesh Power Sector

Till to-date in Bangladesh the power sector has been under the control of government directly or indirectly. The power sector in Bangladesh has been managed, facilitated and regularized by the government in such a way that delivers the flourished outcome. Bangladesh's Ministry of Power, Energy and Mineral Resources (MPEMR) has overall responsibility (Fig. 1.1) for the country's energy sector, with policy formulation and investment decisions under its control. Within MPEMR, the "Power Cell" was created in 1995 which acts as a single point of contact to facilitate the electricity reform and restructuring process, such as development of Independent Power Producers (IPPs). As part of the ongoing program of power sector reform, a regulatory body, the "BERC" (Bangladesh Energy Regulatory Commission) has been set up within the MPEMR. It is an independent organization with the responsibility to create an atmosphere conducive to private investment in the generation of electricity and transmission, transportation, storage and marketing of energy as well as to ensure transparency in the management, operation and tariff determination in this sector; to protect consumer's interest and to promote a competitive market. The Commission started functioning from April 2004 [9].

Overview of Bangladesh power sector has been shown in Appendix A-1.

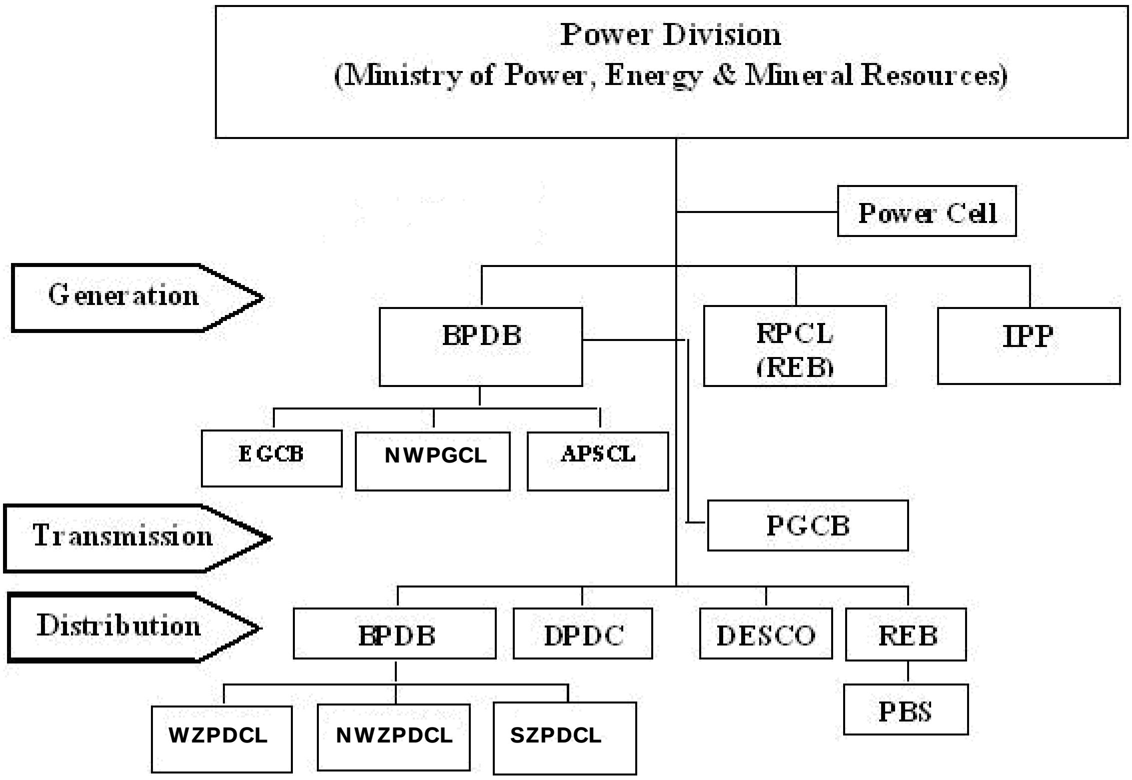

Figure 1.1: Current structure of Bangladesh power sector [10]

1.3 Present Situation of The Power Sector of Bangladesh

The development of any country depends mostly on its power without which the national economy must fail to proceed. Everybody knows about the meager situation of power in Bangladesh. But the policymakers and experts are still not taking initiatives to improve this sector showing unknown reasons, which is unfortunate. However indecision, unnecessary delay in decision making process, bureaucratic tangles and fund constraints may be ascribed to the persisting energy crisis. Despite all the well-meaning intentions, it appears that for years the energy sector of the country is hamstrung by a kind of decision-making paralysis.

1.3.1 Generation capacity and demand

The installed generation capacity is about 5719 MW (as on June 2009) from a meager 88 MW in 1960. Electricity generation has grown at about 7% p. a. during last fifteen (15) years compared with average annual GDP growth rate of about 5.5%. Notwithstanding the progress has made to date, Bangladesh's per capita electricity generation of 182 kWh p.a. is still among the lowest in the world. About 47% of the population has access to electricity, which is also low compared to many developing countries. This implies that there is scope for significant growth in power sector. Given the huge investment requirement for power development in the country, Bangladesh would be looking forward to various sources of finance. The Government has already opened the power sector for private investment [1]. The appendix A-2 depicts power sector at a glance.

The total installed generation capacity in public sector is about 3,812 MW and in private sector is about 1,907 MW. A good number of generation units, in the public sector, have become very old and thus operating at a derated capacity. As a result, their reliability and productivity have fallen. For the last few years, actual demand outmatched supply exposing shortage of our generation capacity. Shortage of gas supply further exacerbated the supply situation. The fall of the water level of Kaptai Lake significantly reduced generation capacity of the Kaptai Hydroelectric power plant. In FY 2009, it was possible to supply 4,162 MW of maximum demand [8]. The installed capacity by plant type and fuel type during FY 2009 are shown in figures 1.2 and 1.3.

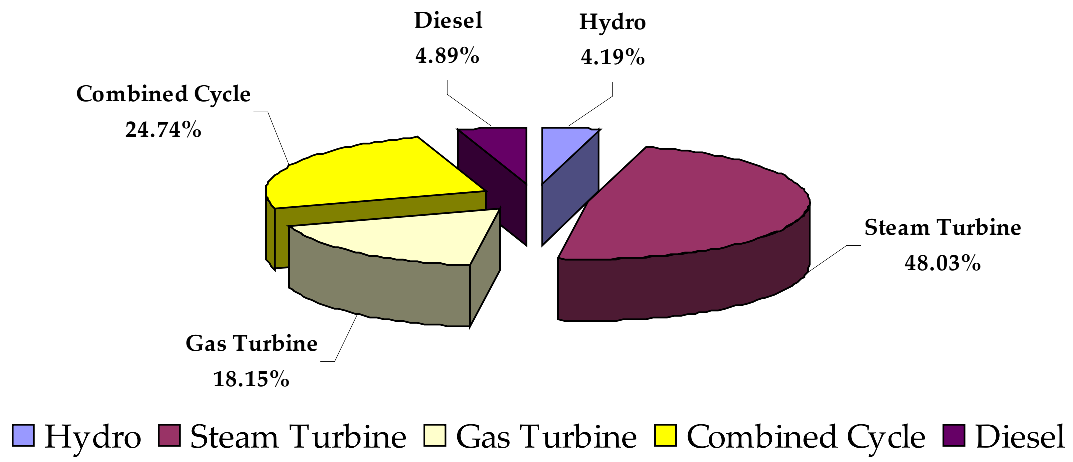

Figure 1.2: Installed capacity by type of plant (FY 2009)

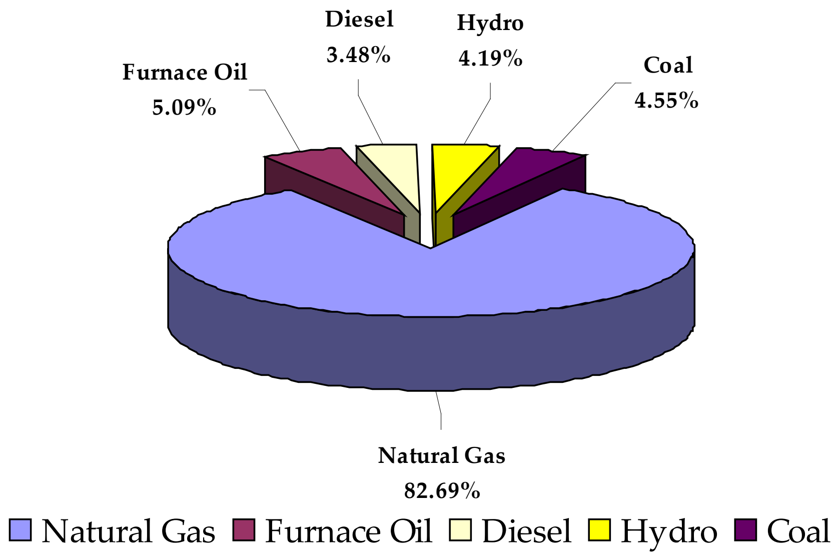

Figure 1.3: Installed capacity by type of fuel (FY 2009)

1.3.2 Energy generation

A total of about 26,603.95 million-kilowatt hours (MkWh) of net energy (16,403.64 MkWh in public sector and 10,173.31 MkWh in private sector) have generated during FY 2009. Of the total net energy generation, 61.66 percent has generated in public sector while the remaining 38.34 percent has generated in the private sector. Of the total net energy generation 88.44 percent is gas based, 1.62 percent hydro based, 4.02 percent coal based and 3.89 percent furnace oil based [8]. Net generation by plant type during FY

2009 is shown in Figure 1.4.

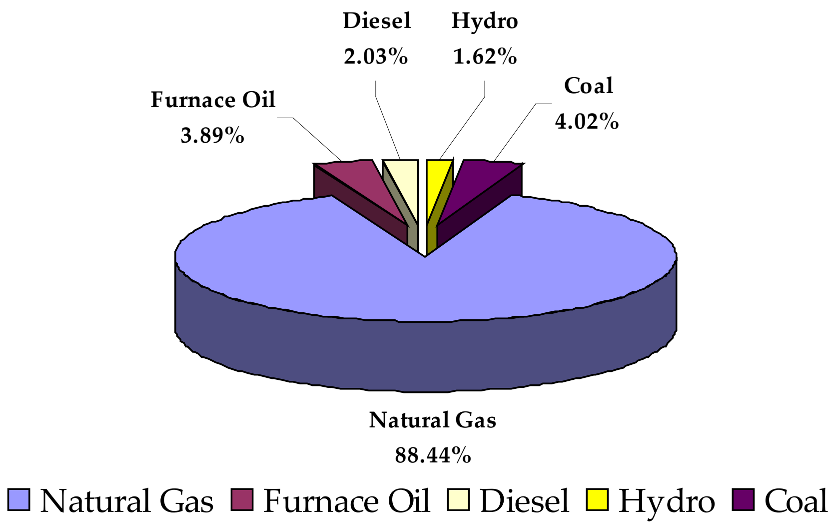

Figure 1.4: Generation pattern (FY 2009)

1.3.3 Load shedding and system loss

Significant load shedding due to lack of generation occurred in each of the historical years. As maximum amount of produced power are being provided to the main load centers like industrial and commercial areas to keep the economy run smoothly and deficit of electricity are being passed to the domestic areas and domestic areas are under huge load shedding. Dhaka alone has around half of the customer of electricity as it is one of the pick lode centers. Another load center is east zone (Chittagong) for commercial use. Still huge load shedding occurs in industrials and commercial areas. Power generation is increasing but at the same time load shedding is also increasing. Because power generation is increasing at a lower rate compared to increased demand of power. Hugh power theft was also a reason for the load shedding.

Another reason for power shortage is system loss. Because of system loss a substantial amount of power are being lost from the net generation. System loss accrues at the time of transmission and distribution. In FY 2008-09, the total system loss (transmission and distribution loss) was 6.58% of net generation, compared to 6.92% in the previous year [8]. Though system loss decreased year to year, still high system loss exists in power sector.

1.4 Effect of Electricity on Economy

Electricity is a vital ingredient, to upgrade the socio-economic condition and to alleviate poverty. This power crisis has been the number one problem of Bangladesh. This power short fall is affecting our economy. Economy of any country is highly dependent on power supply. Industrial and commercial activities are being interrupted for this power crisis.

Table 1.1: Contribution of electricity in GDP and its growth rate [11]

Contribution	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08 (Provisional)
Contribution of electricity in GDP (%)	1.27	1.30	1.34	1.37	1.38	1.30	1.28
Growth rate of electricity (%)	7.78	7.29	9.19	8.58	7.45	1.08	4.29
GDP Growth rate (%)	4.42	5.26	6.27	5.96	6.63	6.43	6.19

Bangladesh economy is growing and industrial activity is increasing. At the same time urbanization is taking place to a great extent so the contribution of electricity in GDP is growing with the growth of electricity as well as with the GDP growth rate. But expansion of electricity is near to the ground than required and this low growth rate of electricity is slowing down GDP growth. Another significant point is growth in the urban population considerably increased by 38% over last decade by birth and migration.

In Bangladesh, 51% of total man-power is involved in agriculture. For irrigation and other purpose electricity is a very necessary issue in agriculture. Irrigation process is being interrupted for insufficient power supply. And as a result the cost of production rises and the timing of the irrigation hampers also. Again when the fuel is used instead of electricity, the extra cost is charged to the final user and again the farmers are having less margin. As the prices are high, the cumulative savings go down in the households as they have to spend more and their fewer saving generates less investment and thus it had its ripple effect on the total GDP of the country [7].

Not only agriculture, industrial and commercial sector are also incurring huge loss for power short fall or load shedding. The daily commutation is hampered as the electricity is having mishaps on its production. Thus to cover up, commercial sector have to depend on the alternatives and again the cost goes high. This electricity also hampers the living condition of the labors as the alternative power sources does not permit to have normal working condition as it would have with electricity thus it reduces the productivity of the employees.

To manage load of the power, the government ordered all commercial and industrial entities to be closed at eight o'clock. Sales percentage is decreasing in shopping malls and grocery shops after this government order. Production level is decreasing in garments and factories. Small to big businessmen, all are incurring huge lose for that.

