R

AN INTEGRATED ENERGY FORECASTING MODEL

BY

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A THESIS

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ABSTRACT

The advantages of auto-machanization has gradually become popular and essential for civilized life. Now every day a huge amount of energy is needed due to worldwide auto-machanization in different sectors. The deposit of primary sources of energy is limited, and if the present consumption rate of energy continues it will be depleted around the middle of the next century. A solution to meet the scarcity of fossil fuel is to spread use of nuclear energy, renewable energy such as solar, wind, tidal etc. Renewable and nuclear energy have some disadvantages and cannot be applicable for everywhere.

The present work aims at developing an energy model for predicting the future energy demand. The mathematical techniques used in this modelling is mainly statistical regression analysis. Regression analysis has been used to formulate prediction equations for various sectors of energy consumption. In this thesis, consumption model of total energy, electricity, gas and petroleum for Bangladesh is prepared on past performance. A more recent technique using artificial neural network has also been used for electrical energy forecasting. Artificial neural network approach realizes the relationship between the demand and

prediction variables by a learning rule based on gradient descent technique which minimizes the sum-squared error.

Prevention of pollution of environment should be given top priority and strong policy should be adopted to utilize our renewable energy to save imported petroleum. The effect of enviornmental issues in energy modelling and prospects of renewable energy is also discussed in this thesis.

A final goal is to creat more informed public demand and discussion on energy policy issue in general, and the energy demand projection in particular.

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CERTIFICATE OF APPROVAL

The thesis titled, "An Integrated Energy Forecasting Model" submitted by Md. Mahbubur Rahman, Roll no. M.Sc. 801353P of session 1988-89 has been accepted as satisfactory in partial fulfillment of the requiremet for the degree of M.Sc.Engineering in Electrical and Electronic Engineering.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Energy is a crucial resource for development. Its rate of consumption may be considered as a measure of the level of development achieved by a nation. Commercial energy plays a decisive role in industrialization, agricultural mechanization and urbanization, etc. A rough and ready parameter to measure the development is the per capita energy consumption which reflects the level of development and the kind of economic status of a country.

We are interested about the energy situation of Bangladesh. Bangladesh is a small country and its population is about 114 million having so density of population much higher than any other country of the world. For the proper development, emphasis should be given on energy sector and this requires an appropriate and efficient energy model. This purpose can be served by gathering information about consumption of energy in future. The forecast determines availability of resources and efficient ways to meet the requirement. A good model should also show the scope of substitution of costly and imported fuel with easily available and renewable energy.

The aim of this thesis was primarily to develop a part of the model and evaluate the amount of total energy consumtion of future years. Separately the amount of electricity, petroleum and gas consumption was also determined. The method used to forecast the above mentioned consumptions is based on the past information. It is assumed that energy consumers will continue to respond to change in energy prices to the same extent that they have done in the past and also it is assumed that the energy price will change in the same way as in the past. If there occur any sudden change in price as it happened in 1973 and 1989 this method may not work. Actually long term forecasts of energy consumption is not a practice due to these reasons [1].

1.2 ENERGY ECONOMY INTERACTION

An energy plan has different meaning for different contries. Some see it as an extension of the medium term national economic plan where a formal linkage is established between the energy sector and the economy at large. Energy plan is a long term perspective somewhat visionary in nature, drawing upon information available in existing economic forecast. Information about energy aspect is often difficult to generate. Its collection is time consuming and expensive because energy is a quantity which cannot be expressed in physical term such as tonnes and barrels or in heat (calorific) values such as joules and BTU. Energy represents a complex system within the even more complex socio-economic system where human activities are related to production, transformation, conversion and consumption of energy. As a part of the socio-economic system, the energy system is subject to continuous changes. Patterns and structure of energy demand undergo rapid changes partly as a result of market adjustments and partly due to technological changes. The process of replacing of traditional energy by commercial energy is of particular interest for developing countries in order to determine the level of demand for commercial energy. Price of energy often fluctuates reflecting varaiable nature of the energy system and external influences exhogenous to the system. Hence energy is not only physical and technological in nature but also have economic, social, political and environmental dimensions.

In most developing countries strategic and policy question of a particular energy sector cannot be answered independent of other subsectors. As a result role of integrated energy planning becomes important. Energy system modelling, particularly a large scale modelling is a last resort even for the planners of developed countries [1]. It happens that this last resort has not often been often needed by developing countries until the concept of integrated energy planning has become important.

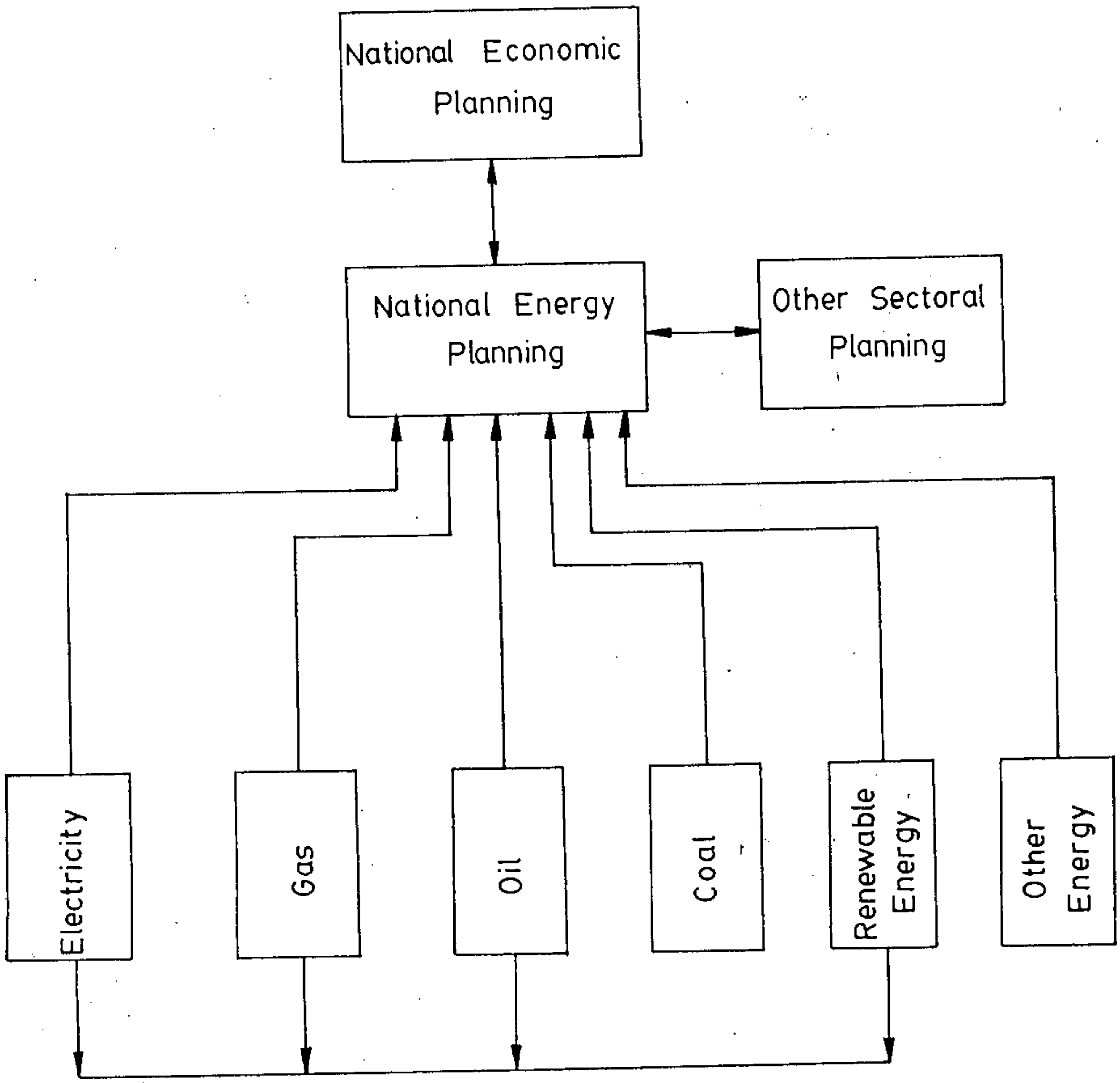


Figure 1.1: The energy economy interaction in Bangladesh can be illustrated by the following simple block diagram.

1.3 DESCRIPTION OF END USES OF ENERGY IN BANGLADESH

End uses relating to energy demands in Bangladesh can be classified into following sectors,

a. Transport sector,

b. Industry sector,

c. Agriculture sector,

d. Domestic sector and

e. Commercial sector

a. Transport sector

This sector includes passenger and freight transport. Each of these end uses can be devided down to several other subend uses such as railway, air, water public and private transports.

b. Industry sector

Several end uses can be identified in relation to industry sector,

1. Uses of electricity for machines,
2. Uses of energy in process heating,
3. Feedstock requirements of the fertilizer industry. This activity pertains largely to nitrogenous fertilizer

production. Coal, fuel oil, naphtha or natural gas can be used for the production of ammonia which is used as an intermediate material in the production of nitrogenous fertilizer.

4. End use activity covering electricity as a feedstock pertains largely to aluminium industry and to some extend to chemical industry.

c. **Agriculture sector**

There are two major activities for energy consumption in this sector and these are,

1. **Irrigation**: Pumps are mainly used for this purpose which lift water from different depths. Pumps may use both electricity or fossil fuels. Human energy is also used in this purpose in our country.

2. **Land preparation**: Tractors and animal power is used for this purpose.

d. **Domestic sector**

End use relating to domestic sector includes lighting, cooking, water heating, refrigeration, radio, TV and fans etc. The

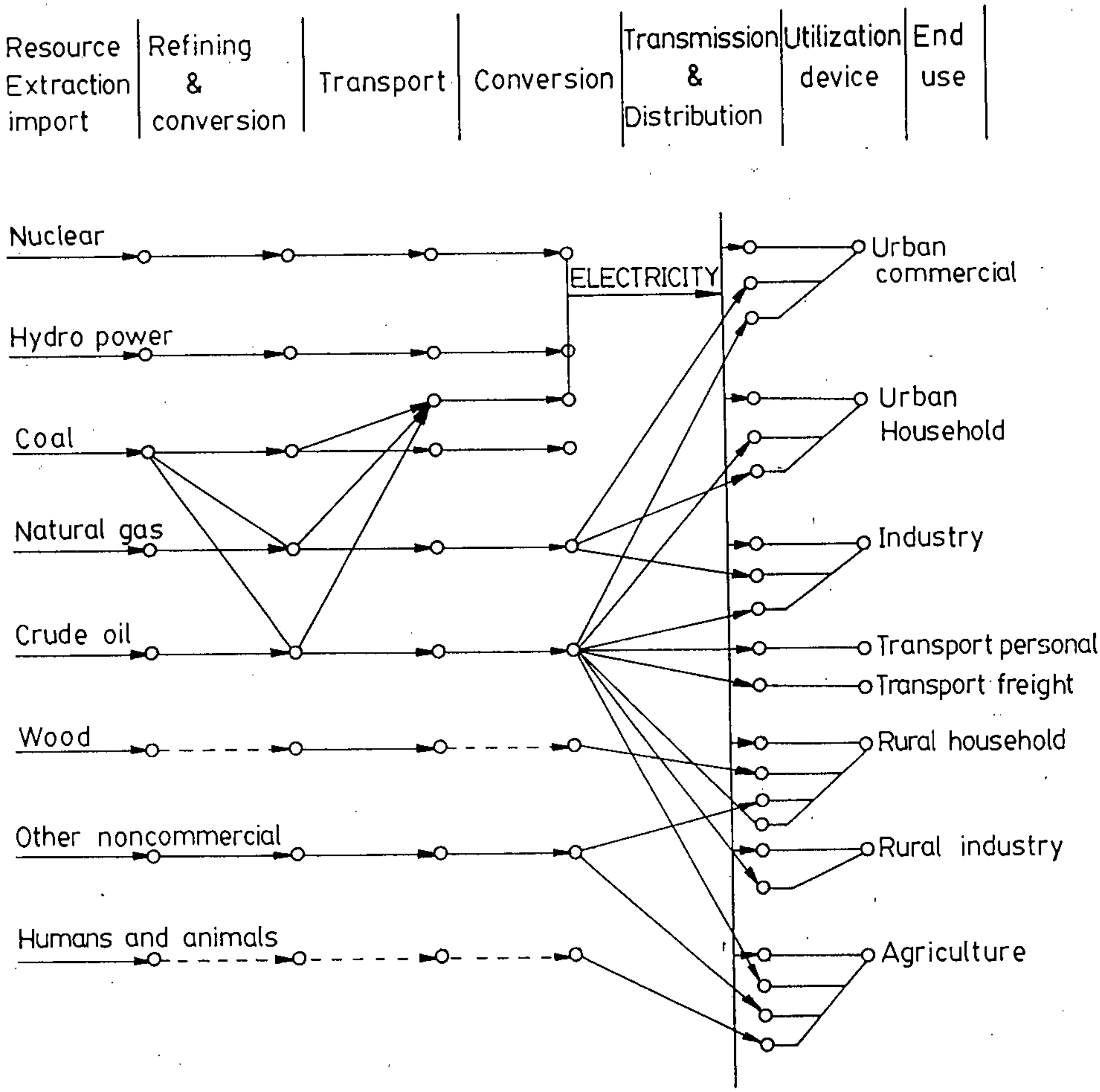


Figure 1.2 : Reference energy system of Bangladesh.

requirement of energy for each of these end use activities are related to population in economic classes. In rural and urban areas different types of energy is used for cooking, lighting, etc.

e. **Commercial sector**

End use in this sector includes lighting, heating fan, airconditioner, accelerator and elevators. In broad sense public waterworks and street lighting is also included in this sector.