Load shedding is also interrupting school, collage and university students. The shortfall in the power sector is hampering the normal practice of our educational sector. The students of today not only have to deal with the books they also had to plan their time of studying while matching with the availability of electricity. Thus it also hampers the broader version of economy in the long run.

Many cottage industries and SMEs are increasing and creating new job opportunities and our economy is having a positive outcome. This improvement also demands steady power supply.

The effect of electricity has a huge impact to play on the economy of a country like Bangladesh, the improvement on electricity will reduce the general cost of production, from agriculture to the manufacturing sector, thus the normal households will be allowed to have better savings, the country will have more cash inflow to the economy as those collective savings will be invested, thus the investment will provide more jobs and the GDP will be escalated automatically.

1.5 Projection of Future Generation and Demand

In the Power System Master Plan (PSMP) of 1995 benchmark load forecast was based on about 8% growth rate. However, due to shortage in generation capacity, the actual demand could not be supplied for the last few years. Electricity development is required to be accelerated to increase access and attain economic development. The desirable economic growth rate would be about 6-8% p.a. According to PSMP- 2005, the net generation and demand forecast is given below:

Table 1.2: Peak demand and net generation based on PSMP-2005 base forecast [12]

Year	Peak Demand (MW)	Net Generation (GWh)
2005	4,308	21,964
2006	4,693	23,945
2007	5,112	26,106
2008	5,569	28,461
2009	6,066	31,028
2010	6,608	33,828
2011	7,148	36,622
2012	7,732	39,647
2013	8,364	42,922
2014	9,047	46,467
2015	9,786	50,306
2016	10,512	54,079
2017	11,291	58,135
2018	12,128	62,496
2019	13,027	67,183
2020	13,993	72,222

1.6 Existing Research Works Regarding Electrical Energy Generation and Demand on Bangladesh Context

Literatures on electrical energy generation and demand forecasting by individual researchers are not very frequently found, rather which is more common is the studies conducted by different national and international agencies employing their own consultants.

A previous thesis of Energy Demand Projection provides a documentation of the approach, assumption and the results that are considered in the Energy Forecasting Methodology for Bangladesh [13]. The mathematical technique used in this projection is mainly statistical regression analysis. Energy models are constructed in sectors like – Industrial sector, domestic sector, transport sector and agricultural sector. Two energy consumption models are constructed for Gas and Electricity consumption and above all a total energy consumption model is studied to predict total energy consumption of the country.

Another thesis developed an energy model for predicting the future energy demand [14]. The mathematical technique used in this modeling is mainly statistical regression analysis. In this thesis, consumption model of total energy, electricity, gas and petroleum for Bangladesh is prepared on past performance. The artificial neural network technique has also been used for electrical energy forecasting.

The expected energy generation of the power system of Bangladesh has been evaluated by using the segmentation method in a previous project [15]. The method is also applied for the evaluation of unserved energy as well as production costs of two interconnected system with jointly owned units.

1.7 Objectives of This Project

A credible and realistic demand forecast is necessary for any country regarding its electrical energy resources for the sake of administering better and efficient policies to ensure a stable and healthy economy. It is even more important for a country like Bangladesh with a very shaky power sector to estimate its electrical energy requirement in the coming years. It is quite evident that extensive dependence of electricity is now put under a strong challenge. Policies are to be made accordingly. Such policy formulations are to be done based on results of realistic and practicable researches regarding power sector. This research will be an approach to develop a demand model and predict the short run demand served. It will investigate if any policy related suggestion can be made based on the results of this research. The objectives of this work are:

1) To develop electrical energy generation and demand served models for Bangladesh.

2) To forecast the electrical energy generation and demand served in the next decade based on the derived models.

3) To find out if there is any policy implications based on the outcomes of the research.

1.8 Report Organization

This report consists of six chapters. In particular the contents of this report have been organized as follows:

Chapter 1 provides the background of this research work. The Background of Bangladesh Power Sector, the organization of Bangladesh power sector, present situation of the power sector of Bangladesh, effect of electricity on economy and projection of future generation and demand have been illustrated briefly. Under the current situation the motivations behind this research and the objectives of this research are also described. So the purpose of this chapter is mainly open the gate through the detailed analysis.

Chapter 2 describes several factors influencing the demand of electricity and three demand modeling methods namely trend analysis, end use method and artificial neural network methods. Theoretical backgrounds, relative advantages, disadvantages and areas of application for all these models have been described.

Chapter 3 provides the key idea about this research work. Theoretical concepts, different functional forms, advantages, disadvantages of econometric modeling are illustrated. Several literatures in this field have also been cited.

Chapter 4 provides the types and sources of data, necessary modifications and other data related issues. Finally, a brief discussion on some points has been noted while using time series data.

Chapter 5 presents trend models for electrical energy generation and demand forecasting in graphical form and provides the outputs of the econometric models with their respective model diagnostics. Comparative studies have been performed based on their model diagnostics and values of specification tests. Finally using the model obtained by this research, a forecast of electricity demand and net energy generation up to 2020 is made and compared with both trend analysis forecast and PSMP-2005 base forecast.

Chapter 6 contains the specific conclusions on the basis of the analysis. Difficulties faced during the research, limitations of the models developed and policy implications from this study are discussed. Finally this chapter concludes the project by providing directions and scopes for future work.

Chapter 2

REVIEW OF DEMAND MODELING AND METHODS

2.0 Introduction

Electricity is a publicly traded commodity. There are multiple factors that influence the electrical energy generation and demand. These factors are to be very carefully considered before modeling. In this chapter, the factors that may influence the electrical energy generation and demand are discussed very briefly. This chapter also digs deeper into the demand modeling methods and focuses on different demand modeling methods depicting their theoretical background, mathematical structure, relative advantages and disadvantages, area of application, etc. Four different demand modeling techniques: Trend Analysis, End Use Method, Econometric Method and Artificial Neural Network (ANN) are described in this dissertation. Among these models three models have been described in this chapter such as Trend Analysis, End Use Method and ANN methods. The fourth method that is Econometric method has been discussed in the next chapter. A separate chapter has been dedicated to this method as it is the integral part of this research.

2.1 Factors Influencing Electrical Energy Generation and Demand

There are several factors directly contributing to the change of electrical energy generation and demand over time such as: economic factor, demographic factor, policy changes, environmental factor, etc. These factors are briefly discussed as follows:

2.1.1 Economic factors

The two principal economic factors driving the electrical energy generation and demand are income and price. The income of a nation's population is typically reflected by the Gross Domestic Product (GDP) of the nation. GDP often indicates the growth of national economy. From the basic economic theory, everyone is quite familiar to the fact that an increase in income leads to higher purchasing power. Higher purchasing power drives an economic entity (An individual or an industry or a firm, etc) to the consumption of superior commodities. Therefore, the demand and energy generation are expected to increase with the growth of economy [16-19].

The second economic factor that may be a crucial factor in determining energy demand is price of the corresponding energy commodity, especially in case of estimating household energy demand [20]. Fundamental Economics says that, price and demand usually follow opposite directions. That is, an increase in the price of a commodity generally leads to reduced consumption. So, it is not very illogical to expect that increased electricity tariff might influence the consumption consequently. So, these factors must be carefully considered to construct the electrical energy generation and demand model in order to frame the model with proper economic essence.

2.1.2 Environmental factors

Climate change often plays a significant role in the economics of energy. Energy demand is dependent on weather variation [21]. For a simple example, when summer temperatures are higher than normal, demand is higher and usually causes an increase in electricity prices. Conversely, cooler summer weather often means lower demand and lower prices. Weather also has the greatest impact on customer bill amounts because it determines how much electricity they use each month: the hotter the weather, the greater the usage. Electricity demand is dependent upon humidity, temperature, wind speed, global radiation level [22], etc. It is now widely accepted that in future, energy demand will largely be affected by temperature change, i.e. global warming.

2.1.3 Demographic factors

Population is an important factor that might influence electricity demand. With growing population, the total energy requirement in all the sectors is expected to rise. But along with the total volume of the population the composition of the population should also be considered to capture the demographic effect on energy consumption. For modeling the demand in domestic sector, several characteristics of the sample households such as size of the location, geographical location of the household, age of the household members, etc. have to be taken under consideration. Abundant literature is available in this regard [23-25].

2.1.4 Factors related to policy change

Global and regional policy changes may influence energy consumption. Government financial policies, building regulations, taxation, commitment to reduce Green House Gas (GHG) emission, shifting towards renewable and cleaner energy as much as possible, use of energy efficient equipments, etc. may play significant role on the variation of demand of electricity. Building regulations have been important in reducing energy consumption in new buildings in Denmark [26]. Announcement and implementation of United Kingdom's Climate Change Levy (CCL) has permanently reduced the energy consumption in commercial and other final user sectors [27].

2.1.5 Technological factors

Technology is another important factor regarding the variation of energy demand. Introduction of newer technologies in the production side, improvement of raw material processing and purification, increase in the efficiency of the machineries may influence energy generation and demand [28].

2.2 Trend Analysis

2.2.1 Theoretical background

This method forecasts the energy generation and demand as a function of time. It explains how the energy demand varies with time without considering economic, geographic, environmental, technological and Government policy related factors as described in section 2.1 of chapter 2. So, according to this model, demand is only affected by the change of time showing a particular time trend for the coming days. A number of functions of time may be chosen to establish the trend model [29]. Some of them are mentioned below along with their mathematical forms:

- **Linear extrapolation:**

The variable to be forecast, Y_t (here, energy generation or demand) at a particular time (t) is expressed as:

$$Y_t = a + bt$$

Where, the slope of the line 'b' specifies the rate of change of consumption which is constant in this model ($b = dY_t / dt$) and 'a' specifies the level of consumption in the beginning.

- **Polynomial extrapolation:**

This model considers a varying rate of consumption instead of assuming it to constant as it was done in the previous model. Such a model is mentioned below with a second degree relationship between Y_t and t.

$$Y_t = a + bt + ct^2$$

Where, the rate of consumption itself is a function of time instead of being constant ($b + 2ct = dY_t / dt$).

- **Exponential growth:**

This model predicts the future consumption of energy demand an exponential function of time and expressed as:

$$Y_t = ae^{bt}$$

Where, the rate of consumption is specified by the parameter 'b'. In practice, this model is a little modified to make it suitable for use in the following way:

$$ln\ Y_t = lna + bln(t)$$

It resembles a linear model for consumption and can be treated like a linear model for analysis considering $ln\ Y_t$ and $ln(t)$ as variables.

- **Growth curves:**

Sometimes growth curves are employed to obtain a forecast of the consumption variable. The following growth functions may be utilized in this regard:

a) Logistic function : $\boldsymbol{Y_t = L/(1 + e^{-bt})}$

b) Gompertz function: $\boldsymbol{Y_t = L\, exp\, (-ae^{-bt})}$

Both the functions trace the consumption pattern of energy from minus '*infinity*' to plus '*infinity*'. *L* is a prescribed limit at which the consumption saturates. '*a*' and '*b*' are the parameters to be estimated. The curves of the two functions are '*S*' shaped. *Gompertz* function shows faster growth at the initial stage than that of in the declining stage. *Logistic* function is structured by just mirror reflecting the initial stage with respect to the point of inflexion and appending it to the initial stage. These models are basically used for predicting per capita energy consumption rather than total energy consumption. Because, per capita energy consumption reaches a plateau when the demand for the energy is saturated at a particular value when the lifestyle of the people of the region for which the forecast is made reaches such a stage that any improvement regarding energy consumption is rather unlikely.

2.2.2 Relative advantages and disadvantages of time trend model

- **Advantages**

The trend method has the advantage of its simplicity and ease of use. The underlying notion of trend analysis is that time is the factor determining the value of the variable under study, or in other words, the pattern of the variable in the past will continue into the future. This method is important as it provides a preliminary estimate of the forecasted value of the variable. It may well serve as a useful cross check in the case of short-term forecasts [30].

- **Disadvantages**

Simple time trend analysis models are plagued with substantial degree of imperfections and often unreliable and unrealistic. The principal disadvantage of this method is that it considers time as the only factor governing the energy demand. It completely ignores the economic factors (i.e. Fuel prices, income of the consumers etc), demographic factors (i.e. Population growth, Urbanization etc), geographical factors (i.e. Source of fuel etc), technological factors (i.e. Change in the level of efficiency in the supply sources), environmental factors (i.e. Change in temperature etc) [30]. As an example, if the per capita GDP (Gross Domestic

Product) increases, it is expected that people will tend to consume more energy as their standard of living will be elevated. Moreover, there will be more and more industrialization and consumption in the industry sectors will also be increased. However, a decrease in per capita GDP will lead to less energy consumption. But in the time trend models, it is inherently assumed that consumption will rise with the advancement of time irrespective of change in other pertinent factors. Besides, time trend models ignore any major policy change at the decision making levels that might influence the consumption pattern in future. Apart from these issues, the effect of technological or innovative changes in a specific time period is not transferred to the succeeding periods in these types of trend models. A major change in the consumption pattern at a certain period is certainly to influence the following periods. But time trend models readily discard any such possibility. These disadvantages make the time trend models unreliable in most cases and the viability of these models can be easily questioned [31].

2.2.3 Area of application of this model

Despite having some severe disadvantages, time trend models are often used in short term forecasts where a rough estimate is required in the near future. These models are simple and easily understandable [30].

2.3 End Use Method

2.3.1 Theoretical background

Untill now only the time effect on the energy consumption pattern has been considered. This approach is not quite realizable in practice. End use method is a different approach to estimate energy demand. It concentrates on the analysis in micro levels by accumulating the energy consumption data for different devices and systems used by the elementary consumers in domestic, agricultural, industrial, commercial sectors and other sub-sectors. According to the acquired data, the analysis is performed and the forecast is made. The energy consumed for a particular type of device can be represented as follows:

$$E = S * N * P * H$$

Where, E = Total energy consumption by a particular energy consuming device in kWh.

S = Penetration level in terms of such devices used per customer.

N = Number of customers.

P = Power required by the device in kW.

H = Hours of energy usage.

Thus the overall consumption is obtained by summing these data for all the associated devices in individual sectors and utilized to forecast the overall consumption [34].