1.4 PURPOSE OF ENERGY MODELLING IN DEVELOPING COUNTRIES LIKE BANGLADESH

The purpose of energy modelling in developing countries like Bangladesh [1,2] can be summerised as follows:

a. To meet the increased demand of energy at most economical cost and in most efficient way.

b. To reduce the use of imported fuel (oil) and to optimize the use of indigeneous energy resources keeping in view technical and economic consideration.

c. To remove the imbalances of energy demand and supply in rural and urban areas.

d. To consider short and long term projoet for proper management.

e. To consider environmental and atmospheric pollution in generation and consumption of energy.

f. To forecast future technical changes, population growth and subsequent requirement of energy considering industrial and agriculatural development.

g. To accelerate research on development of nonconventional energy technology.

h. To identify more appropriate, less energy intensive technologies.

i. To change towards less energy intensive life style.

j. To assess the impact of energy demand/supply changes on the rest of the system.

1.5 FACTORS TO BE CONSIDERED FOR ENERGY PLANNING

The importance of planning in energy sector as a whole arises from the fact that the future mix of energy sources to be used in Bangladesh would have to change substantially in keeping with our changing resource endowments. Also energy policy must be based on a qualification of changes in energy technologies whioh are applicable to both supply options and demand management strategies. Thus energy modelling has to be estimated within a large macroeconomic framework based on a qualitative analysis of future choice. Salient factors to be considered for modelling are discussed below,

a. Development/Discovery of energy resources

It is necessary to develop and discover indigenous renewable and nonrenewable energy resources depending on the characteristic of the resource itself such as location, quality, potential level of production, cost of investment, requirement and future demand, etc.

b. Decision in Energy investment

Some of the most concrete questions in energy planning are those dealing with potential investment in new refineries, new generation plants, pipeline etc. Analytical techniques must be able to compare diverse options. A well formulated national energy plan should provide the general framework to justify loans or assistance of various forms in all sector of energy system [3]. It should also lead to detailed justification for specific project investment.

c. **Energy Pricing Policy**

A large number of non energy and non economic factors must be considered when establishing energy prices. In this area even simple policy changes can have diverse and cascading effect. For example increasing the cost of fuel oil to industry can lead to greater use of wood which may or may not be desirable and which can have complex environmental consequence and effect on agricultural production.

d.**Energy Conservation Policy**

Increasing the overall efficiency of energy use is often the most direct and least expensive way of increasing ability of energy to a country. A unit of energy saved through conservation is a unit earned and available to the energy system.

e. **Strategy of research and development**

There are typical questions that must be addressed together in order to establish a national energy research and developmen policy. Question such as how much money should be invested in solar energy research and in the development of biomas conversio technologies in energy conservation techniques.

f. Substitution of fuel

Increases in imported oil, bill directs attention to the possibility of substituting lower cost fuels other than imported petroleum. Strategies of relevance depend on individual country situation and might include increased use of domestic or imported coal, substitution of electricity for liquid fuel, increased use of renewable energy forms such as wood or wind power. Evaluating these options requires a combined analysis of supply and the economics and technological of utilization for specific purposes.

g. Other sectoral policies

Energy decision are not made by energy institutions only. The decision of agricultural sectors encourage large scale machinery and irrigation based agriculture and has major energy implication. Certain industrial development strategies commit a country to long energy intensive future. This is by no means implicate that lower energy use is always favorable. But one of the important function of energy analysis is to enhance other sectoral decisions regarding the energy implication of alternative development strategies.

1.6 EVALUATION OF SYSTEM IN MATHEMATICAL MODEL BUILDING

For complete evaluation of a system the following elements must be considered,

1. Establishing criteria,
2. Creating mathematical model,
3. Establishing component characteristics,
4. Testing components,
5. Testing subsystem and
6. Evaluating the system from the mathematical model.

Once the objective of the system design has been established and suitable criteria for component test and optimization have been agreed, the description may be presented by mathematical means. If one describe the system by block diagram and mathematical equations performance may be predicted using well established methods for solution of equations.

In case that a straight forward analytical solution of equation is not practical numerical calculations by means of high speed computers can be undertaken. It is apparent that if the evaluation of a system is to be possible one must be able to describe the components of the system and their interrelation by means of mathematical equations. If one can do this, he has created a mathematical model of that system.

It is necessary to develop confidence in the use of mathematical model in the system evaluation. There is a tendency to feel that actual tests are better than modelling of the system. The impossibility of tests on very large scale and need for time compression for observing effect of all possible inputs to a system dictate use of models. There is a difference between evaluation of a system in this manner and simple tests. If the transfer function of all the elements of a system are known with a reasonable degree of accuracy; the overall performance can be predicted with confidence. In certain cases the performance of the component is critical and if it varies even a small amount from that indicated by its transfer function, instability in the system might arise. Moreover, such instabilities on critical points can be predicted ahead of time and extreme care should be taken in the evaluation [4] of particular components involved. If it be a portion of circuitry that is critical, a similar investigation will reveal its adequacy.

The model has an additional advantage in the evaluation of performacne that one can introduce unexpected infrequent or hazardous inputs and determine its effect on the whole. In general the model gives much better flexibility in evaluation than does the system itself.

1.7 SCOPE OF THE THESIS

In this thesis, attempt has been made to develop a mathmatical model for energy consumption. Statistical method of regression analysis is used in this study. Regression analysis is has been used to formulate prediction equation for various sector of energy consumption, such as electricity, gas, petroleum and others terms of energy. The actual data of different sectors from 1981-1992 has been taken and from linear regression, consumption projection was made for 1993-2000 AD.

A more recent technique using artificial neural network has also been used for electrical energy forecasting. Artificial neural network is inspired from the studies of biological nervous systems and composed of many simple nonlinear elements connected by variable links. The inherent parallelism of neural network enable then to capture the past trend of an event and make future prediction for best guess. In the present work, a neural network was trained and used to predict only the future electrical energy demand.

In particular the contents of this thesis have been organised as follows:

Chapter 1, gives a brief introduction with information about energy interaction, end used of energy, purpose of energy modelling, factor's considered for energy planning etc. Chapter 2, deals with statistical approach of curvefitting by linear regression.

In chapter 3, using linear regression method energy consumption of different sectors have been forecasted and also results and discussion are added here.

In chapter 4, Electrical energy has been forecasted by using a artifical neural network and in chapter 5, Environmental issues in energy modelling are discussed.

CHAPTER 2

STATISTICAL METHOD OF MODELLING

2.1 INTRODUCTION

This chapter describes in brief statistical method of regression analysis. Regression procedure constitutes the vital part of modelling process in this thesis. Regression analysis has been used to formulate prediction equation for various sectors of energy consumption in our study. This chapter deals with statistical approach of curve fitting by linear regression. The statistical measure for accuracy of the equation and prediction are also dealt with in brief. Some of the important procedures like "t" test and multiple regression with best selection procedures have been omitted in our study for limitation on data available in our energy consumption sectors.

2.2 STATISTICAL APPROACH

There are two meaning of the word "Statistics". As a plural Statistics refer to accumulation of data. The singular usage of the word statistics refer to application of mathematical laws of probability to analysis of samples of data so that statement made by them about the source from which the samples were taken can be set within definite bounds. Information about only a sample may not necessarily be true for the whole system. Statistics provides a mathematical basis for setting probability limits to statement made for the total system from a study of the sample.

2.2.1 **Need for Statistical Analysis**

In most of today's system there is no shortage of information. This applies no matter how small or how straight forward a process may be, measuring devices abound. Some of these readings are available at regular intervals others are observed continuously. Some readings can be measured directly, whereas, others are derived quantities.

In many systems we find huge accumulation of data and many of them are simply collected without any real purpose or reason in mind. In any system in which variable quantity change it is of interest to examine the effects that some variables exert on others. There may in fact be simple functional relationship between variables. In most physical processes this is an exception rather than a rule. Often there exists a functional relationship which is complicated to grasp or to describe in simple terms. In this case we may wish to approximate the true function over some limited ranges of variables involved. By examination of such graduating function we may be able to learn more about the underlyning true relationsip and to appreciate the separate and joint effect produced by changes in certain important variables.

Even where no sensible physical relationsip exists between variables, we may wish to relate them by some sort of mathematical equation. While the equation might be physically meaningless it may nevertheless be extemlly valuable for prediction of values of variables from knowledge of other variables, perhaps under certain stated restrictions.

In this effort of energy modelling, we shall use one particular method of obtaining a mathematical relationship, linear in unknown parameters. The unknown parameters are estimated under certain assumptions with the help of available data and a fitted equation is obtained. The value of fitted equation can be gauged and cheques can be made of the underlying assumption to see if any of these assumptions be erroneous.

2.2.2 Curve fitting by linear regression analysis based on least square method

In this section we will see how the method of analysis called least square error method can be used to examine data and to draw meaningful conclusion about dependency relationship that may exist. This mehtod of analysis is often called regression analysis.

Linear regression

We shall present the least square method in the context of the simplest application, fitting the best straight line in order to relate two variables X an Y for a given data and will dicuss how it can be extended to cases where more variables are involved.

Fitting a straight line

If we assume a regression line of variable Y on variable X has the form $Y=b_0+b_1X$, then we can write the linear first order model

$$Y=\beta_0+\beta_1X+\epsilon \qquad (2.1)$$

ϵ is the increment by which any individual Y may fall off the regression line. β_0 and β_1 are called the parameters of the model. We usually start with entertaining this assumed modeland examine it somewhere alongside the line and this assumption must have to be changed if we find at a later stage, that the facts are against β_0 and β_1. It is difficult to find `ϵ', since it changes with each observation but β_0 and β_1 are fixed and can be estimated from the data.

Let the estimated equation be $Y=b_o+b_1X$ (2.2)

and Y be the predicted value of Y for a given X

If we have n sets of observation

$Y_i=\beta_o+\beta_1X_i+\epsilon,$

then the sum of squares of deviation from true line is

$$s=\Sigma\ \epsilon^2=\Sigma(Y_i-\beta_o-\beta_1X_i)^2 \quad (2.3)$$

We can determine estimates β_o and β_1 by differentiating the equation with respect to parameters and equating them to zero.

$$\delta s/\delta\beta_o=-2\Sigma(Y_i-\beta_o-\beta_1X_i)=0$$

$$\delta s/\delta\beta_1=-2\Sigma\ X_i(Y_i-\beta_o-\beta_1X_i)=0$$

If we replace β_o and β_1 with b_o and b_1 respectively, we have the equation as

$$\Sigma\ (Y_i-b_o-b_1X_i)=0$$

$$\Sigma\ X_i(Y_i-b_o-b_1X_i)=0$$

or

$$nb_o+b_1\ \Sigma\ X_i=\ \Sigma\ Y_i$$

$$b_o\ \Sigma\ X_i+b_1\ \Sigma\ X_i^2=\ \Sigma\ X_iY_i$$

Solving we get

$$b_1=\frac{\Sigma\ X_iY_i-\dfrac{\Sigma\ X_i\ \Sigma\ Y_i}{n}}{\Sigma\ X_i^2-\dfrac{(\Sigma\ X_i)^2}{n}}$$

Again $nb_o+b_1\Sigma X_i=\Sigma Y_i$ gives

therefore

$$b_o=\frac{\Sigma Y_i}{n}-b_i\frac{\Sigma X_i}{n}=\bar{Y}-b_1\bar{X}$$

therefore $Y=\bar{Y}-b_1\bar{X}+b_1X=\bar{Y}+b_1(X-\bar{X})$

2.2.3 Precision of estimated equation

Let Y_i be the observed value of estimated value of $\hat{Y}_i$. Then $Y_i-\hat{Y}_i$ is the difference or error, which can be written as

$$Y_i-\hat{Y}_i=(Y_i-\bar{Y})-(\hat{Y}_i-\bar{Y})$$

Taking squares of the error and simplifying we have

$$(Y_i-\hat{Y}_i)^2=(Y_i-\bar{Y})^2+(\hat{Y}_i-\bar{Y})^2$$

Y_i-Y is the deviation of the ith observation from overall mean. It is the deviation of observation from mean shortened as sum of squares (SS) about the mean. $\hat{Y}_i-\bar{Y}$ is the deviation of the predicted value of ith observation from mean. So we can write,

SS about mean = SS about regression + SS due to regression

Actual observation do not all lie on the regression line. If they do the SS about regression would be equal to zero. From this we can find a way of assessing how useful the regression will be as predictor (i.e to see how much SS about mean has fallen into SS about regression and how much into the SS due to regression). We shall be happy to have SS due to regression greater than SS about regression.