2.3.2 Relative advantages and disadvantages of end use method

- **Advantages**

Factors like efficiency of the devices, population, price, income etc. are indirectly embedded in this type of model. It is an effective strategy when detailed data are available and newer technologies are to be introduced [30].

- **Disadvantages**

This approach requires data from very minute level. It is a Herculean task in a country like Bangladesh to collect such microscopic data with adequate degree of detail due to various reasons which are discussed in a later section. Furthermore, this approach often faces the criticism that it fails to bear the change in the behavioral response of the consumers subjected to the socio-economic and demographic factors that may influence the consumption pattern of the consumers [30]. Under the context of Bangladesh, it is very difficult for as to follow this approach in order to construct an appropriate energy demand model.

2.3.3 Area of application of this model

This is an effective method of demand forecasting when large volume and variety of data are available. Indian Planning Commission uses an end user based integrated energy demand forecasting model called DEFENDUS (Development Focused End Use oriented Service Directed) approach [32].

2.4 Artificial Neural Network (ANN) Method

2.4.1 Theoretical background

An Artificial Neural Network (ANN) is an information processing model that is influenced by the way biological nervous systems, such as the brain, process information in a human body. The structure of the information processing system is composed of a large number of highly interconnected processing elements (neurones) functioning coherently to solve specific problems. ANNs, like human beings, learn by example. An ANN is configured for a specific application, such as pattern recognition, data classification, energy forecasting etc. through a learning process [33]. In order to forecast energy demand, ANN interpolates between the energy consumption and its determinants in a training data set. Forecasting performance is usually measured by Mean Square Errors (MSE), Mean Absolute Deviations (MAD), Mean Percentage Square Errors (MPSE), Mean Absolute Percentage Errors (MAPE), etc. [34]. There are many types of neural networks: multilayer perception network, self-organizing network, etc. There are multiple hidden layers in the network. In each hidden layer there are many neurons. Inputs are multiplied by weights, and are added to a threshold to form an inner product number called the net function. The net function used is put through the activation function to produce the final output [35].

2.4.2 Relative advantages and disadvantages of ANN method

- **Advantages**

Artificial neural networks have remarkable ability to derive meaning from complicated or unorganized data. Thus they can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques [33]. Some other advantages are as follows:

1. Adaptive learning: ANN has the ability to learn how to do tasks based on the data given for training or initial experience.
2. Self-Organization: An ANN can create its own organization or representation of the information it receives during learning time.

3. Real Time Operation: ANN computations may be carried out in parallel, and special hardware devices are being designed and manufactured which take advantage of this capability.
4. Fault Tolerance via Redundant Information Coding: Partial destruction of a network leads to the corresponding degradation of performance. However, some network capabilities may be retained even with major network damage.

- **Disadvantages**

Neural networks learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise useful time is wasted or even worse the network might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself, its operation can be unpredictable. Another problem is that ANN models are predominately data oriented and does not have behavioral underpinning [33].

2.4.3 Area of application and the existing literature

ANN is currently considered as a very productive research area. Abundant literature is found on energy forecasting especially electrical load forecasting [35]. Lots of literatures are found establishing superiority of ANN over regular forecasting models. Dependence on functional forms by regular forecasting models is overcome by ANN models [36]. Park and Osama [37] used ANN approach for forecasting electrical load demand which, compared to regression methods, gave more flexibility. An ANN model based on back propagation for forecasting was used by Srinivasan *et al*. [38] and they showed its superiority to traditional methods. Liu *et al*. [39] compared ANN and autoregressive models (AR) concluding that ANN is much superior to AR models. So, ANN is a prospective area for research under the context of Bangladesh.

2.5 Conclusions

This chapter introduces demand modeling by illustrating the factors influencing energy demand. Three demand modeling techniques have also been approached and discussed in this chapter explicitly mentioning their theoretical frameworks, advantages, disadvantages and area of applications. Several existing research works have also been cited in this regard.

Chapter 3

ECONOMETRIC MODELING

3.0 Introduction

The effect of socio-economic and demographic factors responsible for the variation of consumption over the coming years is not clearly visible from the three models described in chapter 2. In a developing country like Bangladesh adoption of such a model is required that will reflect the requirement of energy from socio-economic point of view. To analyze the energy issue from economic horizon, knowledge on 'Econometrics' is the primary requirement. 'Econometrics' may be defined as "*The quantitative analysis of actual economic phenomena based on the concurrent development of theory and observation, related by appropriate methods of inference*" [40]. To be simpler, under our context, 'Econometrics' is the understanding and analysis of economic phenomena (Economic phenomena refers to energy issue in this case) with the theories of Economics, Mathematics and pertinent Statistical methods of inference. This chapter will gradually unveil the theoretical underpinning of econometric models, different functional forms, relative advantages and disadvantages of econometric models. To describe the theoretical aspects of the econometric model in detail step by step formation of the model has been clearly illustrated.

3.1 Theoretical Background

3.1.1 Model definition

At first the variables concerned with the study have to be identified and a causal relationship between them has to be defined so that the effect of the independent variables on the dependent variable can be analyzed [41]. To study the electrical energy generation and demand of Bangladesh the consumption variable may be defined as a function of various socio-economic parameters that may influence the demand.

$$Cons = f\,(\,Price,\,GDP,\,Pop,\,Govt,\,\Sigma X)$$

where, Cons = Electrical Energy Generation or Demand
Price = Average Price of Electricity
GDP = Gross Domestic Product
Pop= Population of the country
Govt= Government policy change
ΣX = A range of socio-economic and miscellaneous factors that affect the Demand but cannot be taken into account due to lack of relevant information

It is indeed not always possible to include all the related parameters in the model because a developing country like Bangladesh suffers from the limited extent of data management [42] which is essential for including more explanatory variables.

3.1.2 Model specification

The mathematical model establishing the relationship among these variables may be expressed as follows:

$$Cons = \beta 0 + \beta 1\ (Price) + \beta 2\ (GDP\ per\ capita)$$

This model assumes an exact relationship between the dependent variable (Cons) and explanatory variables (Price & GDP per capita). But, generally relationship between such economic variables is inexact and has to be modified [43]. The modified model is:

$$Cons = \beta 0 + \beta 1\ (Price) + \beta 2\ (GDP\ per\ capita) + \varepsilon$$

where, ε is the stochastic disturbance term. It may account for the variables that were omitted in the model due to lack of availability of data or it may include the effect of those variables that are not readily observable from theoretical point of view. Intrinsic randomness of the human behavior that may affect consumption may also be embedded into this error term [43]. This type of model is generally called a Linear Regression Model (LRM). The magnitudes of the coefficients (β1, β2) of the variables (Price, GDP per capita) indicate the strength of the impact of these variables upon electricity demand. And the signs of the coefficients indicate the direction of the demand subjected to a change in the explanatory variables.

The model discussed thus far is linear in variables and linear in parameters. There are several functional forms that are linear in parameters but non-linear in variables. That is, the variables are related by non-linear functions (such as logarithmic, exponential, reciprocal etc functions) [43]. These special functional forms are described in section 3.1.3.

3.1.3 Functional forms

Several functional forms of the econometric models are illustrated in tabular form as follows:

Table 3.1: Various functional forms of the linear regression model

Model	**Equation**
Log- Linear	ln(Cons) = β0 + β1 ln(Price) + β2 ln (GDP)
Log- Lin	ln(Cons) = β0 + β1(Price) + β2(GDP)
Lin- Log	Cons = β0 + β1 ln(Price) + β2 ln (GDP)
Reciprocal	Cons = β0 + β1 (1/Price) + β2 (1/GDP)
Log- Reciprocal	lnCons = β0 - β1 (1/Price) - β2 (1/GDP)

- **The Log- Linear model**

The functional relationship among the variables in the Log- Linear Model is shown in the Table 3.1. This model is superior over the simple Linear Regression model from two perspectives. Firstly, this model directly measures the elasticity (Price elasticity and income elasticity in this case). The coefficients of ln(Price) and ln(GDP) are the direct measures of the corresponding elasticities. Elasticities are significant means of policy implication in the economic arena [44]. Secondly, this model reflects the non-linear nature of the variables. Considering the data non-linearly stochastic makes more sense than considering it to be linearly stochastic [45]. A noteworthy application of such model is the Cobb- Douglas Production Function. The function expresses the Production (Q) as a function of Capital (K) and Land (L) and fits an exponential relationship *ln Q= β1 ln(K)+ β2 ln(L)* and is the only production function that has a property of constant functional distribution of income.

- **Semi log models**

These models are classified into two types: i) Log-Lin Models and ii) Lin- Log Models. The functional forms of the two types are shown in the Table 3.1. In such models regressors (independent variables) or regressand (dependent variable) is logarithmic. In Log- Lin model regressand is logarithmic and in Lin- Log model regressors are logarithmic. Growth of certain economic parameters like population, GNP (Gross National Product), money supply, etc. are predicted using these models. One such application is Engel's Expenditure Model that shows how the consumer's purchase of a particular commodity varies as the consumer's total expenditure or income varies. If the purchase for a certain good varies linearly with time, the total expenditure usually varies non-linearly depending on the quality of the good. These phenomena can be captured by Lin-Log Model.

- **Reciprocal models**

The functional forms of these types of models are shown in the Table 3.1. According to this model, the dependent variable tends to take a constant limiting value as anyone of the independent variables increases indefinitely keeping the other variables constant. One of the remarkable applications of this model is the Phillip's Curve. It is shown by A.W.

Phillips (1958) that generating higher inflation can significantly lower unemployment rate and it can be economically modeled by Reciprocal Model.

- **Log- Reciprocal model**

The functional form of this model is shown in the Table 3.1. In such models, the dependent variable initially rises steeply and then gradually flattens after a certain stage. In Microeconomics, the short run production versus Labor relationship is of the Log- Reciprocal form if the Capital is held constant [43].

3.2 Time Series Econometric Models

Time series models are essentially econometric models associated with time series data of the variables where the lagged values of the independent variables and/or dependent variable are used [30]. In a rudimentary econometric model, one of the basic assumptions is that the change in consumption is immediately followed by a change in any on the independent variables. However, when we are dealing with time series data, it is not at all unlikely that the electricity demand and generation will not be immediately affected by the change in per capita GDP or price; rather the consumption response may be delayed in nature. For industries and farms, the consumption may be delayed due to institutional or administrative obligations [43]. This can be incorporated in a time series model.

If the regression model is constructed only by the independent variables and their lagged values, the model is called a Distributed Lag Model. To estimate Distributed Lag Models, the Koyck approach is widely accepted. On the other hand, if the model is formed by including one or more lagged values of the dependent variable along with the independent variables, it is called an Auto-Regressive Model (AR) or a Dynamic Model [43]. The functional forms of both models are shown below:

Distributed Lag Model: $Cons(t) = \beta 0 + \beta 1 (Price(t)) + \beta 2 (Price(t-1))$

Dynamic/ AR Model: $Cons(t) = \beta 0 + \beta 1 (Price(t)) + \beta 2 (Cons(t-1))$

If this time series effect is taken into account, the model previously described in section 3.1.2 and 3.1.3 can be modified as,

$$Cons(t) = \beta 0 + \beta 1 (Price(t)) + \beta 2 (GDP(t)) + \beta 3 (Cons(t-1))$$

Where, the number of lags may vary according to the model dynamics.

3.3 Relative Advantages and Disadvantages Of Econometric Model

Advantages

The significant advantages of econometrics models are:

- Classification of variables: In econometric models there is a clear distinction between variables that are studied in the model (endogenous) and those that are not (exogenous).
- Use of statistical methods for validation: Due to the fact that historical data of the variables is used, it is possible to undertake statistical calculations to validate the model.
- Consistency in forecast: The mathematical interrelationships in the model result.
- Reproducibility of forecast: The reproducibility of the forecast permits the model user to conduct a post mortem analysis to identify the causes of poor predictions.

Disadvantages

The econometric methods require a consistent set of information over a reasonably long duration. This requirement forms a pre-requisite for establishing both short-term and long-term relationships between the variables involved. Thus, for instance, if one were interested in knowing the price elasticity of demand, it is hard to arrive at any meaningful estimates, given the long period of administered tariffs and supply bottlenecks.

Another criticism of this method is that during the process of forecasting it is incorrect to assume a particular growth rate for the explanatory variables. Further, the approach fails to incorporate or capture, in any way, the role of certain policy measures/ economic shocks that might otherwise result in a change in the behavior of the variable being explained. This would have to be built into the model, may be in the form of structural changes [30].

3.4 Conclusions

This chapter introduces the fundamental concepts of econometric modeling, describes the different functional structures of econometric models, their features and applications. Time series econometric model which is also a type of econometric model has also been discussed and finally the advantages, disadvantages of econometric models have been illustrated.

Chapter 4

ANALYSIS OF DATA

4.0 Introduction

This chapter discusses the data associated with this research. Firstly, four major types of data are discussed in brief that are commonly used in energy demand modeling. Range and sources of data used in this research for trend analysis and econometric modeling are discussed afterwards. Relevant modifications of the collected data are explained thereafter. Finally, some points have been mentioned that are to be carefully considered about the data while doing econometric modeling.

4.1 Data Types in Energy Demand Modeling

4.1.1 Time series data

A time series is a set of observations on the values that a variable takes at different times. Such data may be collected at regular time intervals, such as daily (e.g., stock prices, weather reports), weekly (e.g., money supply figures), monthly (e.g., unemployment rate, Consumer Price Index or CPI), quarterly (e.g., GDP), annually (e.g., Government budgets) etc. Some data are available both quarterly and annually, as in the case of the data on GDP and consumer expenditure. Time series data are heavily used in econometric studies [43]. There are several problems associated with time series data which are discussed in section 4.4.

4.1.2 Cross sectional data

Cross sectional data are data on one or more variables collected at the same point in time, such as the census of population conducted by the Census Bureau every 10 years. If data on egg production and egg prices for 50 districts in a country for 2008 and 2009 are collected, for each year the data on the 50 districts are cross sectional data. Cross sectional data are free from the problems involved with time series data, but they have their own problems. Cross sectional data often suffer from the problem of heterogeneity [43].