Any sum of square (SS) has associated with it a number, called the degree of freedom of that SS. This number indicates how many indepnedent places of information involving the n independent numbers are needed to compile the sum of squares.

2.2.4 Examination of regression equation

Basic assumption to be made at this stage for the model are,

1. X_i is a random variable with mean zero and variance δ^2
2. Any variables X_i and X_j are not correlated
3. β is normally distributed random variable with mean zero and variance δ^2.

Standard Error of the scope b_1 and its confidence limit:

Variance of b_1 is

$$V(b_1) = \frac{\delta^2}{(X-\bar{X})^2}$$

estimated standard error of b_1 is

$$se(b_1) = \frac{\delta}{(\Sigma(X_i-\bar{X})^2)^{1/2}}$$

confidence limit for b_1 is given by

$b_1 \pm t \times se(b_1)$

where `t' indicates the distribution point with appropriate degree of freedom.

Standard Error of the Intercept and its confidence level:

Standard Error for b_o is

$$se(b_o)=\{\frac{X^2{}_i}{n(X_i-X)^2}\}^{\frac{1}{2}}\sigma$$

Then 100(1-α) percent confidence level for β_o is given by

$$b_o \pm t\ (n-2,1-\sigma/2)=\left[\frac{X_i{}^2}{n(X_i-\bar{X})^2}\right]^{\frac{1}{2}}\sigma$$

Standard Error for $\hat{Y}$(estimated Y):

$Y=Y+b_1(X-\bar{X})$

Therefore varience of the $\hat{Y}$ for particular Y at k is

$V(Y_k)=V(Y_o)+(X_k-X)V(b_i)$

$$=\frac{\sigma^2}{n}+\frac{(X_k-\bar{X})^2}{(X_i-\bar{X})^2}$$

Estimated standard error of Y_k is

$$\text{est se}(Y_k) = s\left[\frac{1}{n} + \frac{(X_k-\bar{X})^2}{(X_i-\bar{X})^2}\right]^{\frac{1}{2}}$$

Tests

There are various tests for significance of regression and they are subject to samples obeying certain distribution, specially the normal distribution. Among the tests, the following are widely used in regression analysis,

1. Chi square test
2. F-test

Since our data is less then 30 for each variables in regression, they are is not predictable for validity for normal distribution. Hence this study omit this important test procedure in most part of the modelling process except some few exception.

Correlation between X and Y

When we fit a postulated straight line model, we are tentatively entertaining the idea that Y can be expressed apart from error as first order function of X. In such relationship X is usually assumed to be fixed while Y is a random variable subject to error.

If X and Y are both random variables following some unknown distribution then we can define correlation coefficient between X and Y as,

$$P_{xy} = \frac{\text{cov}\ (X,Y)}{[\ V(Y)\ V(X)\ ]^{1/2}}$$

If f(X,Y) be continuous joint probabilty distribution of X and Y then the covarience is given by

$$COV(X,Y)=\int_{-\alpha}^{\alpha}\int_{-\alpha}^{\alpha}(Y-E(Y))(X-E(X))f(X,Y)dxdy,$$

$-1 \leq P_{xy} \leq +1$

and P_{xy} is a measure of the association between the random variables X and Y,

If $P_{xy}=1$, X and Y are perfectly positively correlated

If $P_{xy}=-1$, X and Y are perfectly negatively correlated

If $P_{xy}= 0$,X and Y are said to be uncorrelated

2.3 MATRIX APPROACH TO LINEAR REGRESSION EQUATION

Sometimes it may appear that the regression analysis becomes simpler in form, when solved with the help of matrices. A brief outline of this matrix approach to linear regression will be treated at this stage and its application to multiple regression will be evident when we discuss it.

2.3.1 Straight line regression with matrices

We have from our previous discussion for sum of squares to be minimum in least square technique,

$$b_o n + b_1 \Sigma X = \Sigma Y$$
$$b_o \Sigma X + b_1 \Sigma X^2 = \Sigma XY$$

which can be written in matrix form as

$$[b_o \ \ b] \begin{bmatrix} n & \Sigma X \\ \Sigma X & \Sigma X \end{bmatrix} = \begin{bmatrix} \Sigma Y & \\ \Sigma X & Y \end{bmatrix}$$

If we consider a matrix $\mathbf{X} = \begin{bmatrix} 1 & X_1 \\ 1 & X_2 \\ . & . \\ . & . \\ 1 & X_n \end{bmatrix}$

containing n observation of X and dummy variable $X_o = 1.00$

and matrix $\mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ . \\ . \\ Y_n \end{bmatrix}$

And X^t and Y^t be the transpose matrices of **X** and **Y** respectively then,

$$X^tX = \begin{bmatrix} n & \Sigma X_i \\ \Sigma X_i & \Sigma X_i \end{bmatrix}$$

$$X^tY = \begin{bmatrix} \Sigma Y \\ \Sigma XY \end{bmatrix}$$

so that $BX^tX = X^tY$ where $B=[b_o \; b_1]$.

Solution of above matrix equation gives the coefficient matrix B as

$$B=(X^tX)^{-1}(X^tY)$$

where $(X^t X)^{-1}$ is the inverse matrix of $(X^t X)$

2.4 MULTIPLE REGRESSION BY MATRICS

We shall consider first order multiple regression analysis for two independent variables and its extension to multiple variables by induction method.

$$Y=\beta_o+\beta_1X_1+\beta_2X_2+\epsilon$$

for convenience we shall write the equation as

$$Y=\beta_oX_o+\beta_1X_1+\beta_2X_2+\epsilon$$

where X_o is the dummy variable having value equal to one.The situation is the same as in straight line regression with one variable. For the sum of squares to be minimum we have following equations,

$\beta_o n+\beta_1\Sigma X_{1i}+\beta_2\Sigma X_{2i}=\Sigma Y_i$

$\beta_o\Sigma X_{1i}+\beta_1\Sigma X^2{}_{1i}+\beta_2\Sigma X_{1i}X_{2i}=\Sigma X_{1i}Y_i$

$\beta_o\Sigma X_{2i}+\beta_1\Sigma X_{2i}X_{1i}+\beta_2\Sigma X_{2i}{}^2=\Sigma X_{2i}Y_i$

which can be written as

$$\begin{bmatrix} n & \Sigma X_{1i} & \Sigma X_{2i} \\ \Sigma X_{1i} & \Sigma X^2{}_{1i} & \Sigma X_{1i}X_{2i} \\ \Sigma X_{2i} & \Sigma X_{2i}X_{1i} & \Sigma X^2{}_{2i} \end{bmatrix} \begin{bmatrix} \beta_o \\ \beta_1 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} \Sigma Y_i \\ \Sigma X_{1i}Y_i \\ \Sigma X_{2i}Y_i \end{bmatrix}$$

Similarly for n independant variables,

$Y=\beta_o+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots\ldots+\beta_mX_m+\epsilon$

we have to differentiate the equation $S=\Sigma(Y_i-\beta_o-\beta_1X_{1i}-\beta_2X_{2i}\ldots-\beta_m X_{mi})^2$ with respect to $\beta_o,\beta_1,\beta_2\ldots$ etc. The results give the following equations:

$(\delta S/\delta\beta_o)=-2\Sigma(Y-\beta_o-\beta_1X_{1i}-\beta_2X_{2i}-\beta_3X_{3i}\ldots\ldots\ldots-\beta_{mi}X_{mi})=0$

$(\delta S/\delta\beta_1)=-2\Sigma X_{1i}(Y-\beta_o-\beta_1X_{1i}-\beta_2X_{2i}-\beta_3X_{3i}\ldots\ldots-\beta_mX_{mi})=0$

$(\delta S/\delta\beta_m)=-2\Sigma X_{mi}(Y-\beta_o-\beta_1X_{1i}-\beta_2X_{2i}-\beta_3X_{3i}\ldots\ldots-\beta_{mi}X_{mi})=0$

or

$n\beta_o+\beta_1\Sigma X_{1i}+\beta_2\Sigma X_{2i}+\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+\beta_m\Sigma X_{mi}=\Sigma Y_i$

$\beta_o\Sigma X_{1i}+\beta_1\Sigma X_{1i}{}^2+\beta_2\Sigma X_{1i}X_{2i}+\ldots\ldots\ldots\ldots+\beta_m\Sigma X_{1i}X_{mi}=\Sigma X_{1i}Y_i$

$\beta_o\Sigma X_{mi}+\beta_1\Sigma X_{1i}X_{mi}+\ldots\ldots\ldots\ldots\ldots\ldots\ldots+\beta_{mi}\Sigma X_{mi}=\Sigma X_{mi}Y_i$

In matrix form:

$$\begin{bmatrix} n & \Sigma X_{1i} & \Sigma X_{2i} & \Sigma X_{mi} \\ \Sigma X_{1i} & \Sigma X_{1i}^2 & \Sigma X_{2i}X_{1i} & \Sigma X_{mi}X_{1i} \\ \Sigma X_{2i} & \Sigma X_{1i}X_{2i} & \Sigma X^2_{2i} & \Sigma X_{mi}X_{2i} \\ \Sigma X_{mi} & \Sigma X_{1i}X_{mi} & \Sigma X_{2i}X_{mi} & \Sigma X^2_{mi} \end{bmatrix} \begin{bmatrix} \beta_o \\ \beta_1 \\ \beta_2 \\ \beta_m \end{bmatrix} = \begin{bmatrix} \Sigma Y \\ \Sigma X_{1i}Y_i \\ \Sigma X_{2i}Y_i \\ \Sigma X_{mi}Y_i \end{bmatrix}$$

Finally solving the matrix equation for b_o b_1 b_2. b_n we can find estimates of β_o β_1 $\beta_2 \ldots$ β_n etc.

Conclusion

In this chapter, theoretical aspect of multiple linear regression analysis and its use as statistical model for prediction purpose is presented. In devising an energy model, the prediction variable Y can be used as energy to be predicted and the dependent variables X_1, $X_2, \ldots,$ X_n can be used as the factors that determine and significantly influence the energy Y. Depending the type of energy o be predicted, the number of dependent variables will vary. In the following chapter, energy forcasting for different types of energy has been modelled based on the multtiple linear regression analysis discussed in this chapter.

CHAPTER 3

ENERGY MODELLING

3.1 INTRODUCTION

This chapter describes the method by which energy demands are currently projected in the modelling framework. An attempt has been made to base these projection on statistically valid relationship with underlying explanatory variables consistant with the hypothesis that energy demands are derived from other economic wants and activities. Where ever possible, energy price have been included in the estimated relationship along with the levels of economic activities. All equations were estimated by ordinary least square without further correction or refinement. This chapter also describes in more detail how the projection equation are combined with variety of other assumption in order to develop a projection of total energy demands. The first step in projecting energy demands in this framework is the development of assumptions made on various variables used in different sectoral models.

In this thesis projection equations variables are projected seperately and are used in the regression analysis. Variables change, off the mark may upset the projection equation all together which is not impossible in this case. This may occur because some factors governed by economy of the country and by world economy are totally unpredictable. Moreover, change in variables which have been taken into consideration are not liable to change indefinitely. They are bound to stop changing at certain limit according to economic laws. Some of the basic assumptions we have made in our study are energy cost assumption, gross national product, population, transport, etc.