4.1.3 Pooled data

Pooled data are combination of time series and cross sectional data. Referring to the example stated in section 4.1.2, if there are 50 cross sectional observations and for each district there are 2 time series observations on prices and productions of eggs, a total of 100 pooled or combined observations are gathered. Likewise, the data of CPI of 7 countries gathered over 25 years are example of 175 pooled data [43].

4.1.4 Panel data

This is a special type of pooled data in which the same cross-sectional unit is surveyed over time. For example, the U.S. Department of Commerce carries out a census of housing at periodic intervals. At each periodic survey the same household is interviewed to find out if there has been any change in the housing and financial conditions of that household since the last survey. By interviewing the same household periodically, the panel data provides very useful information on the dynamics of household behavior [43].

4.2 Types and Sources of The Data Used in This Research

4.2.1 Data for trend analysis

Data for the electrical energy generation and demand in Bangladesh from 1981-2008 have been used in this research to find a suitable and realistic trend in the data and to perform the forecast. These time series data are collected from Bangladesh Power Development Board Annual Report 2008-2009, 2007-2008, 2005-2006, 1994-1995, 1990-1991, 1989-1990, 1987-1988, 1986-1987 and 1985-1986.

4.2.2 Data for econometric modeling

For econometric modeling time series data (ranging from 1981-2008) for all the variables used in the models have been collected from different national and international sources. Same data for the electrical energy generation and demand are used in econometric analysis as it has been used in the case of trend analysis. Average billing rates of electricity have been collected from Bangladesh Power Development Board Annual Report 2008-2009, 2007-2008, 2005-2006, 1994-1995, 1990-1991, 1989-1990, 1987-1988, 1986-1987 and 1985-1986. Data for per capita GDP and CPI have been collected from the website of International Monetary Fund (IMF) [46]. These data are presented in the website referring Bangladesh Bureau of Statistics.

4.3 Data Conversion and Modification

For using the data in this research some necessary modifications have to be made for the estimation and specification tests. The modifications done to the data in this thesis can be classified into following categories:

- Categorizing generation, maximum demand and average billing rate to year-wise data.
- Establishing constant price GDP (per capita) under same base year.
- Considering the effect of CPI on average billing rate.

These processes are described as follows:

4.3.1 Categorizing generation, maximum demand and average billing rate to year-wise data

The data of generation, maximum demand and average billing rate of electricity that we obtained from our field work were given with respect to fiscal year, but constant per capita GDP values were found to be in per year basis, so we have to convert the data of generation, maximum demand and average billing rate to per year basis from the fiscal year data.

In order to do so, we considered the data of two consecutive years and take the average value of them to consider it as the data of later year. After converting the data of generation, maximum demand and average billing rate of electricity starting from fiscal year 1980-1981 to 2008-09, the time series data from year 1981 to 2008 was acquired.

The following table represents the data conversion method adopted in this category. For example, we have considered respectively the data of generation, maximum demand and average billing rate here.

Table 4.1: Modification of net electrical energy generation

Fiscal Year	Net generation (GWh)	Year	Net generation (GWh)
1980-1981	2,661.81	1981	2,849.125
1981-1982	3,036.44		

Table 4.2: Modification of maximum demand served

Fiscal Year	Maximum demand (MW)	Year	Maximum demand (MW)
1994-1995	1,970	1995	2,028.50
1995-1996	2,087		

Table 4.3: Modification of average billing rate of electricity

Fiscal Year	Average billing rate (Taka/KWh)	Year	Average billing rate (Taka/KWh)
2002-2003	2.45	2003	2.425
2003-2004	2.40		

This modification has been applied to the data of generation, maximum demand and average billing rate of electricity. The data of generation and maximum demand are used both in trend analysis and econometric modeling. The data of average billing rate of electricity and other two modifications to be discussed later (section 4.3.2 and 4.3.3) are only applicable to the econometric analysis.

4.3.2 Establishing constant price GDP (per capita) under same base year

The GDP data available was per capita current price GDP at national currency. An appropriate data format of GDP for estimating and simulating the electrical energy generation and demand would be per capita constant price GDP on national currency under a specific base year. The conversion to appropriate data format requires involvement of another statistical parameter which is called Consumer Price Index (CPI). The following steps are performed to acquire an appropriate data set for the analysis. Firstly, base year was selected. The CPI data available was under the base year 2000 (that is, the CPI data were given considering CPI of year 2000 equal to 100), so for maintaining simplicity in the calculation year 2000 was considered as the base year. Secondly, GDP per capita of current price has to be converted to GDP per capita of constant price. To do so, current price GDP of a year was divided by the corresponding CPI of that year and then multiplied by the result with the CPI of the base year 2000 (which is 100). The result thus obtained gives the desired per capita constant price GDP under the base year 2000 at national currency. The following example illustrates the process mentioned above. The per capita current price GDP at national currency (Taka) for the year 1990 is 9325.51. The consumer price index (CPI) of the year 1990 is 58.24. The CPI of the base year 2000 is 100.

Table 4.4: Modification of GDP per capita

Year	GDP per capita at Current price (Taka)	CPI of the year	GDP per capita at constant price (Taka)
1990	9,325.51	58.235	16,013.58

So, per capita constant price GDP of the year 1990 at national currency under the base year 2000 can be calculated as,

Constant price GDP (1990) = {Current price GDP (1990)*CPI of base year (2000)}/ CPI (1990);
Or, Constant price GDP (1990) = (9325.51*100)/58.235;
So, Constant price GDP (1990) = 16013.58 Taka.
Thus constant price GDP (under base year 2000) time series data were obtained.

4.3.3 Considering the effect of CPI on average billing rate

The raw field work data contains average billing rate of any specific year which are found by modification from average billing rate of the corresponding fiscal year (discussed in section 4.3.1), but the statistical estimation of the consumption under influence of the price of the commodity requires the average billing rates to be expressed under a same base year. To accomplish this task, the current average billing rate of a year was divided by the corresponding CPI of that year and then multiplied by the result with the CPI of the base year 2000 (which is 100). The result thus obtained gives the desired constant average billing rate under the base year 2000 at national currency. The process is illustrated below:

The current average billing rate of electricity for the year 2003 is 2.425 Taka/kWh. The consumer price index (CPI) of the year 2003 is 111.364. The CPI of the base year 2000 is 100.

Table 4.5: Conversion of current average billing rate to constant average billing rate

Year	Current average billing rate (Taka/kWh)	CPI	Constant average billing rate (Taka/kWh)
2003	2.425	111.364	2.178
2004	2.335	118.161	1.976

So, constant average billing rate of electricity for the year 2003 at national currency under the base year 2000 can be calculated as,

Constant average billing rate (2003) = {Current average billing rate (2003)*CPI of base year (2000)}/ CPI (2003);
Or, Constant average billing rate (2003) = (2.425*100)/ 111.364;
So, Constant average billing rate (2003) = 2.178 Taka/kWh.
Thus Constant average billing rate of electricity (under base year 2000) time series data were obtained.

4.4 Few Points on Time Series Data

Though time series data are widely used for demand forecasting, they pose several challenges to researchers. Researchers have to deal with several aspects of time series data such as stationarity, autocorrelation, spurious regression, etc. [43]. This dissertation mainly focuses on treating the auto-correlation problem of time series data. Auto-correlation is a phenomenon that occurs mostly in time series data. The usual assumption for the regression model is that the random error terms in the model will be uncorrelated. Whenever, this assumption is violated, auto-correlation occurs. Omission of relevant explanatory variables is the driving factor for auto-correlation. Auto-correlation typically leads the researcher to wrong inferences [43].

4.5 Conclusions

This chapter encapsulates all the topics related to data for trend analysis and econometric modeling. Types of data used in energy demand modeling have been briefly described. The data type and data sources used in this thesis are described afterwards. Several modifications of the data before making them suitable for modeling are explicitly discussed along with illustrative examples. In the end, a few aspects of time series data have been mentioned.

Chapter 5

ANALYSIS OF RESULTS

5.0 Introduction

This chapter is dedicated to the analysis of results of econometric models as well as time trend models developed in this research work. Time trend model results are presented using figures showing the actual and forecasted electrical energy generation and demand on the same graph. For demonstrating the results of Econometric analysis, the results of estimations and specification tests are presented in this chapter. Econometric analysis was performed under socio economic variables like per capita GDP (Gross Domestic Product) which represents income and average billing rate of electricity. Moreover, in order to consider the effect of generation and consumption inertia, previous year generation and consumption of electricity was included in the model for estimating current generation and demand. Several models have been chosen and a single model was preferred to other models based on their economic underpinning, results of estimation and specification tests, etc. Finally, the electrical energy generation and demand forecast are presented and compared to forecast from time trend model and PSMP-2005 base forecast model.

5.1 Result Analysis of Time Trend Models

Recalling from section 2.3, the time trend analysis builds up on the simple concept that demand of any commodity is a function of time. In functional form,

$$\text{Electricity Demand} = f\ (\text{Time})$$

In this type of models the future demand of a commodity is assumed to be dependent only on the past trend of demand of that commodity. For the analysis with time trend model the data set available was time series data of electrical energy generation and demand of Bangladesh for 28 years ranging from year 1981 to 2008 as mentioned in section 4.2.

In case of time trend analysis three types of trend models are considered,

1) Linear time trend model
2) Quadratic time trend model
3) Exponential growth time trend model

The analysis and forecasted results of time trend models for electrical energy generation and demand are as follows:

5.1.1 Electricity demand

The results of the time trend analysis for electricity demand are shown in figures 5.1 (linear trend), 5.2 (quadratic trend) and 5.3 (exponential growth trend). Referring to the figures the x- axis designates year of consumption from year 1981 to 2020 and the y- axis shows corresponding electricity demand in MW. The black line represents the actual electricity demand from year 1981 to 2008, the blue line shows fitted electricity demand from year 1981 to 2008 and the red line shows predicted electricity demand up to year 2020. The model diagnostics for the three models are shown in Tables 5.1, 5.2 and 5.3.