In projection methodology, we have a total energy demand model and three sectoral demand model. These are

- Electricity consumption model
- Gas consumption model
- Petroleum consumption model

Results of each regression is given in two parts. First part deals with the projection results (equation) and the next part discusses the various aspects of the projection results together with future demand projection.

3.2 ElECTRICITY CONSUMPTION MODEL

3.2.1 Introduction to Electricity Consumption Model

Todays world community perhaps cannot think of continuing without electricity which is delevered at the consumer's end often through an integrated electric networks system. Also it is the most convenient form of energy and its abundant supply is essential for sustainable socio-economic development of any country. In Bangladesh total installed capacity at present of 2608 MW compared to 7 MW in 1947 may appear significant. But present per capita generation of 81 kwh is still among the lowest in the world. Only 14% of the population have excess to the electricity and load is experted to grow at the rate of 10 percent or more per year [5]. In this chapter considering past trend of electic consumption, future consumption of electricity from the year 1993-2000 has been projected.

3.2.2 Consumption Modelling

Future projection for electricity demand growth rate are difficult to make with certainity. Such projection are affected by uncertainities in demographic, economic, social, political and technological changes. Planners and economist usually try to incorporate electricity consumption model with population and GNP growth rate as done in Scheer´s formula for prediction of annual growth rate of electricity conumption. But these efforts assume that electricity consumption is not dependent on the past trend, which however, is not a correct assumption. We have taken the past trend of electricity consumption. In this study we have taken the past trend of electricity consumption and its control variables into account. The equation is in linear form. It takes into consideration population, per capita electricity consumption, number of villages electrified and distribution line length etc. The equation, its control variables and the results are given below:

X1=dummy variable=1.00

X2=population in 10^7

X3=per capita electricity consumption in KWH

X4=number of consumers in 10^5

X5=number of villages electrified in hundred

X6=length of distribution line in thousand KM.

Y =electricity consumption in 10^8 KWH

The equation is

$$Y=6.161X_1-0.291X_2+1.221X_3+0.489X_4-0.0382X_5+0.105X_6$$

3.2.3 Discussion on Electricity Consumption Model

In 1992 electricity consumption shown in data is 60.21×10^8 KWH which would increses to 91.85×10^8 KWH accoring to our projection. But actual demand may not be same because development in electricity mostly depend on foreign aid. If sufficient foreign aid is available and generation increased to 6000 MW, and sufficient transmission and distribution lines are constructed with installation of sufficient substations then electricy consumption will be much higher than the rate now. Table 3-2 shows the load shedding condition of our country from 1984 to 1992. That picture shows that the demand is higher but due to inadequate generation and distribution system, sufficient supply of electricity to the consumer end is not possible. In this situation demand projection has been made which may be called suppressed demand projection. This is the limtations of this projection. Again Table 3.1 shows the system [6] loss picture in electricity sector. The variable x_2, per capita electricity consumption is calculated as total electrical energy sales divided by total population. But the system loss is not included in energy sales. Large portion of the system loss is pilferage and it is consumed by the consumers. So this variable limits the demand projection also. This demand projection may be correct for city areas or divisional towns. For rural areas demand of electricity exists but availability limits its use. Major change in policy such as intensified rural electrification may change the total scenerio altogether.

Table 3.1

System Loss

Year	(%) System Loss
1980-81	34.65
1981-82	33.20
1982-83	30.13
1983-84	31.84
1984-85	37.27
1985-86	31.11
1986-87	37.62
1987-88	42.33
1988-89	34.01
1989-90	39.14
1990-91	41.11
1991-92	41.33
1992-93	36.29

Table-3.2

Load Shedding in the Past Years

Year	Number of Days	Maximum (MW)
1984	-	250
1985	-	180
1986	337	300
1987	-	300
1988	-	20
1989	-	120
1990	49	160
1991	133	340
1992	241	550
1993	264	480

TABLE: 3.3

TABLE FOR ELECTRICITY CONSUMPTION MODEL

YEAR	X2	X3	X4	X5	X6	Y
1981	89.90	19.35	5.79	7.06	24.41	17.40
1982	92.10	22.02	6.73	8.31	29.45	20.28
1983	94.30	25.44	7.73	11.79	33.83	23.99
1984	96.50	28.02	7.28	8.78	37.55	27.04
1985	98.70	28.80	9.57	7.32	42.78	28.41
1986	100.80	32.81	10.86	9.45	46.21	33.07
1987	103.10	33.80	12.33	16.11	50.15	34.85
1988	105.30	35.83	13.71	14.68	57.53	37.72
1989	107.60	43.63	15.58	14.43	63.26	46.94
1990	110.00	42.77	16.70	13.85	69.92	47.05
1991	111.50	43.68	18.34	13.82	79.04	48.71
1992	113.60	53.04	20.04	9.33	83.46	60.21

TABLE: 3.4

ELECTRICAL ENERGY CONSUMPTION PROJECTION FROM YEAR 1993-2000

YEAR	X2	X3	X4	X5	X6	Y
1993	116.1045	51.9848	20.6766	14.5617	86.1302	64.459076
1994	118.2822	54.7365	22.0030	15.0721	91.4631	68.372676
1995	120.4598	57.4881	23.3293	15.5824	96.7961	72.286276
1996	122.6374	60.2398	24.6556	16.0928	102.1291	76.199876
1997	124.8150	62.9914	25.9820	16.6032	107.4620	80.113475
1998	126.9927	65.7431	27.3083	17.1136	112.7950	84.027075
1999	129.1703	68.4947	28.6346	17.6240	118.1280	87.940675
2000	131.3479	71.2464	29.9609	18.1344	123.4610	91.854275

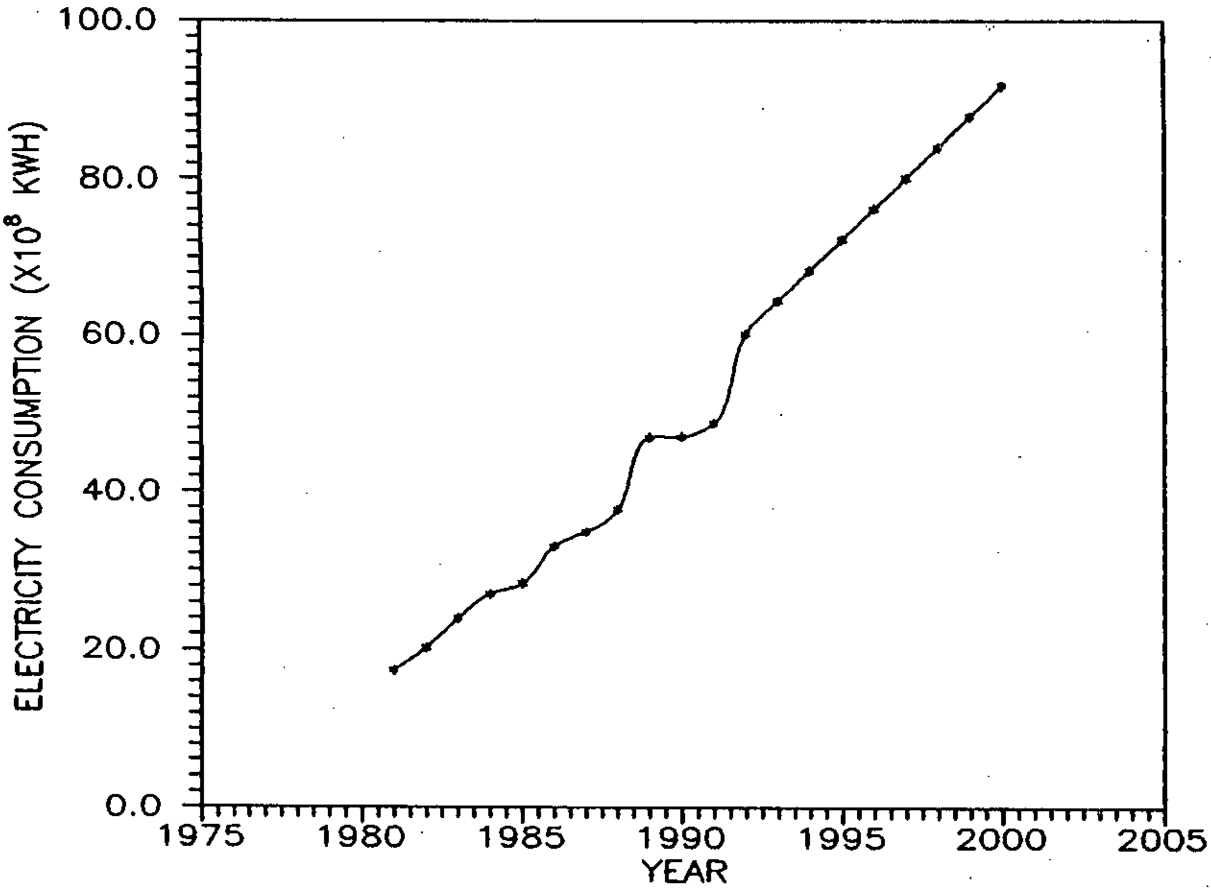


FIGURE 3.1 Electricity Consumption Projection from year 1993–2000 (Linear model)

3.2.4 Remarks

Accurate and reliable forecast of electricity consumption is necessary for future expansion of whole generation transmission and distribution of electricity. Otherwise the past trend of expansion of system without knowledge into its future would be wastage of national resources in this sector.

3.3 GAS CONSUMPTION MODEL

3.3.1 Introduction to Gas Consumption Model

The history of the use of natural gas as a source of energy and feed stock in Bangladesh dates back to early 60's. Natural Gas plays a dominant and critical role in the socio-economic development of Bangladesh. It constitute major source of industrial and agricultural energy of the country and hence maintain the balance of payment by reducing the import bill for oil, coal and supply fertilizer. Until 1970, electricity was the main energy consumption in industries and domestic sector. But now natural gas has emerged as a good competitor of electricity. Gas has already occupied a great portion of electrical energy market and electricity generation itself is now greatly dependent on gas.

Category wise gas consumption in different sector are as follows,

a) Power sector - 58.9%

b) Fertilizer - 26.3%

c) Industrial - 5.9%

d) Commercial - 1.9%

e) Domestic - 7.2%

Gas consumption has been projected upto year 1993-2000 A.D. following past trend of consumption.

3.3.2 Consumption Modelling

Simple linear equation has been formulated for gas demand for a certain period. Consideration was given to relate gas demand projection with per capita income, per capita energy consumption, average gas price, length of transmission line etc. Gas used for production of fertilizer constitute a vital control variable in projection of gas demand. But in our projection gas for fertilizer production has been accounted in total gas consumption and no separate model for non energy use been tried. The variables together with projection equation is given below,

X1=dummy variable=1.00

X2=per capita energy consumption in 10^5 BTUs

X3=growth rate of gas consumption

X4=average gas price in taka per thousand cuft.

X5=per capita income in hundred taka

X6=length of transmission line in hundred kilometer

Y =total gas consumption in 10^{10} cuft.

The equation is

$$Y=-6.7430X_1+0.0419X_2+4.6891X_3+0.0288X_4-0.0556X_5+0.5906X_6$$

3.3.3 Discussions on Gas Consumption Model

Out of total gas consumption 58.9% is consumed in power sector and 26.3% is consumed in fertilizer sector [6]. Gas consumption in power and fertilizer sector can be considered as two variables that would determine gas consumption in future. In 1992 Gas consumption was 17.85×10^{10} cuft, and this will increase to 27.66×10^{10} cuft by year 2000 according to this research. But actual consumption may not be the same shown in 2000 AD. With commissioning of Jamuna bridge by 1997 and North Bengal will come under gas supply and extra two or three new fertilizer factories and power stations will need gas supply. As a result gas consumption will increase drastically after 1997 and projection results will be valid due to changed situation. Proven reserve of gas in Bangladesh will start diminishing at the beginning of 1997 and increased demand can only be met from other estimated probable resereves. Due to insufficient distribution line actual consumption can not be met. These are limitations of this study.

Gas price in different sectors are different. At present following are the gas prices prevailing in our country,

a) Power and fertilizer

b) Industrial

c) Seasonal brick field

d) Commercial

e) domestic

We have however, considered an average gas price for our projected purpose, which, however, limits the accuracy of our model.

3.3.4 **Remarks**

An accurate gas consumption projection is needed for our country to reduce import burden on oil. For optimum utilization of natural gas we need an appropriate tarrif system for conservation and economic use of natural gas.

TABLE: 3.5

TABLE FOR GAS CONSUMPTION MODEL

YEAR	X2	X3	X4	X5	X6	Y
1981	10.96	0.12	22.56	31.56	19.76	4.95
1982	12.10	0.22	26.10	33.03	21.63	6.37
1983	11.71	0.09	30.70	33.67	23.24	7.01
1984	11.55	0.13	35.94	35.05	24.60	8.03
1985	12.17	0.12	43.78	36.93	26.59	9.10
1986	13.32	0.10	51.96	37.66	28.16	10.11
1987	14.15	0.15	53.87	39.45	30.15	11.90
1988	12.84	0.15	66.48	40.07	33.66	14.08
1989	16.13	0.04	69.50	40.09	35.30	14.63
1990	17.32	0.08	79.95	41.51	36.37	15.91
1991	16.27	0.04	87.84	42.30	37.70	16.50
1992	16.19	0.08	93.89	43.33	39.26	17.85

TABLE:3.6

TOTAL GAS CONSUMPTION PROJECTION FROM YEAR 1993-2000

YEAR	X2	X3	X4	X5	X6	Y
1993	17.3638	0.0521	98.9153	44.8009	41.6971	19.212159
1994	17.9235	0.0433	105.6386	45.8645	43.5423	20.418637
1995	18.4832	0.0345	112.3618	46.9281	45.3875	21.625114
1996	19.0428	0.0257	119.0851	47.9917	47.2327	22.831591
1997	19.6025	0.0169	125.8083	49.0553	49.0779	24.038068
1998	20.1622	0.0081	132.5316	50.1189	50.9231	25.244546
1999	20.7219	-0.0007	139.2548	51.1825	52.7683	26.451023
2000	21.2816	-0.0095	145.9781	52.2461	54.6135	27.657500

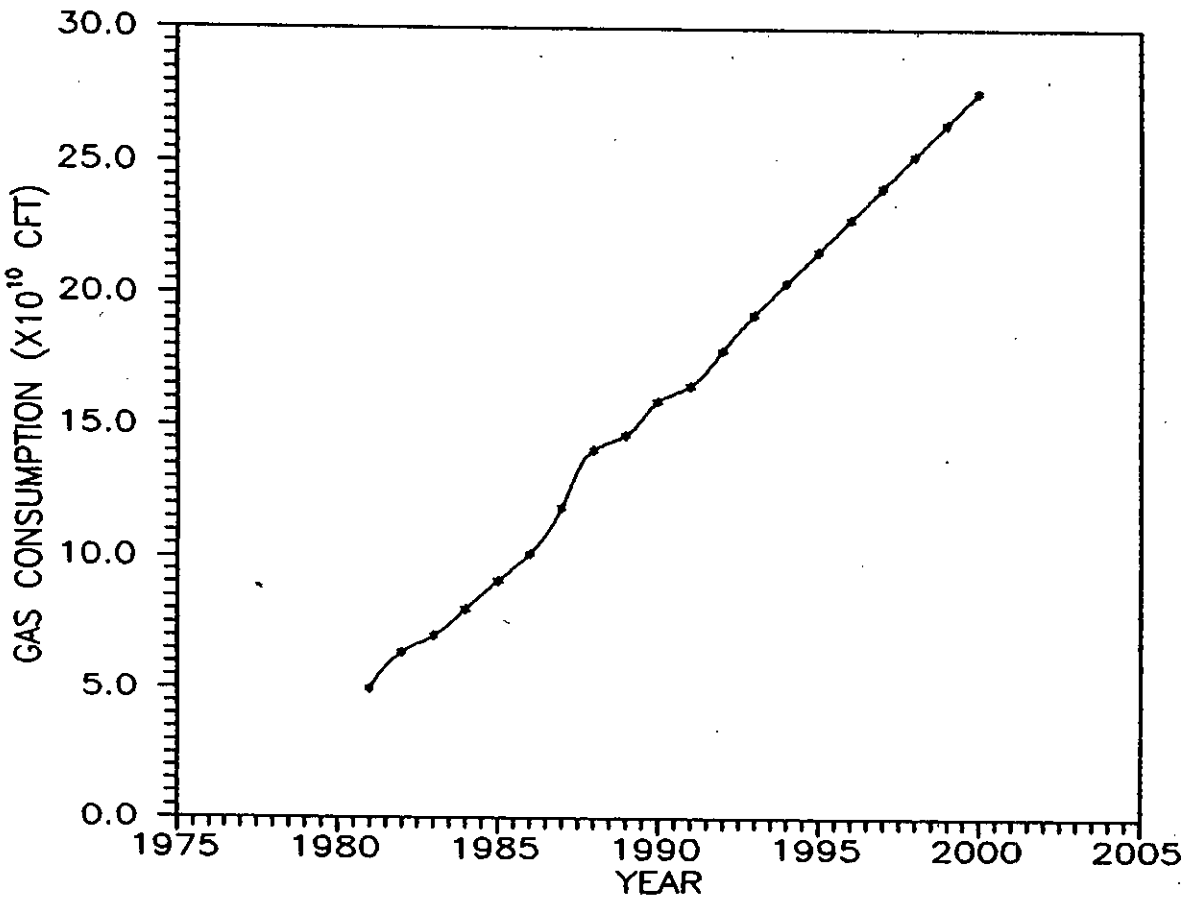


FIGURE 3.2 Gas Consumption Projection from year 1981–2000 (Linear model)

3.4 PETROLIUM CONSUMPTION MODEL

3.4.1 Introduction to Petroleum Consumption Model

Consumption of petroleum is one of the yard stick of the economic activity of a country. It provides a driving forcc in the economic infrastructure and growth of GDP of the country. Annual demand of petroleum products in the country are monitored and planned, considering consumption pattern of diesel, kerosene and petrol in the country which comprises almost 80% of total energy requirement. Petroleum is vigorously used in transport, agriculture, power and industrial sectors. Sector wise demand of petroleum products [6] for the year 1990-91 are as follows,

a) Agriculture sector - 13%
b) Power sector - 3%
c) Industry sector - 12%
d) Transport sector (Rail, road,river and air) - 48%
e) Domestic - 24%

Here considering past trend of petroleum consumptions, future projection for year 1993-2000 was made.

3.4.2 Consumption Model

Consideration was given for petroleum demand projection with length of road, total kilometer run by all railway engines, total kilometer flown by all aircraft, total generation of electricity by type of fuel etc. Linear equation has been formulated for petroleum demand projection. The equation, its control variables and the results are given below:

X1=Dummy variable=1.00

X2=length of machanised vehicles on road in 10^4

X3=length of road in thousand kilometer

X4=total kilometer run by all railway engines in 10^5

X5=total kilometer fly by all aircraft in 10^6

X6=total kilometer move by all marine vehicles in 10^4

X7=generation of electrical energy by type of fuel in GWHx10

Y =total petroleum energy consumption in 10^{12} BTU.

The equation is

$$Y=-28.661X_1+1.703X_2+0.659X_3-0.671X_4+4.281X_5-1.00X_6-0.0424X_7$$

3.4.3 Discussion on petroleum consumption model

With increasing machanization in all sectors, demand of petroleum product is on the increase. Mainly crude petroleum are imported from Middle East Countries and after refinements petroleum products are distributed to different sectors. In the year 1990-91 about 1.182 million tons crude oil were imported at a cost of taka 7830.4 million [6]. Petroleum consumption model was based on data from 1981-1992 and the projection was made for the year 1993-2000 A.D. Actually data for total petroleum product for different year is given in metric ton which was converted to calorific value in BTU for the model.

In this work X_7 is the generation of electricity by type of fuel. This variable is decreasing, which means use of petroleum in generation of electricy is decreasing. In this study we did not consider irrigation pump which are using petroleum product due to lack of availability of data and it limits the projection. Further study is needed with more variables in the model to get better projection. The projected consumption of petroleum may not be correct for unforeseen situations. Such as during Iraq-Kwait war, the price of petroleum was high and supply was not sufficient. About 50% of total petroleum products is consumed in transport sector (HSD - High Speed Diesel). If liquid gas used in high rate as substitutes of petroleum in transport sector, then our projected consumption will differ. Hence further study is needed in this sector by taking all this constraints and uncertainties.

TABLE: 3.7

TABLE FOR PETROLEUM ENERGY CONSUMPTION MODEL

YEAR	X2	X3	X4	X5	X6	X7	Y
1982	11.82	6.59	32.60	20.89	11.79	69.30	48.30
1983	12.64	7.99	34.14	19.58	14.30	63.10	38.05
1984	13.47	9.39	32.85	20.51	20.58	72.90	42.59
1985	14.42	10.37	33.72	20.54	27.57	88.50	39.26
1986	15.46	11.18	33.46	20.84	28.20	131.82	41.45
1987	16.56	11.82	33.72	21.21	29.52	84.10	40.65
1988	17.72	12.32	37.06	21.10	29.65	79.10	39.64
1989	20.28	12.96	35.22	19.95	33.39	58.26	43.91
1990	21.73	13.63	35.89	21.54	35.07	33.26	41.14
1991	23.30	13.84	35.34	23.27	35.63	14.55	47.70
1992	24.01	14.45	35.66	23.98	35.87	39.55	68.89

* SOURCE [7]

TABLE: 3.8

PETROLEUM ENERGY CONSUMPTION PROJECTION FROM YEAR 1993-2000

YEAR	X2	X3	X4	X5	X6	Y
1993	116.1045	51.9848	20.6766	14.5617	86.1302	64.459076
1994	118.2822	54.7365	22.0030	15.0721	91.4631	68.372676
1995	120.4598	57.4881	23.3293	15.5824	96.7961	72.286276
1996	122.6374	60.2398	24.6556	16.0928	102.1291	76.199876
1997	124.8150	62.9914	25.9820	16.6032	107.4620	80.113475
1998	126.9927	65.7431	27.3083	17.1136	112.7950	84.027075
1999	129.1703	68.4947	28.6346	17.6240	118.1280	87.940675
2000	131.3479	71.2464	29.9609	18.1344	123.4610	91.854275

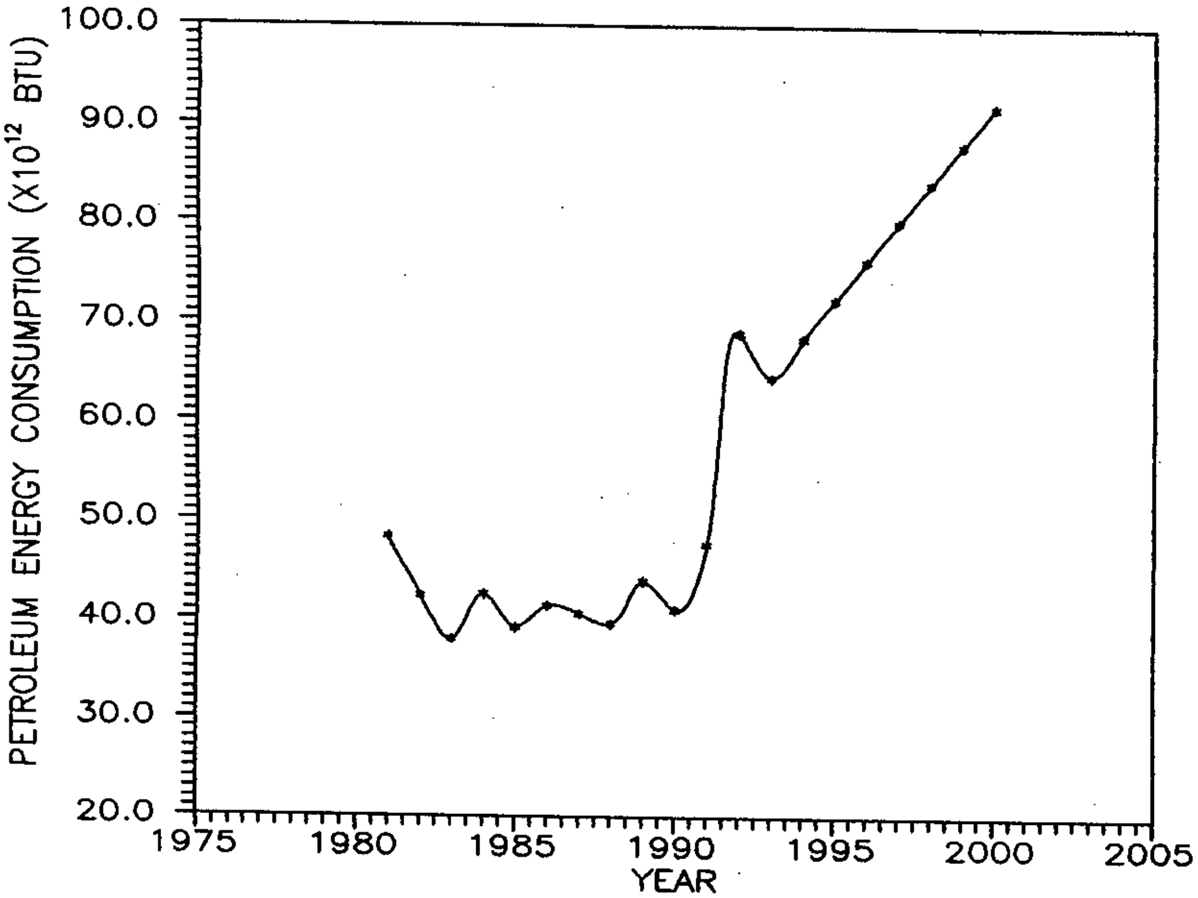


FIGURE 3.3 Petroleum Energy Consumption Projection from year 1993–2000 (Linear model)

3.4.4 Remarks

A heavy amount of our national budget goes towards import of crude petroelum. To save huge foreign currency and for optimum use of petroleum products better consumption model is required.