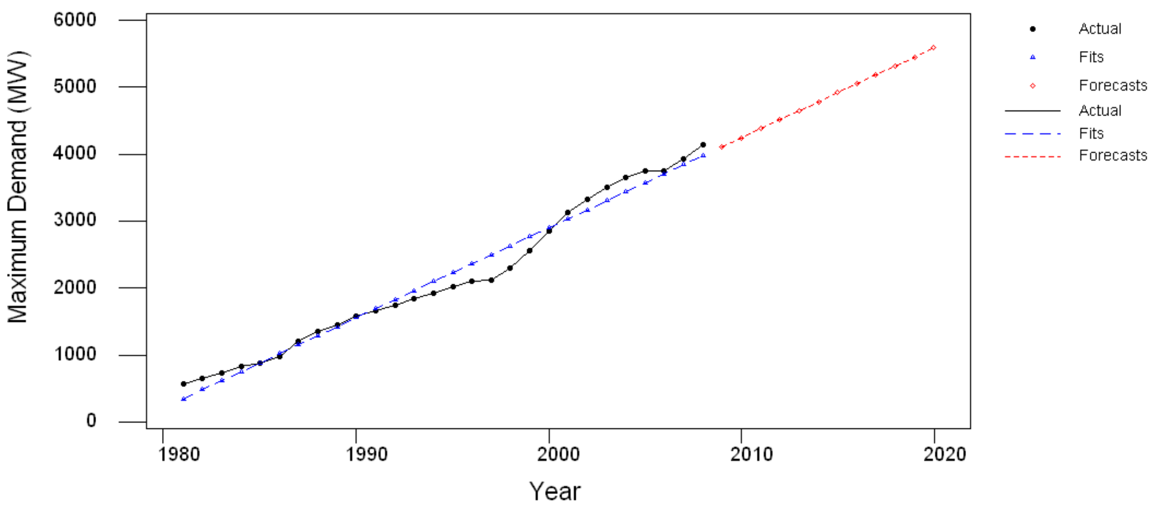

Figure 5.1: Linear trend of maximum demand

Table 5.1: Linear trend model diagnostic for maximum demand

Parameters	Value
MAPE	8.0
MAD	134.3
MSD	27173.3

Where, MAPE = Mean Absolute Percentage Error

MAD = Mean Absolute Deviation

MSD = Mean Standard Deviation

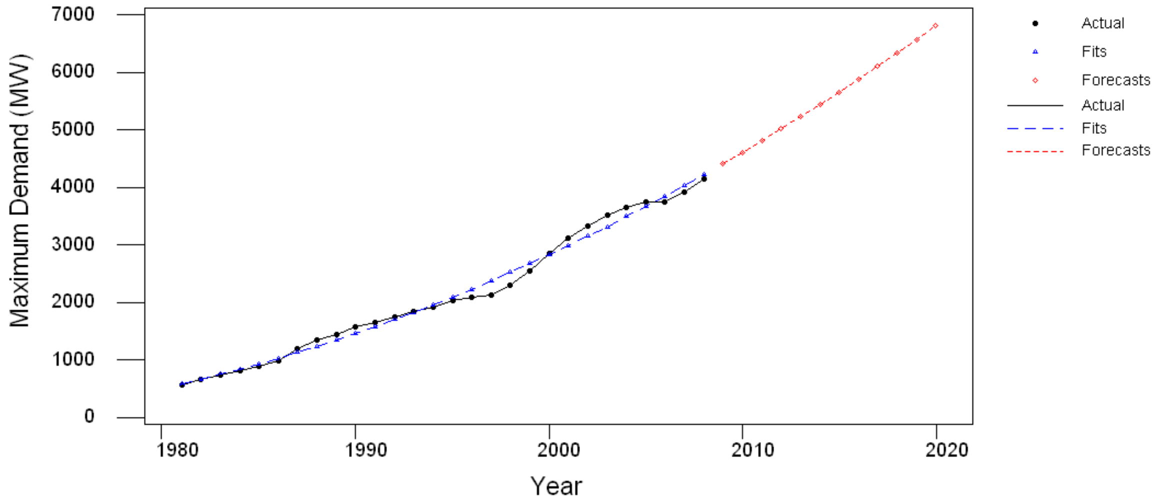

Figure 5.2: Quadratic trend of maximum demand

Table 5.2: Quadratic trend model diagnostic for maximum demand

Parameters	Value
MAPE	4.5
MAD	92.3
MSD	12592.2

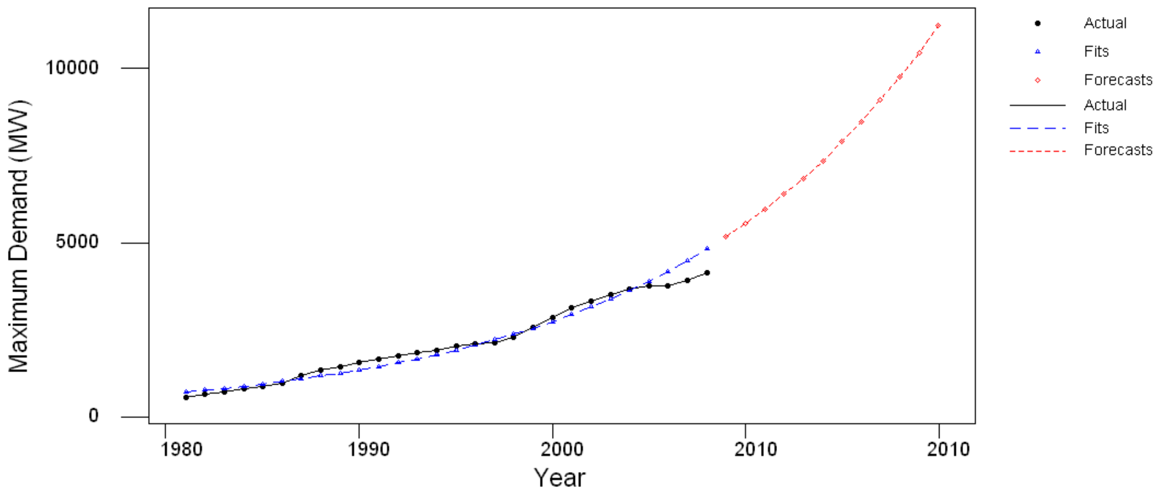

Figure 5.3: Exponential growth trend of maximum demand

Table 5.3: Exponential growth trend model diagnostic for maximum demand

Parameters	Value
MAPE	8.6
MAD	166.0
MSD	49937.7

The results of linear time trend analysis in figure 5.1 have shown two deficiencies of this model. Firstly linear trend cannot track the actual demand well. Consumption of a commodity is not a linear function of time as it normally does not follow a constant increasing or decreasing pattern. Comparing the actual and fitted demand curve from year 1991 to 2000 has emphasized this notion. Secondly, the fitted as well as forecasted demand fails to follow the actual demand from 2006 and onwards as actual demand curve has a larger slope than fitted that of demand curve. It can be inferred from the analysis above that linear trend analysis is not a good model for forecasting the electricity demand in this case. The model diagnostics presented in Tables 5.1, 5.2 and 5.3 clearly shows that quadratic trend model is superior to linear and exponential growth trend models. For linear time trend analysis forecasted electricity demand in year 2020 will be 5,588 MW, for quadratic time trend analysis forecasted electricity demand in year 2020 will be 6,801 MW and exponential growth trend analysis forecasted electricity demand in year 2020 will be 11,223 MW.

5.1.2 Electrical energy generation

The forecasted electrical energy generation is shown in figures 5.4, 5.5 and 5.6 using linear, quadratic and exponential growth time trend analysis respectively.

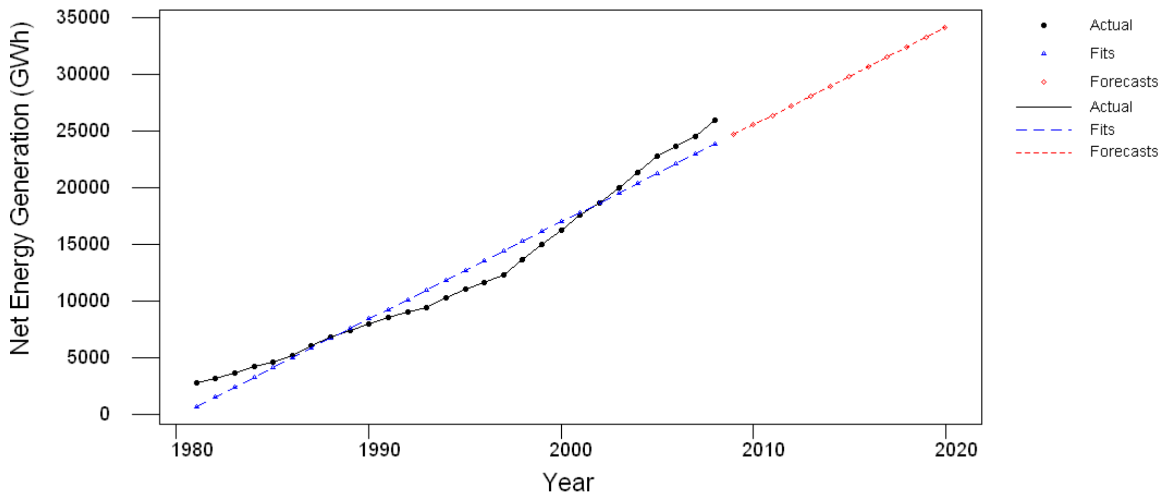

Figure 5.4: Linear trend of net generation

Table 5.4: Linear trend model diagnostic for net generation

Parameters	Value
MAPE	13
MAD	1067
MSD	1585872

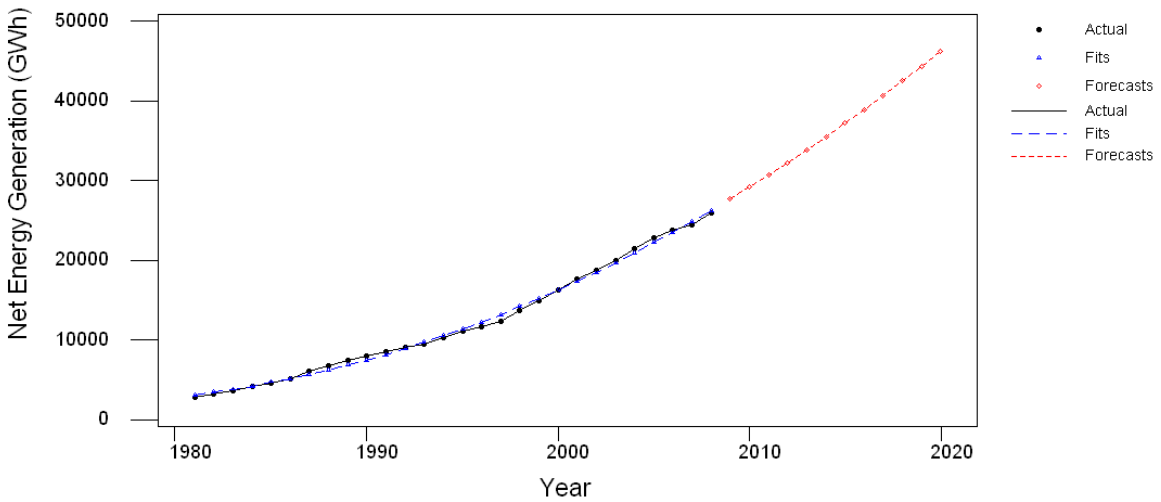

Figure 5.5: Quadratic trend of net generation

Table 5.5: Quadratic trend model diagnostic for net generation

Parameters	Value
MAPE	3
MAD	314
MSD	142278

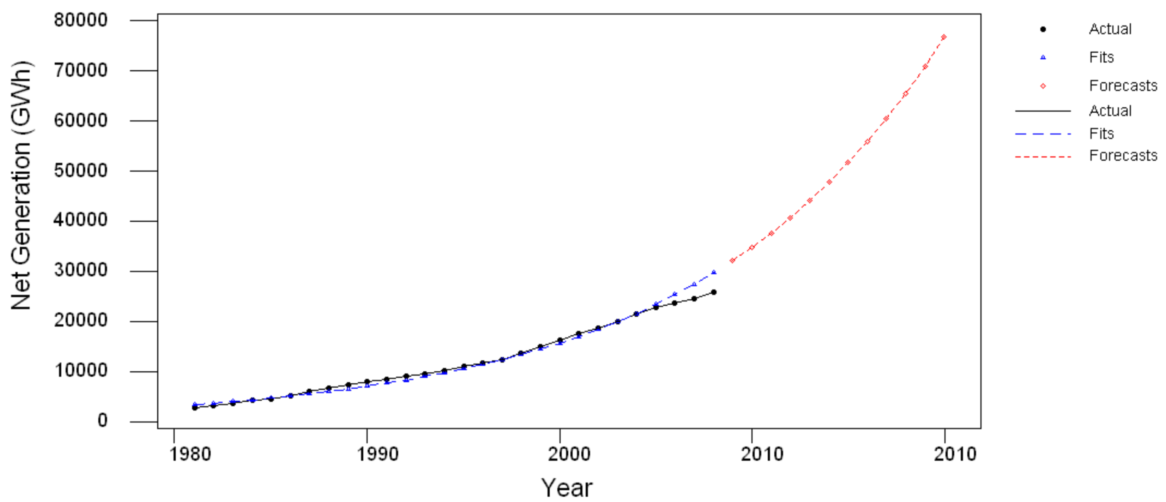

Figure 5.6: Exponential growth trend of net generation

Table 5.6: Exponential growth trend model diagnostic for net generation

Parameters	Value
MAPE	6
MAD	683
MSD	1119573

The results of these three analysis and the model diagnostics presented in Tables 5.4, 5.5 and 5.6 clearly show that quadratic trend model is superior to linear and exponential growth trend models. For linear time trend analysis forecasted electricity demand in year 2020 will be 34,127 GWh, for quadratic time trend analysis forecasted electricity demand in year 2020 will be 46,193 GWh and exponential growth trend analysis forecasted electricity demand in year 2020 will be 76,750 GWh.

5.1.3 GDP per capita

The forecasted GDP per capita at current price is shown in figure 5.7, 5.8 and 5.9 using linear, quadratic and exponential growth time trend analysis respectively.