3.5 TOTAL ENERGY CONSUMPTION MODEL

In the linear regression model the variables used for total energy consumption model are,

X1=dummy variable=1.00

X2=energy cost per thousand BTU in paisa

X3=per capita energy consumption in 10^5 BTUs

X4=per capita income in hundred taka

X5=population in million

X6=GNP growth rate

Y = total energy consumption in 10^{13} BTUs

The use of above variable are obvious. The total energy demand naturally depends on energy cost, per capita income and population. The other two variables included were for taking more consideration of economic activities on total energy consumption. The resulting demand equation is of simple linear form,

$$Y=7.785X_1+3.603X_2+1.158X_3+0.729X_4-0.345X_5+0.0129X_6$$

TABLE 3.9

TABLE FOR TOTAL ENERGY CONSUMPTION MODEL

YEAR	X2	X3	X4	X5	X6	Y
1981	4.92	10.96	31.45	89.90	2.50	9.85
1982	5.17	12.10	33.05	92.10	1.10	11.14
1983	5.43	11.71	33.67	94.30	2.40	10.04
1984	5.69	11.55	35.05	96.50	2.60	11.15
1985	5.95	12.17	36.93	98.70	2.40	12.01
1986	6.20	13.32	37.66	100.80	2.00	13.43
1987	6.46	14.15	39.45	103.10	2.27	14.59
1988	6.72	12.84	40.07	105.30	1.65	13.52
1989	6.97	16.13	40.09	107.60	0.23	17.36
1990	7.23	17.32	41.51	110.00	4.28	19.05
1991	7.48	15.66	42.30	111.50	1.22	17.46
1992	7.74	16.69	43.33	113.60	2.39	18.96

TABLE: 3.10

TOTAL ENERGY CONSUMPTION PROJECTION FORM YEAR 1993-2000

YEAR	X2	X3	X4	X5	X6	Y
1993	7.9977	17.3548	44.8168	116.1045	2.0685	19.8858
1994	8.2543	17.9146	45.8840	118.2822	2.0657	20.7841
1995	8.5109	18.4743	46.9512	120.4598	2.0629	21.6824
1996	8.7674	19.0340	48.0184	122.6374	2.0601	22.5807
1997	9.0240	19.5937	49.0856	124.8150	2.0573	23.4791
1998	9.2806	20.1534	50.1528	126.9927	2.0545	24.3774
1999	9.5372	20.7132	51.2200	129.1703	2.0517	25.2757
2000	9.7937	21.2729	52.2872	131.3479	2.0489	26.1740

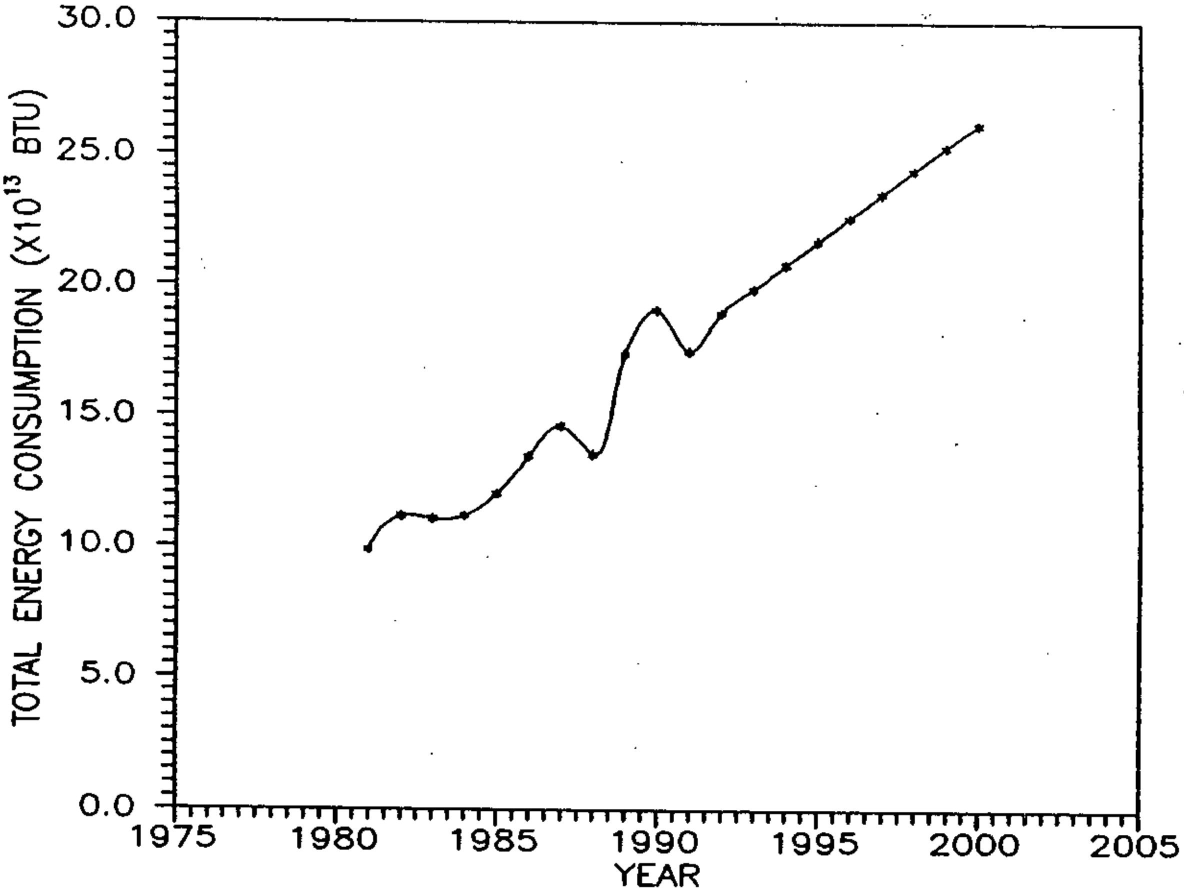


FIGURE 3.4 Total Energy Consumption Projection from year 1981–2000 (Linear model)

3.5.1 **Brief discussion on total energy consumption model**

The data for the total energy consumption model has been obtained by adding the sectoral demands for conventional energy consumption. Non-conventinal energy shares a major part of our total energy consumption and it is supposed to play more important role in our future total energy consumption in the context of high price of conventional fuels. But in this study we have to omit their share for lack of sufficient and authorative data.

The total energy consumption model is based on data from 1981-1992. A projection was made for the period 1993-2000, with the assumption that the present trend in economic growth will remain the same for prediction period. The results are presented in tabular and graphical form.

3.5.2 **Remarks**

In Bangladesh although the per capita energy consumption is low in comparison to other countries of the region but there is good potential to conserve energy through better management and use of efficient end use devices. Energy modelling should be done for area based, and for long term, medium terms and short term basis. The supply of energy source is limited, so a better projection is necessary to meet the increased demand of energy at the most economical and efficient way.

3.6 CONCLUSIONS

The supply of adequate energy in right form is essential and crucial for any socio-economic development. Bangladesh's thrust towards fast growth through enhanced activities in the agriculture, industry and the services sector calls for an increasing demand for energy, particularly the commercial energy, as it is the key production factor [8] in the productive sectors [9]. Its importance in the domestic sector is no less, since it satisfies basic human needs such as cooking and lighting.

In this chapter, consumption model for the year 1993-2000 A.D. of total energy, electricity, gas and petroleum is prepared using the past consumption from the year 1981-1992. The following strategies should be adopted in energy sector:

i) To develop and effective regional balance in energy supply, more gas-based electricity would be taken to the western zone and efforts should also be made to take gas pipeline to that zone via Jamuna Bridge. Besides, emphasis will be given to develop the coal and peat resources discovered in the west zone.

ii) Ensuring reliable and uninterrupted power supply through maximum utilisation of the existing capacities, adding generation capacities at least cost by optimising energy mix and balanced expansion of transmission and distribution network system.

iii) To reduce the import burden for oil, natural gas fields should be developed.

iv) To increased allocation for the development of new and renewable energy techlogies to conserve traditional energy and maintain ecological balance.

As electricity should not and cannot be used to meet all types of energy needs, there is a need to pay attention for the planned development of all types of energy sources for both rural and urban areas.

CHAPTER 4

ELECTRICAL ENERGY FORECASTING BY NEURAL NETWORKS

4.1 INTRODUCTION

The idea of Artificial Neural Networks (ANN) which gave birth to a relatively new type of artificial intelligence has been primarily inspired from the functioning of biological nervous systems with the hope of capturing human intelligence in machine learning. Different ANN models have been developed to teach computer to achieve human like performance in the field of recognition, reasoning and dealing with fuzzy situations etc. Modelled after the behavior and architecture of human neural system, ANN can achieve the capability of robust generalization and error tolerance found in human expert. They can discern patterns and relationship that are beyond the capabilities of the methods like numerical regression and pattern matching [9],[10].

The basic building block of all biological brain is the nerve cell, or neuron. Each neuron act as an independent information processing unit. Our brain consists of billions of simple neurons, biological information processing units, all are heavily interconnected and operating in parallel. Each neuron takes inputs from all the other neurons which send information to it, sum up all the inputs, applies a transfer function, and the output is sent to all other neurons receiving information from this neuron. There are many artificial neural net models existing in neural net literature. In the following, we describe a multilayer feedforward network trained by Back propagation learning algorithm [11] which is the most widely used learning algorithm in supervised learning.

4.2 DESCRIPTION OF BACK PROPAGATION LEARNING ALGORITHM

The Back propagation learning algorithm developed by Rumelhart et al. [11] is a gradient descent method that will establish the weights in a multilayer, feed forward adaptive "neural" network. Small arbitrary weights are chosen to initialize the system. Learning is accomplished by successively adjusting the weights based repeated presentation of a set of input patterns and the corresponding set of desired output patterns. During this iterative process, an input pattern is presented to the network and propagated forward to determine the resulting signal at the output units. The differences between the actually resulting output signal and the predetermined desired output signal at each output unit represents an error that is back-propagated through the network in order to adjust the weights. The learning process continues until the network responds with output signals the sum of whose root-mean-square errors from the desired output signals is less than a preset value. The equations governing Rumelhart's method are reproduced in the following equations.