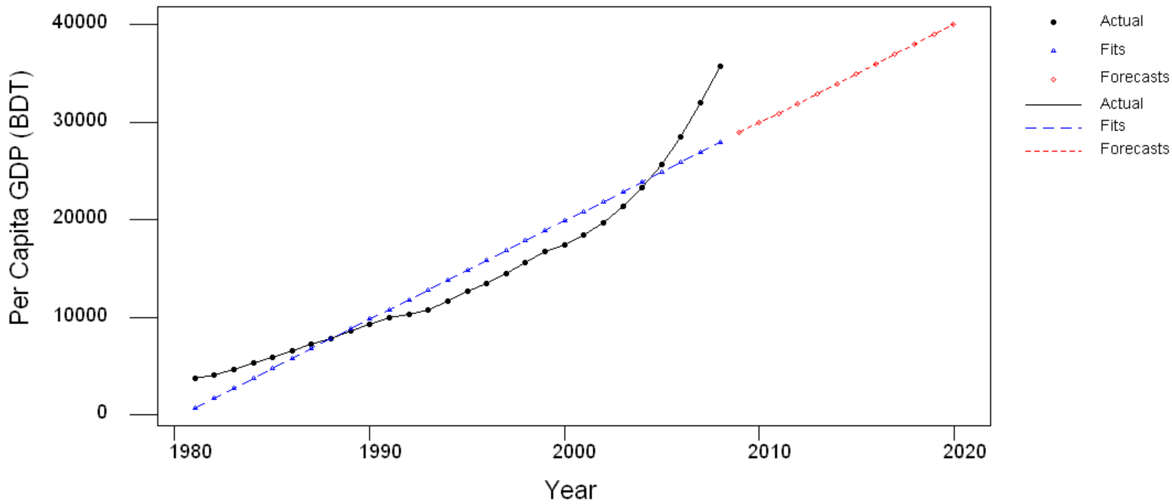

Figure 5.7: Linear trend of GDP per capita at current price

Table 5.7: Linear trend model diagnostic for GDP per capita

Parameters	Value
MAPE	18
MAD	1975
MSD	6237052

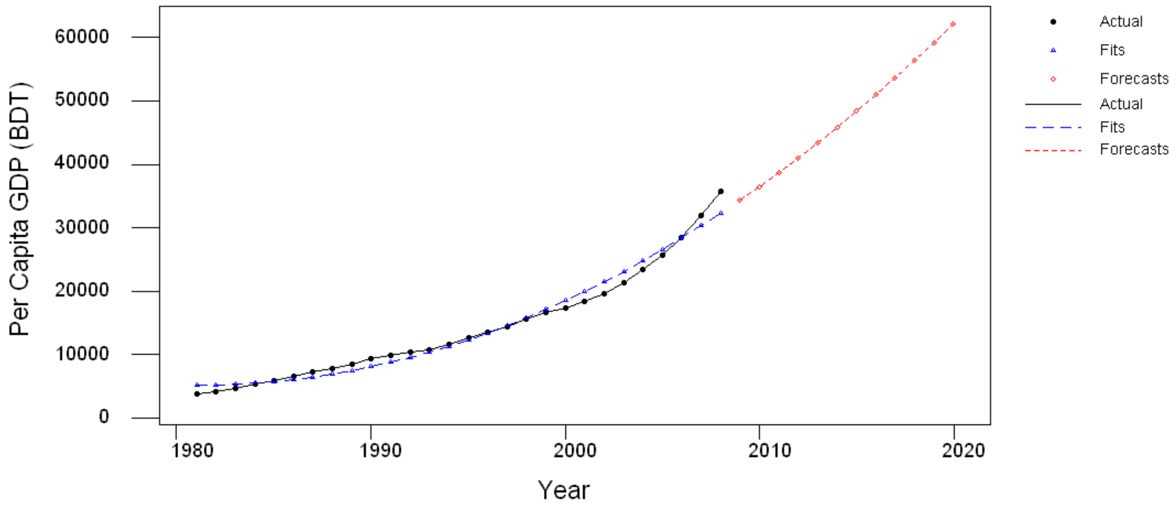

Figure 5.8: Quadratic trend of GDP per capita at current price

Table 5.8: Quadratic trend model diagnostic for GDP per capita

Parameters	Value
MAPE	8
MAD	907
MSD	1366371

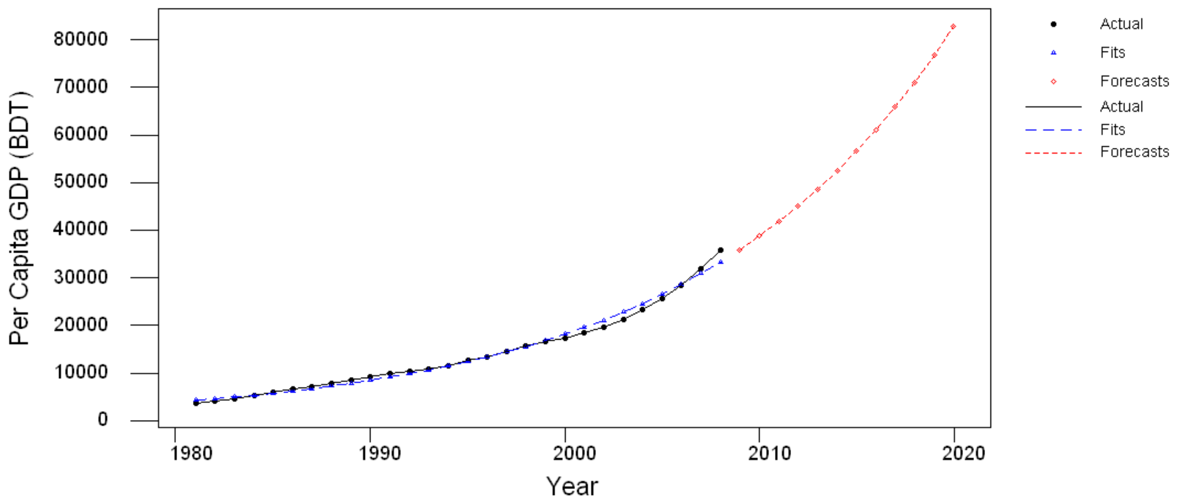

Figure 5.9: Exponential growth trend of GDP per capita at current price

Table 5.9: Exponential growth trend model diagnostic for GDP per capita

Parameters	Value
MAPE	5
MAD	600
MSD	674750

The results of these three analysis and the model diagnostics presented in Table 5.7, 5.8 and 5.9 clearly shows that exponential growth trend model is superior to linear and quadratic trend models. For exponential growth trend analysis, forecasted GDP per capita (current price) in year 2020 will be 82,715 BDT. By analyzing the previous data of CPI (from year 1996 to 2008), it is found that the average incremental rate of CPI is 5.50%. Therefore, GDP per capita of current price has to be converted to GDP per capita of constant price which is discussed in section 4.3.2. The results of forecasted GDP per capita (current price), CPI and GDP per capita (constant price) are shown in tabular form in Appendix A-4.

5.2 Results of Econometric Analysis

5.2.1 Electricity demand analysis

Five econometric models have been chosen for this analysis. The results of the five models are separately presented in Tables 5.10, 5.11, 5.12, 5.13 and 5.14. Comparison among these models is presented in the Table 5.15. Finally the preferred model is chosen for forecasting the electricity demand.

Model 1:
Electricity Demand(t) = f (GDP(t), Avg. billing rate(t), Demand(t-1), Demand(t-2))

Table 5.10: Results of model 1 for maximum demand

Variable	Coefficient	Standard error	Probability
Ln(GDP)	.0487803	.110294	0.663
Ln(Avg. billing rate)	-.014347	.0771913	0.854
Ln(Demand(t-1))	1.401794	.2117865	0.000
Ln(Demand(t-2))	-.4427536	.2184471	0.056
Constant	-.1151825	1.156612	0.922
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.3507		
Observations	26		
R squared	0.9966		
Adjusted R squared	0.9960		
Root MSE	0.03277		

From Table 5.10 it is found that model 1 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.3507) as the p-value is higher than the usual threshold of 0.05 (95% significance). R squared shows the amount of variance of outcome variable explained by predictor variables. In this case the model explains 99.66% of the variance in electricity demand. Adjusted R squared shows the same as R squared but adjusted by the number of cases and number of predictor variables. When the number of predictor variables is small and the number of cases is very large then adjusted R squared is closer to R squared. In this case, the adjusted R squared indicates that about 99.60% of the variability of electricity demand is accounted for by the model. This provides a more honest association between predictor variables and outcome variable. Root MSE (root mean squared error) is the standard deviation of the regression; the closer to zero better the fit. In this case, Root MSE is 0.03277 which is near about to zero. GDP per capita (p=0.663) and average billing rate (p=0.854) are not significant because the significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. So model 1 is not a suitable model for forecasting maximum electricity demand.

Model 2:

Electricity Demand(t) = f (GDP(t), Demand(t-1), Demand(t-2))

Table 5.11: Results of model 2 for maximum demand

Variable	Coefficient	Standard error	Probability
Ln(GDP)	.0569093	.099005	0.571
Ln(Demand(t-1))	1.386923	.1917404	0.000
Ln(Demand(t-2))	-.4215429	.1821349	0.030
Constant	-.2549957	.8590788	0.769
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.3664		
Observations	26		
R squared	0.9966		
Adjusted R squared	0.9962		
Root MSE	0.03204		

From Table 5.11 it is found that model 2 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.3664) as the p-value is higher than the usual threshold of 0.05 (95% significance). The R-squared is 0.9966, meaning that approximately 99.66% of the variability of electricity demand is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.62% of the variability of electricity demand is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.03204 which is closer to zero. If 95% confidence interval is considered, GDP per capita (p=0.571) is not significant as its probability is greater than 0.05. So model 2 is also not a suitable model for forecasting maximum electricity demand.

Model 3:

Electricity Demand(t) = f (GDP(t), Avg. billing rate(t), Year(t), Demand(t-1))

Table 5.12: Results of model 3 for maximum demand

Variable	Coefficient	Standard error	Probability
Ln(GDP)	-.4726411	.1551817	0.006
Ln(Avg. billing rate)	.3800496	.0886814	0.000
Ln(Year)	94.65244	21.67955	0.000
Ln(Demand(t-1))	.59672	.0894522	0.000
Constant	-711.8766	162.8979	0.000
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0907		
Observations	27		
R squared	0.9982		
Adjusted R squared	0.9978		
Root MSE	0.02577		

From Table 5.12 it is found that model 3 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0907). The R-squared is 0.9982, meaning that approximately 99.82% of the variability of electricity demand is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.78% of the variability of electricity demand is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.02577 which is closer to zero. If 95% confidence interval is considered, GDP per capita (p=0.006) and average billing rate (p=0.000) are significant as their probability are less than 0.05. But the coefficient of GDP per capita is negative which would indicate that decrease in GDP per capita is related to increase in maximum demand which quite contradictory to the regular economic understanding. So model 3 is also not a suitable model for forecasting maximum electricity demand.

Model 4:

Electricity Demand(t) = f (GDP(t))

Table 5.13: Results of model 4 for maximum demand

Variable	Coefficient	Standard error	Probability
Ln(GDP)	4.400912	.6472305	0.000
Constant	-35.41848	6.316422	0.000
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0744		
Observations	28		
R squared	0.6401		
Adjusted R squared	0.6262		
Root MSE	0.36005		

From Table 5.13 it is found that model 4 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0744) as the p-value is higher than the usual threshold of 0.05 (95% significance). The R-squared is 0.6401, meaning that approximately 64.01% of the variability of electricity demand is accounted for by the variables in the model. The adjusted R-squared indicates that about 62.62% of the variability of electricity demand is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.36005 which is closer to zero. Again it is found that GDP per capita (p=0.000) is significant because the significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. So model 4 is a suitable model for forecasting maximum electricity demand.

Model 5:

Electricity Demand(t) = f (GDP(t), Avg. billing rate(t))

Table 5.14: Results of model 5 for maximum demand

Variable	Coefficient	Standard error	Probability
Ln(GDP)	.4353048	.7358857	0.559
Ln(Avg. billing rate)	-1.462872	.2267994	0.000
Constant	4.769392	7.375309	0.524
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0003		
Observations	28		

R squared	0.8649
Adjusted R squared	0.8541
Root MSE	0.22495

The value of Ramsey RESET test (Prob > F = 0.0003) reveals that model 5 is not the suitable one as it might have omitted variables because the p-value should be higher than the usual threshold of 0.05 (95% significance).

Table 5.15: Comparison among the five models for maximum demand

	Model 1	Model 2	Model 3	Model 4	Model 5
Ramsey RESET test	0.3507	0.3664	0.0907	0.0744	0.0003
Probability of GDP	0.663	0.571	0.006	0.000	0.559
Probability of Avg. billing rate	0.854	---	0.000	---	0.000
Coefficient of GDP	.0487803	.0569093	-.4726411	4.400912	.4353048
Coefficient of Avg. billing rate	-.014347	---	.3800496	---	-1.462872

A decision should be made about the suitable model by comparing the results of specification tests and the economic underpinning behind each model. The value of Ramsey RESET test reveals that model 5 is not the suitable one as it might have omitted variables. Other 4 models don't have any omitted variable. The significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. From Table 5.15 it is found that GDP per capita and average billing rate are not significant for model 1, but they are significant for model 3 in explaining maximum electricity demand. It is also found that GDP per capita is not significant for model 2, but it is significant for model 4 in explaining maximum electricity demand. In model 3, the coefficient of GDP per capita is negative which would indicate that decrease in GDP per capita is related to increase in maximum demand which quite contradictory to the regular economic understanding. So the left model 4 is considered the only suitable model for forecasting maximum electricity demand. From this analysis, no superior model is found by considering average billing rate which proves that in Bangladesh demand of electricity is invariant of its price. Model 4 also considers consumption inertia and both GDP per capita and consumption inertia are found statistically significant. So the structure of the accepted GDP based model (model 4) is:

Electricity Demand(t) = f (GDP(t)) ………………..(5.1)

5.2.2 Electrical energy generation analysis

Five econometric models have been chosen for this analysis. The results of the five models are separately presented in Tables 5.16, 5.17, 5.18, 5.19 and 5.20. Comparison among these models is presented in the Table 5.21. Finally the preferred model is chosen for forecasting the energy generation.

Model 1:

Net Generation(t)

= f (GDP(t), Avg. billing rate(t), Year(t), Generation(t-1), Generation(t-2))

Table 5.16: Results of model 1 for net generation

Variable	Coefficient	Standard error	Probability
Ln(GDP)	-.2735745	.1143452	0.027
Ln(Avg. billing rate)	.1546978	.0638091	0.025
Ln(Year)	68.96443	20.7637	0.003
Ln(Generation(t-1))	.9568024	.2063481	0.000
Ln(Generation(t-2))	-.294419	.1674087	0.094
Constant	-518.3405	156.0246	0.003
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0776		
Observations	26		
R squared	0.9993		
Adjusted R squared	0.9992		
Root MSE	0.01671		

From Table 5.16 it is found that model 1 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0776) as the p-value is higher than the usual threshold of 0.05 (95% significance). The R-squared is

0.9993, meaning that approximately 99.93% of the variability of net generation is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.92% of the variability of net generation is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.01671 which is closer to zero. If 95% confidence interval is considered, GDP per capita (p=0.027) and average billing rate (p=0.025) are significant as their probability are less than 0.05. But the coefficient of GDP per capita is negative which would indicate that decrease in GDP per capita is related to increase in net generation which quite contradictory to the regular economic understanding. So model 1 is not a suitable model for forecasting net generation.

Model 2:

Net Generation(t) = f (GDP(t), Year(t), Generation(t-1))

Table 5.17: Results of model 2 for net generation

Variable	Coefficient	Standard error	Probability
Ln(GDP)	-.0064699	.1011236	0.950
Ln(Year)	14.1024	12.48802	0.270
Ln(Generation(t-1))	.8767048	.0671669	0.000
Constant	-105.8769	93.53642	0.269
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0642		
Observations	27		
R squared	0.9990		
Adjusted R squared	0.9989		
Root MSE	0.02064		

From Table 5.17 it is found that model 1 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0642) as the p-value is higher than the usual threshold of 0.05 (95% significance). The R-squared is 0.9990, meaning that approximately 99.90% of the variability of net generation is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.89% of the variability of net generation is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.02064 which is closer to zero. If 95% confidence interval is considered, GDP per capita (p=0.950) is not significant as its probability is greater than 0.05. Again the coefficient of GDP per capita is negative which would indicate that decrease in GDP per capita is related to increase in net generation which quite contradictory to the regular economic understanding. So model 2 is also not a suitable model for forecasting net generation.

Model 3:

Net Generation(t) = f (GDP(t), Avg. billing rate(t), Generation(t-2))

Table 5.18: Results of model 3 for net generation

Variable	Coefficient	Standard error	Probability
Ln(GDP)	.1707728	.1160168	0.155
Ln(Avg. billing rate)	.0514479	.0786136	0.520
Ln(Generation(t-2))	.9283705	.041917	0.000
Constant	-.8998091	1.186241	0.456
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0536		
Observations	26		
R squared	0.9968		
Adjusted R squared	0.9964		
Root MSE	0.03501		

From Table 5.18 it is found that model 3 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0536) as the p-value is higher than the usual threshold of 0.05 (95% significance). The R-squared is 0.9968, meaning that approximately 99.68% of the variability of net generation is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.64% of the variability of net generation is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.03501 which is closer to zero. GDP per capita (p=0.155) and average billing rate (p=0.520) are not significant because the significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. So model 3 is also not a suitable model for forecasting net generation.

Model 4:

Net Generation(t) = f (GDP(t))

Table 5.19: Results of model 4 for net generation

Variable	Coefficient	Standard error	Probability
Ln(GDP)	5.036668	.686397	0.000
Constant	-39.92121	6.698655	0.000
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.0606		
Observations	28		
R squared	0.6744		
Adjusted R squared	0.6618		
Root MSE	0.38183		

From Table 5.19 it is found that model 4 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.0606). The R-squared is 0.6744, meaning that approximately 67.44% of the variability of net generation is accounted for by the variables in the model. The adjusted R-squared indicates that about 66.18% of the variability of net generation is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.38183 which is closer to zero. Again it is found that GDP per capita (p=0.000) is significant because the significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. So model 4 is a suitable model for forecasting net generation.