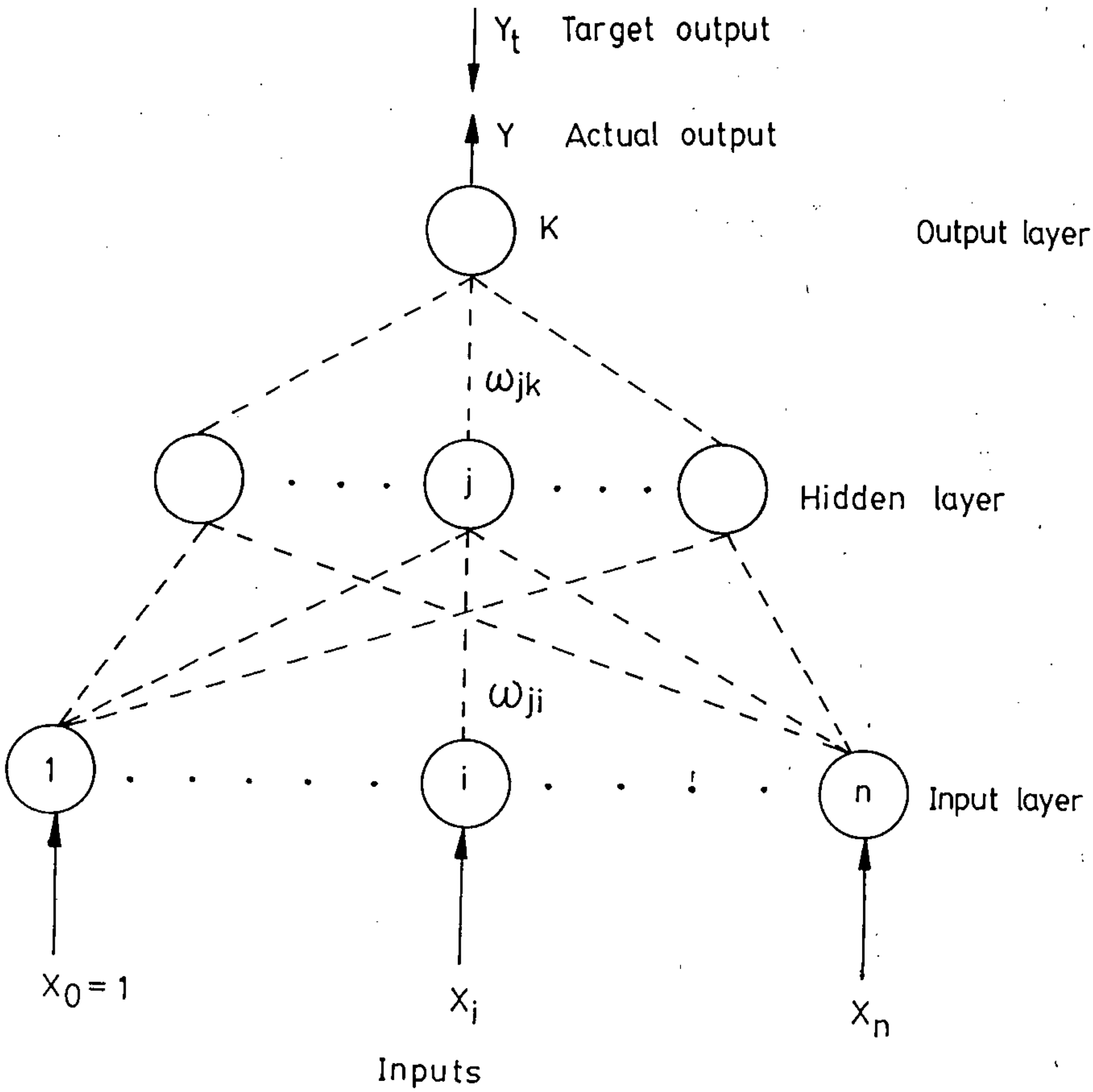


Figure 4.1: A three-layer Backpropagation network.

Fig.4.1 shows a three-layer network trained by Back propagation network. The first, second and third are the input, hidden and output layer respectively. In this figure, only one output unit is shown which is needed in the present work but, depending on the problem, it can be extended to any number of units. In supervised learning, each input vector is associated with a corresponding output vector. X_0, X_1, ..., X_n is the input presented to the network and Y_t is the corresponding output. W_{ji} is the weight between the unit 'i' and 'j'. When an input vector is presented to the input layer, each input value is multiplied by the corresponding weight, summed up, and the hidden unit 'j' produces an output h_j according to the sigmoid activation function as follows:

$$h_j = \frac{1}{1+\exp(-\Sigma\ w_{ji}X_j)} \qquad (4.1)$$

where X_0 is constant '1' which provides bias for the hidden unit.

Similarly the signal at the hidden layer is propagated forward through the hidden-output weight layer and produces an output at the output layer. The whole training set is presented to the network sequentially during the training cycle. As each input is presented to the net, the error at the output layer is determined by comparing the actual output to the target output. According to the error at the output, all the weights are modified to minimize the sum-squared error $\Sigma(Y_t-Y)^2$ over the whole training set.

The weight update rule can be simplified as follows,

$$w_{ji}(n+1)=\beta.\delta_j.X_i+\alpha.\ w_{ji}(n) \qquad (4.2)$$

where β is the learning rate and δ_i is error signal of unit `i'. Error signal for hidden and output layer unit is given as follows

$$\delta_k=(Y_t-Y)Y(1-Y) \qquad \text{for output units} \qquad (4.3)$$

$$\delta_j=h_i(1-h_i)\Sigma\delta_k w_k \qquad \text{for hidden units} \qquad (4.4)$$

Initially the network starts with small random values assigned as weights and ultimatly settles down to appropriate weights which is capable of learning the desired input-output relationship.

In practice this algorithm is employed as follows: after each input pattern is presented to the network, the consequent error vector across output units is determined and back-propagated through the network to update the weights. The next pattern is then presented and the process repeated. Two parameters β and α, respectively an adjustment of step size and a weight on the "memory" of previous steps, are at the disposal of the user. Assuming β and α are appropriately chosen, the back-propagation process will generally coverge to a minimum that statisfies the criterion imposed by the user, usually that the sum of the squares of the error of the output signal, $\Sigma(t_{pj}-O_{pj})^2$ will be less than a predetermined value for all p.

4.3 FORECASTING BY NEURAL NET

A three-layer backpropagation network was trained with five units at the input layer to represent the five prediction variables used in the electrical energy forecasting as discussed in the previous chapter and one output units at the output layer to represent the total consumption. The network was trained with the data obtained for the years 1981-1992. Four hidden units were needed to realize the learning task. After the network had been trained it was presented with the inputs which are the variables predicted by regression method. The network forecasted total electrical energy demand. Since the output of neural network is also dependent on the initially choseen random weights, the network was trained five times, each time starting with different set of weights. The predicted energy varied slightly each time and the average value was taken. Energy demand for the present decade was forecasted by this method and the results are shown in Fig. 4.2.

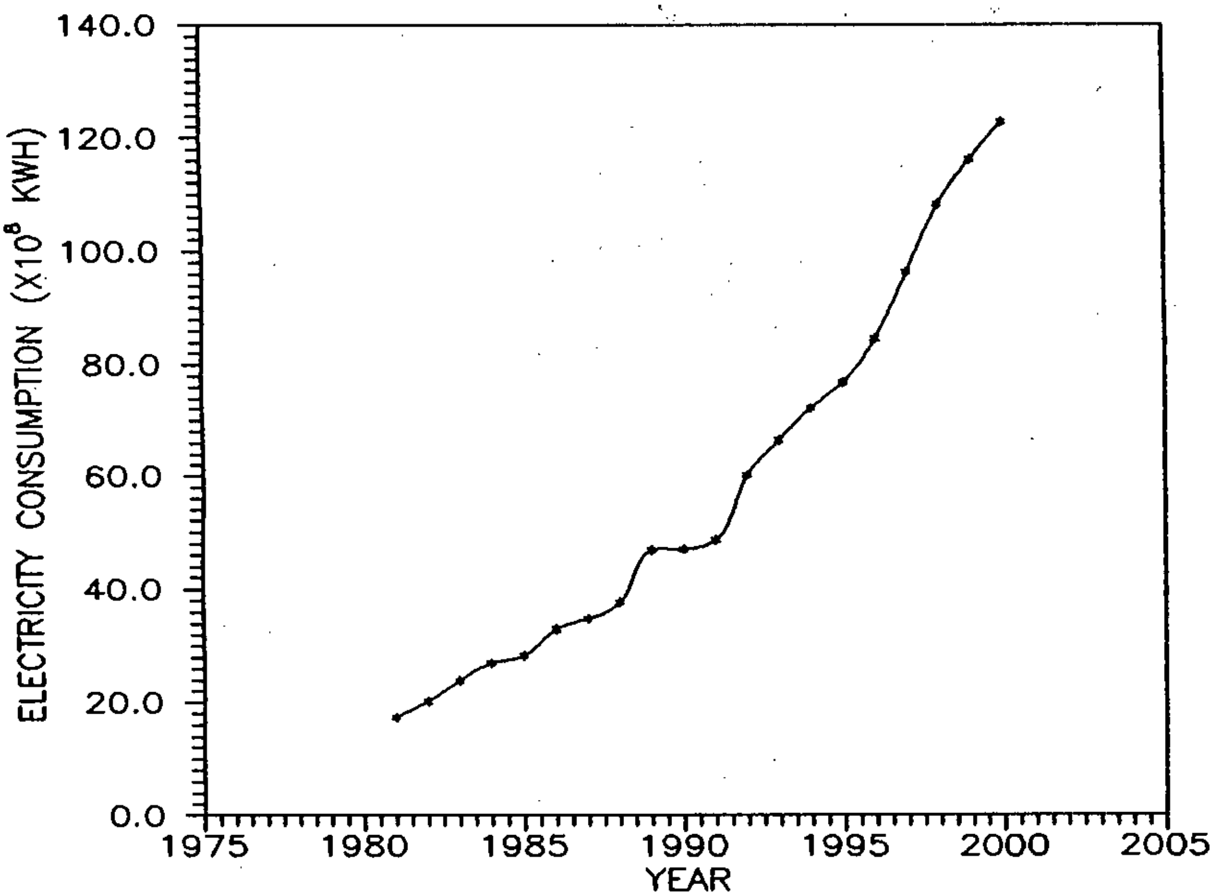


FIGURE 4.2 Electricity Consumption Projection by neural network (for year 1993–2000)

TABLE: 4.1

ELECTRICAL ENERGY CONSUMPTION PROJECTION FORM YEAR 1993-2000

YEAR	X2	X3	X4	X5	X6	Y*1	Y*2
1993	7.9977	17.3548	44.8168	116.1045	2.0685	19.8858	63.78
1994	8.2543	17.9146	45.8840	118.2822	2.0657	20.7841	67.84
1995	8.5109	18.4743	46.9512	120.4598	2.0629	21.6824	73.46
1996	8.7674	19.0340	48.0184	122.6374	2.0601	22.5807	81.78
1997	9.0240	19.5937	49.0856	124.8150	2.0573	23.4791	93.82
1998	9.2806	20.1534	50.1528	126.9927	2.0545	24.3774	105.91
1999	9.5372	20.7132	51.2200	129.1703	2.0517	25.2757	113.46
2000	9.7937	21.2729	52.2872	131.3479	2.0489	26.1740	121.28

*1 by linear regression, *2 by Artificial Neural Networks

4.4 COMPARISON WITH LINEAR REGRESSION ANALYSIS

Future electrical energy demand projected by a neural network-based model is shown in Table 4.1 and is illustrated in figure 4.2. Comparison of projected electrical energy demand by linear regression analysis (results shown in Table 3.4 and Fig. 3.1) with that by neural network (results shown in Table 4.1 and Fig. 4.2) shows clear distinction in projected results. While in the early years of projection, from 1993 to 1996, the two methods give almost similar projections, neural network forecasts comparatively high electrical energy demand in subsequent years leading to 121.28×10^{8} KWh by the year 2000 in constrast to 91.85×10^{8} KWh project by regression analysis. Since the whole forecasting model is constrainted by suppressed demand projection due to the inadequacy and limations of our generation and distribution system, it is difficult and inappropriate to make a concrete comment on the relative accuracy of forecasting by the two methods. However, demand on the previous years is not strictly of linear nature and, more likely, so will be the future demand. Neural network captures the inherent nonlinear relationship of the data it is trained with. Thus a neural network model also learns the nonlinearity involved in the previous demand and make a prediction on that basis. From this point, it can be said that forecasting by neural network is more likely to follow the past trend.

4.5 CONCLUSIONS

The regression analysis technique as described in the previous chapter basically establishes a linear relationship between the energy demand and the variables that influences the demand. The relationship is formulated on least-squared error minimization. Artificial neural network approach realizes the relationship by a learning rule based on a gradient descent technique which minimizes the sum-squared error. Since the neurons are nonlinear elements, it establishes a non linear input-output relationship. Forecasted electrical energy demand by neural net as shown in Fig.4.2 also shows a nonlinear future demand which seems more likely to follow the past trend than the regression analysis technique.

CHAPTER 5

ENVIRONMENTAL ISSUES IN ENERGY MODELLING

5.1 INTRODUCTION

There are linkages directly or indirectly between envrionment and energy consumption, processing and conversion.

In following paragraphs some of the environmental issues related to the development, processing and consumption of the primary fuels are discussed.