Model 5:

Net Generation(t) = f (GDP(t), Avg. billing rate(t), Generation(t-1))

Table 5.20: Results of model 5 for net generation

Variable	Coefficient	Standard error	Probability
Ln(GDP)	.0867845	.070333	0.230
Ln(Avg. billing rate)	.016289	.0419186	0.701
Ln(Generation(t-1))	.9589193	.0221682	0.000
Constant	-.4040164	.7021235	0.571
Model diagnostic:			
Ramsey RESET test	Prob > F = 0.1641		
Observations	27		
R squared	0.9990		
Adjusted R squared	0.9988		
Root MSE	0.02113		

From Table 5.20 it is found that model 5 does not have any omitted variable according to the value of Ramsey RESET test (Prob > F = 0.1641). The R-squared is 0.9990, meaning that approximately 99.90% of the variability of net generation is accounted for by the variables in the model. The adjusted R-squared indicates that about 99.88% of the variability of net generation is accounted for by the model; even after taking into account the number of predictor variables in the model. Root MSE is 0.02113 which is closer to zero. If 95% confidence interval is considered, GDP per capita (p=0.230) and average billing rate (p=0.701) are not significant as their probability are greater than 0.05. So model 5 is also not a suitable model for forecasting net generation.

Table 5.21: Comparison among the five models for net generation

	Model 1	Model 2	Model 3	Model 4	Model 5
Ramsey RESET test	0.0776	0.0642	0.0536	0.0606	0.1641
Probability of GDP	0.027	0.950	0.155	0.000	0.230
Probability of Avg. billing rate	0.025	---	0.520	---	0.701
Coefficient of GDP	-.2735745	-.0064699	.1707728	5.036668	.0867845
Coefficient of Avg. billing rate	.1546978	---	.0514479	---	.016289

A decision should be made about the suitable model by comparing the results of specification tests and the economic underpinning behind each model. The value of Ramsey RESET test reveals that the above 5 models don't have any omitted variables. The significance level of predictor variables is up to 0.05 if 95% confidence interval is considered. From Table 5.21 it is found that GDP per capita and average billing rate are not significant for model 3 and 5, but they are significant for model 1 in explaining net generation. It is also found that GDP per capita is not significant for model 2, but it is significant for model 4 in explaining net generation. In model 1, the coefficient of GDP per capita is negative which would indicate that decrease in GDP per capita is related to increase in net generation which quite contradictory to the regular economic understanding. So the left model 4 is considered the only suitable model for forecasting net generation. From this analysis, no superior model is found by considering average billing rate which proves that in Bangladesh demand of electricity is invariant of its price. Model 4 also considers generation inertia and both GDP per capita and generation inertia are found statistically significant. So the structure of the accepted GDP based model (model 4) is:

Net Generation(t) = f (GDP(t)) ………………..(5.2)

5.3 Electrical Energy Generation and Demand Forecast

5.3.1 Electricity demand forecast

The forecasted electricity demand is shown in figure 5.10. The black line represents the actual electricity demand from year 1981 to 2008 and the red line shows predicted electricity demand up to year 2020. Here the GDP based model (Equation no. 5.1) from statistical analysis is taken under consideration. The model represents electricity demand as a function of GDP per capita. Forecasted results are shown in tabular form in the Appendix A-4. From the simulation, forecasted electricity demand served in year 2020 will be 13,916 MW.

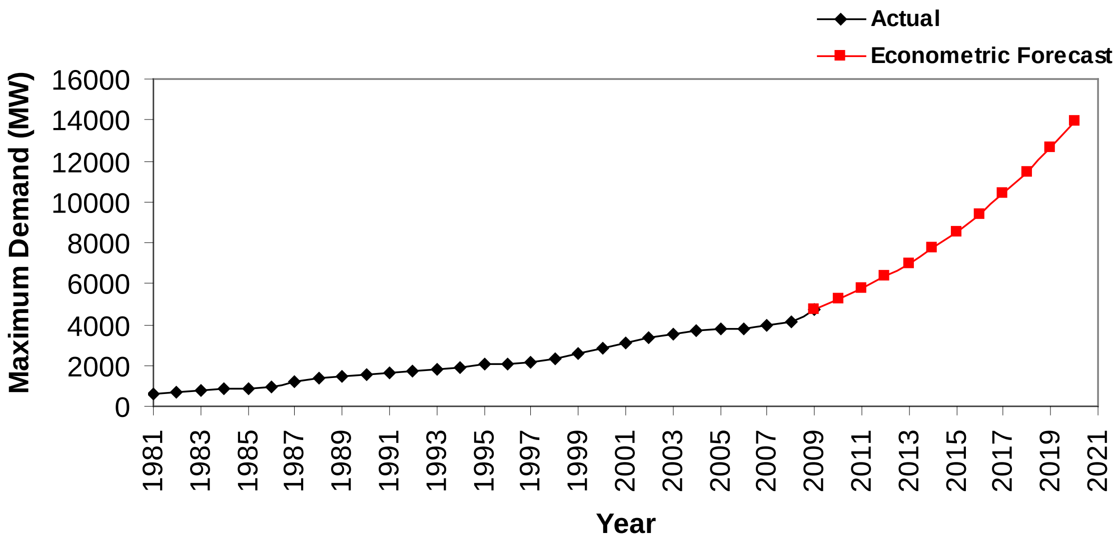

Figure 5.10: Econometric forecast of maximum demand

The figure 5.11 shows comparison between econometric forecast and time trend forecast of electricity demand. Here the black line represents the actual electricity demand from year 1981 to 2008, the red line shows econometric forecast of electricity demand up to year 2020 and the blue line shows time trend forecast of electricity demand up to year 2020. In time trend case, forecasted maximum demand in year 2020 is found to be 6,801 MW which is much less than the result obtained by econometric modeling. Analysis corresponds to this research shows that electricity demand will not follow the "low slope" trend of time trend analysis; because the electricity demand shows its strong dependence on per capita GDP.

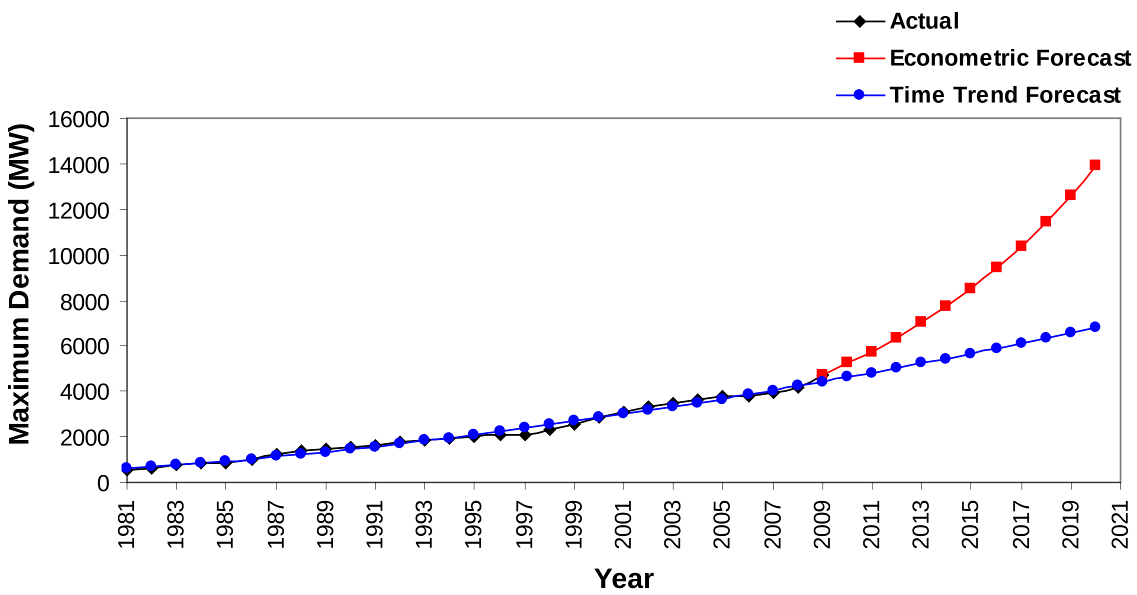

Figure 5.11: Comparison between econometric and time trend forecast of maximum demand

The figure 5.12 shows comparison between econometric forecast and PSMP-2005 base forecast of electricity demand. Here the black line represents the actual electricity demand from year 1981 to 2008, the red line shows econometric forecast of electricity demand up to year 2020 and the blue line shows PSMP-2005 base forecast of electricity demand.

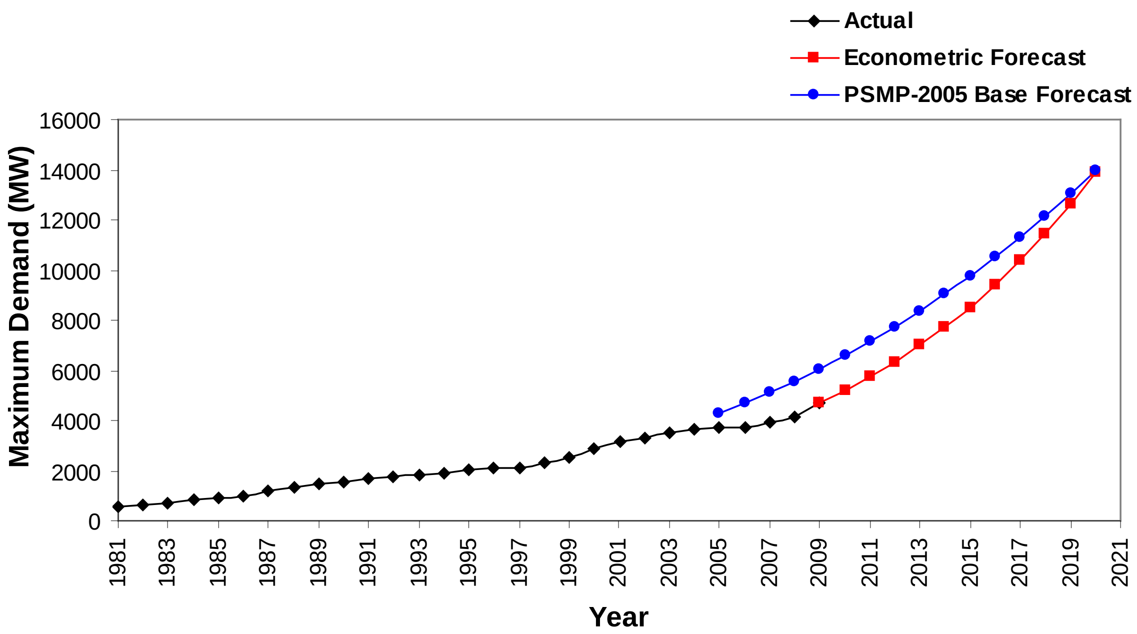

Figure 5.12: Comparison between econometric and PSMP-2005 base forecast of maximum demand

This analysis gives the maximum demand served and Power System Master Plan (PSMP)-2005 shows the net peak demands which are always higher than the demand served of this econometric modeling. But the forecasted net peak demand in year 2020 is found to be 13,993 MW in PSMP-2005 base forecast case which is nearby same as the result of econometric modeling.

5.3.2 Electrical energy generation forecast

The forecasted electrical energy generation is shown in figure 5.13. The black line represents the actual net energy generation from year 1981 to 2008 and the red line shows predicted net energy generation up to year 2020. Here the preferred model (Equation no. 5.2) from statistical analysis is taken under consideration. The model represents net energy generation as a function of GDP per capita. Forecasted results are shown in tabular form in the appendix A-4. From the simulation, forecasted net energy generation in year 2020 will be 102,017 GWh.

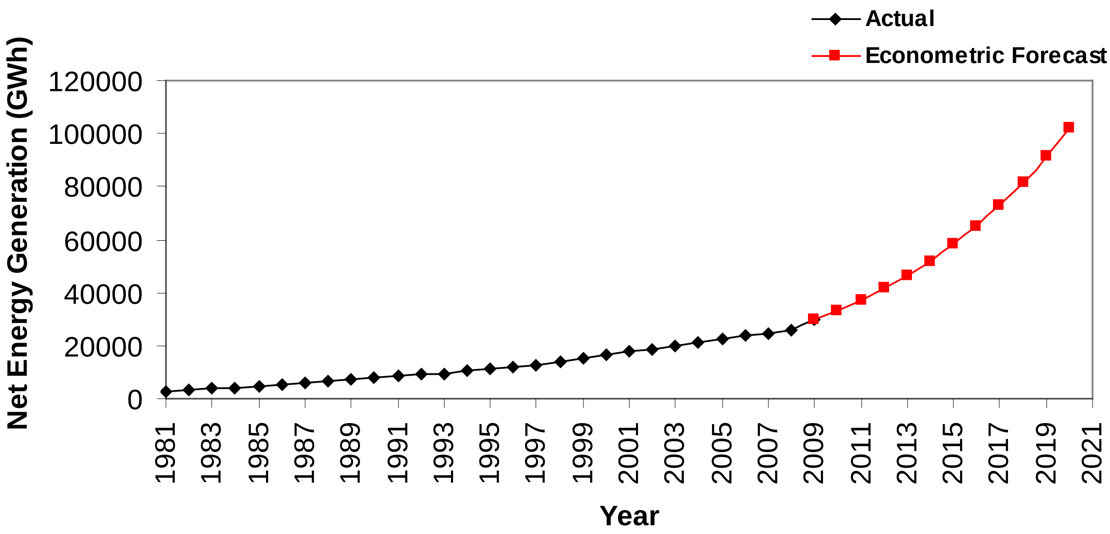

Figure 5.13: Econometric forecast of net energy generation

The figure 5.14 shows comparison between econometric forecast and time trend forecast of net generation. Here the black line represents net generation from year 1981 to 2008, the red line shows econometric forecast of net generation up to year 2020 and the blue line shows time trend forecast of net generation up to year 2020. In time trend case, forecasted net energy generation is found to be 46,193 GWh which is much less than the result obtained by econometric modeling. Analysis corresponds to this research shows that net energy generation will not follow the "low slope" trend of time trend analysis; because the net energy generation shows its strong dependence on per capita GDP.

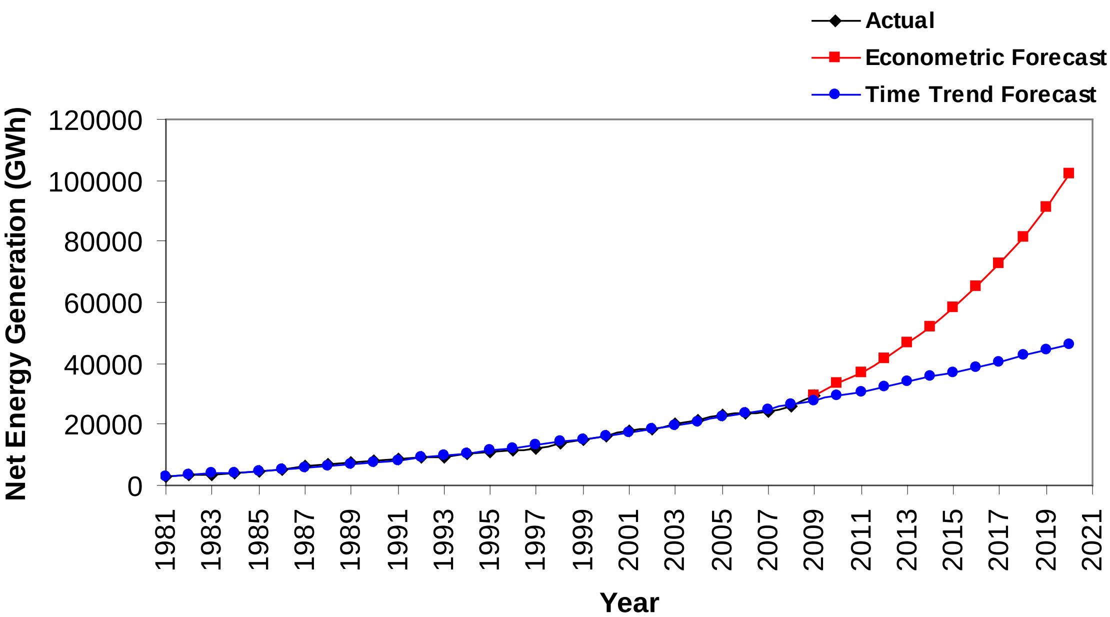

Figure 5.14: Comparison between econometric and time trend forecast of net energy generation

The figure 5.15 shows comparison between econometric forecast and PSMP-2005 base forecast of net generation. Here the black line represents net generation from year 1981 to 2008, the red line shows econometric forecast of net generation up to year 2020 and the blue line shows PSMP-2005 base forecast of net generation. In PSMP-2005 base forecast case, forecasted net generation is found to be 72,222 GWh which is less than result by econometric modeling.

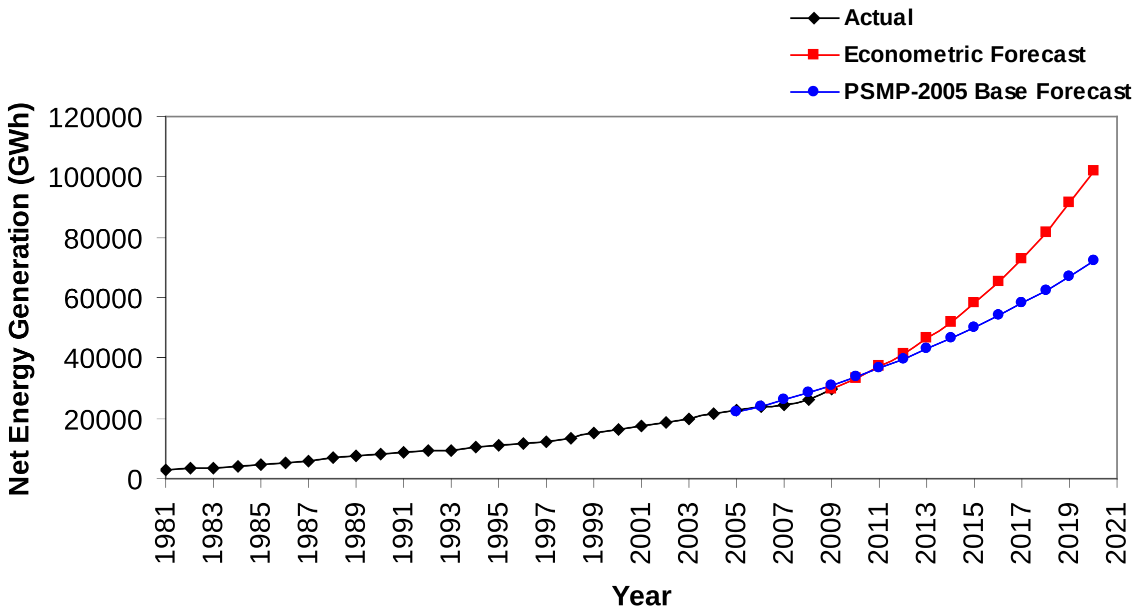

Figure 5.15: Comparison between econometric and PSMP-2005 base forecast of net energy generation

5.4 Conclusions

The results of the econometric models developed in this research have been presented in this chapter and based on the comparisons among the models; the GDP based econometric models have been accepted (Equation no. 5.1 and 5.2) for forecasting the electrical energy generation and demand served. Finally using the model obtained by this research, a forecast of electricity demand and net energy generation up to 2020 is made and compared with both trend analysis forecast and PSMP-2005 base forecast. From the forecast, it can be concluded that the electricity demand and generation are increasing rapidly with the advancement of time and these GDP based econometric models are more suitable for forecasting the electrical energy generation and demand served.

Chapter 6

CONCLUSION

6.0 General Conclusion

Based on the data of electrical energy generation and demand, econometric models are developed to estimate, analyze and forecast net energy generation and demand in Bangladesh. In modeling net electricity generation and demand, they are incorporated with GDP (Gross Domestic Product) per capita. The results are analyzed based on proper theoretical underpinning and model specification tests.

From this research it is evident that in Bangladesh electricity generation and demand are invariant of price and consumption cannot possibly be controlled by price management. So, to raise the price of electricity can perhaps be an effective measure in this regard as power sector is heavily subsidized in Bangladesh and international market price for electricity is higher than that of Bangladesh. Moreover, the electricity demand modeled and forecasted in the research is suppressed demand because the consumption data available were the consumption statistics of electricity consumers to whom electrical connection is provided. However the real scenario is, there are many entities (e.g. citizens, industries, various organizations etc.) available that are probably willing to pay for electricity but the government cannot provide electricity to them due to supply constraint. So the demand analysis performed is a perhaps a constrained demand analysis. Actual demand is not truly reflected in this research. And demand analysis is not expected to be fruitful until supply of electricity is substantially strengthened. If the supply side is strengthened, availability of electricity among the people, industries, various organizations etc. is increased and a competitive market for electricity is established, demand analysis might play a more effective role in the energy economics.

The problems faced in order to accomplish this research were mostly related to data. Unavailability of proper data was very troublesome. The available data suffered from their narrow range. Moderately long time series data were obtained after arduous efforts. Unavailability of sufficient literature related to the power sector of Bangladesh was another problem. Moreover, the existing analyses performed by the Government and non Government organizations are mostly focused towards their findings rather than the methodology that lead to such outcomes. Most of the forecasts and demand forecasts are vague about the procedures followed. Another important fact that must be taken into account is that the data provided by the concerned organizations are plagued by abnormalities. The socio-political condition, economic and energy policies might be the reason behind that. But the possibility of improper and careless acquisition and management of data by the authorities cannot possibly be ignored. However, the research continued facing these difficulties and is expected to continue in future with more efforts.

This dissertation is a rudimentary approach towards econometric modeling and does not necessarily be evaluated as a professional venture. The study was to be conducted facing the above difficulties. Some problems could be solved, some could not be solved. So, this research has some drawbacks indeed. The series of data available for the analysis were not sufficient to run more sophisticated econometric models. So analysis was confined to linear regression.

The need of electricity in Bangladesh can not be expressed in words; the effect of power in each and every growing sector of Bangladesh is undeniable. The economic goals of the country can not be achieved without flourishing the power sector of Bangladesh. At present, it is way over the time that we still locating the gaps and shortfalls on the power sector, now it is the time to act. A jam-packed plan needs to be implemented as soon as possible to make the power sector effective.

6.1 Recommendation for Further Research

It has already been mentioned that this research is not yet a professional enterprise. To refine the models and improve reliability of the models it is essential to exercise more sophisticated techniques. Based on the foundation this research has established, more advance modeling techniques will be applied in future to model electricity demand and generation in Bangladesh. For time series data, Co-integration is one of the most advanced modeling techniques. Vast literatures are found now-a-days on modeling energy demand by co-integration [31, 47-49]. Co-integration is essentially a variant of the time-series approach. This method attempts to overcome some of the limitations of the simple econometric forecasts where a growth rate is prescribed to the explanatory economic factors. The underlying concept here is that the overall pattern or relationship between any set of variables is likely to persist into the future as well. It is observed that some economic variables tend to behave in a similar fashion in the long run. That is to say that there is an implicit time-trend in the pattern of variables. In this model, a cause-and-effect relationship is established between variables and to make this relationship evidently strong a larger time series data of electricity consumption is required. This work has just opened the gate towards the long corridor of econometric analysis for Bangladesh Power System.

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APPENDIX A-1

Overview of Bangladesh power sector has been given below:

Owner & Regulator

- Power Division, Ministry of Power, Energy & Mineral Resources

Generation

- Bangladesh Power Development Board (BPDB)
- Ashuganj Power Station Company Ltd. (APSCL)
- Electricity Generation Company of Bangladesh Ltd. (EGCBL)
- North West Power Generation Company Ltd. (NWPGCL)
- Rural Power Company Ltd. (RPCL)
- Independent Power Producers (IPPs)

Transmission

- Power Grid Company of Bangladesh Ltd. (PGCB)

Distribution

- Bangladesh Power Development Board (BPDB)
- Dhaka Power Distribution Company Limited (DPDC)
- Dhaka Electric Supply Company Ltd. (DESCO)
- Rural Electrification Board (REB) through Rural Electric Co-operatives, Palli Biddyut Samities (PBS)
- West Zone Power Distribution Company Ltd. (WZPDCL)
- North West Zone Power Distribution Company Ltd. (NWZPDCL)
- South Zone Power Distribution Company Ltd. (SZPDCL)

APPENDIX A-2

Power Sector at a glance (As on June 2009)

Generation	
Installed Capacity	
(a) BPDB	3,812 MW
(b) IPP & Mixed Sector Total	1,907 MW
Total	**5,719 MW**
Maximum Demand Served	
Total	**4,162 MW**
Net Energy Generation	**26,604 MkWh**
Transmission	
Transmission Line	
230 kV	2,644.5 Ckt km
132 kV	5,684.6 Ckt km
Capacity of Grid S/S	
230/132 kV S/S	6,625 MVA
132/33 kV S/S	9,529 MVA
Distribution	
Distribution Line	
(33 kV, 11 kV & 0.4 kV)	2,83,494 km
Total no. of Consumers	11.25 Million
Total no. of Agricultural Consumers	2 Lac
Total no. of Village Electrified	51,136
Access to Electricity	47%
Per Capita Generation	182 kWh
System Loss (T&D)	16.85%

APPENDIX A-3

Data Used for Analysis

1. GDP

Year	GDP per capita at Current Price (BDT)	CPI (Base Year=2000)	GDP per capita at Constant Price (BDT)
1981	3755	24.00	15650
1982	4125	27.09	15229
1983	4692	29.67	15816
1984	5360	32.76	16364
1985	5942	36.19	16420
1986	6605	39.87	16568
1987	7243	44.18	16394
1988	7830	48.46	16159
1989	8571	52.69	16268
1990	9326	58.24	16014
1991	9945	63.06	15771
1992	10350	65.35	15839
1993	10778	67.29	16017
1994	11643	71.43	16300
1995	12623	78.66	16048
1996	13459	80.59	16701
1997	14479	84.58	17118
1998	15652	91.90	17032
1999	16701	97.58	17115
2000	17427	100.00	17427
2001	18381	101.91	18036
2002	19677	105.70	18617
2003	21363	111.36	19183
2004	23343	118.16	19755
2005	25680	126.48	20304
2006	28476	135.43	21027
2007	31931	147.77	21609
2008	35762	159.16	22468

APPENDIX A-3 (Contd…)

2. Maximum Demand and Net Generation

Year	Maximum Demand Served (MW)	Net Energy Generation (GWh)
1981	575	2849
1982	657	3235
1983	735	3699
1984	824	4247
1985	885	4664
1986	984	5194
1987	1201	6064
1988	1355	6828
1989	1451	7423
1990	1575	8001
1991	1656	8582
1992	1748	9050
1993	1849	9495
1994	1923	10295
1995	2029	11140
1996	2101	11666
1997	2125	12370
1998	2293	13666
1999	2557	15007
2000	2849	16292
2001	3125	17621
2002	3323	18700
2003	3510	20000
2004	3656	21413
2005	3751	22855
2006	3750	23721
2007	3924	24516
2008	4146	25948

APPENDIX A-4

Forecasted Results

1. Forecasted GDP

Year	GDP per capita at Current Price (BDT)	CPI (Base Year=2000)	GDP per capita at Constant Price (BDT)
2009	35920	167.92	21392
2010	38750	177.15	21874
2011	41802	186.90	22367
2012	45096	197.18	22871
2013	48648	208.02	23386
2014	52480	219.46	23913
2015	56614	231.53	24452
2016	61074	244.27	25003
2017	65886	257.70	25567
2018	71076	271.88	26143
2019	76675	286.83	26732
2020	82715	302.60	27334

APPENDIX A-4 (Contd…)

2. Forecasted Maximum Demand and Net Generation

Year	Maximum Demand Served (MW)	Net Energy Generation (GWh)
2009	4731	29677
2010	5219	33203
2011	5756	37147
2012	6350	41560
2013	7004	46497
2014	7726	52020
2015	8522	58200
2016	9400	65114
2017	10369	72849
2018	11437	81503
2019	12616	91184
2020	13916	102017