5.2 BIOMASS ENERGY SOURCES

Biomass energy sources are the traditional energy sources of Bangladesh. According to BEPP [2] (Bangladesh Energy Planning Project) about 77% of total energy supply in 1983/84 was provided by biomass. The contribution of biomass in the year 2000 has been projected as 55%.

(a) Agricultural Residues

In Bangladesh 59% of total land is cultivated and agricultural residues are the major sources of fuel. According to BEPP estimate total agricultural residue for 1983/84 was 70 million tonnes of which 38% was burnt as fuel.

The use of agricultural residues as fuel deprives the soil from organic matters and nutrients. The productivity of agricultural land is thus affected by the burning of agricultural residues as fuel.

The end-use efficiency of agricultural residues (as well as wood and biomass) in traditional cooking is generally low. Cooking by agricultural residues and biomass units undersirable carbonmonixide gas and smoke which are harmful to health. The introduction of improved stoves would result in fuel savings and improvement of the environmental quality.

(b) **Animal Dung**

According to estimate of BEPP total annual quantity of dung produced by cattle is 19.6 million tonnes. Of the total 45% is used as manure, 34% as fuel, 5% as building materials and 16% is wasted. With this estimate about 6.7 million tonnes of dung are currently used as fuel per year. This is substantial denial of biomass as potential fertilizer becasue the quantity of dung would be equivalent to about 72,000 tonnes of urea, 43,000 tonnes of TSP and 33,000 tonnes of MP fertilizer. If subsitutes for dung such as wood fuel can be made available significant savings [2] of chemical fertilizer and hence natural gas is possible.

In addition large scale use of chemical fertilizers and continued shortage of organic fertilizers causes deterioriation or the physical character of the soil.

(c) **Wood Fuels**

According to BEPP estimates, 5.7 million tonnes of wood fuels were consumed in 1983/84. The sustainable limit of woodfuel extraction from the present forests and village woodlots is estimated to be about 3 million tonnes. Therefore approximately 2.7 million tonnes of fuelwood are being extracted by overcutting of resources. Providence of currently used quantity of wood fuels from the existing growing stock of tree resources is resulting in serious envrionmental damage.

Though the entire country will be affected if the present trend of deforestation continues, the first affected group will be the population of the north-west where national forest resources are nominal and a serious imbalance exists between demand and supply.

The combined destruction of forests and village wood lots will further increase the pressure on crop resiudes and cow dung which is detrimental to other use of these resources and will raise demand for kerosene in the areas having no natural gas supply.

5.2.1 **Commercial Fuels**

(a) **Coal**

From environmental viewpoint, problems may arise during extraction and processing of coal. The drying stage can produce air pollution as the product is exposed to a stream of hot **gases**. Emissions consists mainly of Sox, Nox and fine coal dust. Coal storage may also give rise to water pollution. Coal mining will result in loss of agricultural land and dislocation of the population.

The main use of coal would be for large scale power generation. The environmental concerns in this regard would be thermal pollution from cooling water dischares and atmospheric pollution. Air pollution will be due to emission or particulates. SOx, CO, HC, NOx and Aldehyde. Out of these particulate emissions are high which consist of ash and unburnt coal during the turbulent combustion.

(b) **Petroleum Products**

According to BEPP estimate, about 2.7 million tonnes of crude oil and petroleum products are expected to the imported annually by the year 2000.

(1) **Transportation**

In transportation sector process oil may be discharged into sea and rivers as a result of deballasting, tank washing and spillage during loading and unloading operations. There is also a very small probability of major accidents. It is estimated that 0.5% of the oil may be lost during transportation. The quantity of oil likely to dischage into water could be approximately 100 tonnes annualy.

(2) **Refining of Petroleum**

The annual design capacity of the refinery is about 1.5 million tonnes crude oil with 70,000 tonnes of bitumin production as by product. Based on an API refinery effluent profile the expected volumes of liquid effluents from refinery streams would be between 25 to 110 percent of crude throughout for crude fractionation. The biological oxigen demand (BOD) and sulphide levels would be about 0.006 and 0.003 kg/tonne of crude respectively. Again if the flare system from the bitumin plant does not work peroperly then the particulates will escape without being combusted resulting in atmospheric pollution.

(3) **Power Generation**

In Bangladesh the share of oil in electric powr generation is modest.

A 200 MW oil fired electric power plant will be require about 0.4 million tonnes of oil annually. The most significant component in the emissions generated is SOx.

(4) **Use of Oil in Transport Sector**

Probably the most significant impact of oil utilization arises from motor vehicles in the cities like of Dhaka and Chittagong. Petrol driven vehicles emit over 1000 chemical compounds, most significant emission being CO and NOx and unburnt hydrocarbons.

(c) **Natural Gas**

Natural gas is the chief indigenous source of commerical energy in Bangladesh.

Natural gas is burnt in the domestic and commercial and in the industrial sectors for heat and electricity generation.

A typical thermal plant operating on natural gas would emit pariticulates SOx, NOx and Aldehyde.

The extend of thermal pollution depends on the volume of the receiving waters (the heat sink).

Generally a thermal power section of about 40% efficiency will reject about 50% of the heat imput of the cooling water. For the river Shitalakhha some dischage values of Ghorasal power plant are shown below:

1979	cu m/s max.	min
February-April	50	15
July-September	1800	750

From the above qualitative data on flow volumes it is clear that there is a risk of thermal pollution during the winter months.

(d) **Hydropower Development**

The only hydropower plant of the country is located at Kaptai in Chittagong Hill Tracts with five gnerating units.

After the closure of the Karnafully river in 1962 significant ecological and socio-economic changes occured. A number of large lakes were formed and reserve forests has to be cleared to the 36 m contour level with teak platations sacrificed. A large area of Kassalong Reserve Forest had to be cut down for the rehabilitation of displaced people. In time, some tribal people reverted to their traditional shifting cultivation such that by 1980-81 about 23 thousand hectares of land in Rangkeang reserve forest had been invaded and denuded. The submersion of low areas in the forest damaged species which were used to grow abudantly on the flats and banks of the marshes. Due to lack of bamboo Karnaphuli Paper Mills had to cease operation from time to time. However, the presence of the reservour considerably increased the fishery potential in the area and the marshes around the resulting lake attracted numerious water birds. Below the dam the farmers are now protected from floods and are provided with irrigation facilities.

(e) Peat

The major peat deposits are located in scattered fields in Sylhet, Faridpur and Khulna districts.

The supply of peat for the power stations would involve dislocation of local population. The developed land could be returned to them afterwards. Due to excavation the top layer of the soil, which is important for agricultural production becomes dislocated and it takes considerable time for the soil to come back to its norml formation. The third group of people likely to be affected are the land owners of the transport routes from the site to the power plants including intermediate storage places.

5.3 DISCUSSION ABOUT ENVIRONMENTAL ISSUES

We have discussed some environmental issues related to energy developments in Bangladesh. It may be noted that the issues discussed are not all encompassing. Issues may be taken into consideration in energy development and efforts be made to minimize the average effects on environment. Institutional settings, like Environmental pollution control board is already there in the country. This institution may be made more active and effective. Environmental quality standards have been devised for a limited number of industries in Bangladesh including oil refiniries and fertilizer factories. However, they do not cover power plants or other energy producing facilities. Necessary measures should be taken to cover all energy producting facilities.

5.4 PROSPECT OF RENEWABLE ENERGY IN BANGLADESH

The storage of fossil fuel in the whole world will be depleted in the long run. Then we have to depend on alternative sources of energy. Nuclear energy has good prospect but has risk of accident and harmful radiation problem. Different types of renewable energy is free from this obstacles, though efficient and economic technology to use renewable energy is not still available. We have to try to utilize renewable energy sources for the following causes,

1. To save fossil fuels for specific purposes
2. To reduce environmental pollution

A very high percentage of national earning is used to import a very small percentage of the total energy consumed in Bangladesh. These imported fuels include crude oil, pertroleum products and coal.

Several renewable energy and their prospects in the context of Bangladesh is discussed below.

5.4.1 **Solar Energy**

Bangladesh is situated between 24°34/ and 26°38/ north latitudes and hence is favourably located for solar energy. The average daily total radiaton varies from 261 cal/sq.cm (1 cal/sq.cm=41.868 KJ/sq.m=0.01163 KWh/sq.m day) in December to 423 cal/sq.cm in April, while the annual mean value is 231 cal/sq.m.[1].

Solar energy may be considered for direct conversion into thermal energy and electrical energy. On the thermal side, considering the present level of technology at both international and Banladesh level and the expertise available in Bangladesh, only low temperature applications centering simple flat plate and parabolic plate collector principle are possible.

It is believed that in Bangladesh solar pre-heated water has good prospect. It may be used for parboiling of paddy, normal cooking, process heat, cottage industries, hospitals, etc. A simple calculation shows that for cooking rice alone by the traditional rural stoves, a total of about 4-5 million tonnes firewood equivalent will be saved per year if solar preheated water at 80°F is used and this temperature is easily attainable with properly designed heaters under local climatic conditions [3]. Paraboiling of rice is also equally important. Another area which may be probed into is solar drying. Simple and cheap dryers have been fabricated and tested and the results are encouraging. The drying problem should be looked into with a special attention to paddy drying during monsoon months when chances of wastage are more. The dryers should be extensively field tested and developed meeting the specific requirements of the farmers including the financial and social aspects. Other areas like solar distillation, solar refrigeration, etc. may not appear technically sound at this stage, though works have been carried in Bangladesh. Salt production by solar energy should, however, be looked into scientifically for improvement in the yield per hectare.

Solar photovoltaics may demand immediate attention, since its technology and cell production volume are both growing fast. To increase food production at least for self sufficiency, Bangladesh will have to move gradually from traditional agriculture to commercial energy intesive modern agriculture. In fact it she is now passing through trditional regime. It means that more commericial fuels like diesel, electricity, etc. will be needed for agriculture (1.6 PJ/year in 1981 to 8.3 PJ/year in 2000) and irrigation will claim a large share. The patterns of solar insolation, rainfall, croppings, land distribution and underground and surface water distribution, suggest that small scale solar photovoltaic pumping systems of hydraulic power out put of 100-800 W may be considered.

Solar photovoltaics may also be considered for rural electrification and agro-based cottage industries. When compared with the cost per unit electrical energy at the users' level from conventional sources taking into account all costs including capital investment and fuel (not for hydro), transmission and distribution costs, the PV arrays may become competitive in near future. The economics of the problem should be looked into. Because decentralized in nature, PV arrays will bring more social benefits under socio-economic structure in Bangladesh.

5.4.2 **Wind Energy**

Bangladesh may be a stormy but not a windy country. The analysis of the wind data recorded by various meteorological stations substantiates the statement (14,15,15a). Data for Chittagong and Cox's Bazar and coastal districts on the Bay of Bengal indicate that they respectively have a wind speed of (5.75) mph, 2.57 m/a) or more for about 4000 and 2000 hours a year.

Wind energy is very much site specific. Before making any final conclusion, the wind speed and direction should be measured approximately at the prospective sites. Based on meteorological data it is, however, felt that if wind energy is to be harnessed, it should be done in the coastal areas. Because of not very high wind speed, the question of high speed wind turbines and feeding the national electric grids does not arise at all. Low speed turbines may be considered for simplicity in technology and control and they should preferable be installed in isolated areas.

Wind energy is extensively used in sail boats for transportation through the water ways of Bangladesh. Both boats and sails therefore need attention for optimisation with existing wind regimes.

5.4.3 Ocean Energy

Though on the south of Bangladesh lies the Bay of Bengal, no attempt has ever been made to evaluate the prospects of harnessing energy from tides gradients, waves and currents of ocean.

Tides in the estuaries of Bangladesh are semi-diurnal in nature with a period of 12 hours 25 minutes. There are pronounced diurnal variations in the water levels due to the moon's declination. The phases of the moon, upland discharge and cyclonic surges have got pronounced effect on the high and low waters of these estuaries. Tide range in general varies between 3-6 m. It is estimated that the total energy available from tides is about 430 PWH per year.

5.4.4 Hydropower

Bangladesh is a flat deltaic country spotted with few hills here and there on the northern and eastern regions of the country. Therefore the potentials of large, small, miny and micro scale hydropower are very limited. The only hydropower plant of the country is located at Kaptai in the Chittagong hill tracts of 230 MW (40 MW x 2 + 50 MW x 3). Two other significant hydropowr sources are Sangu and Matamuhari river valley both of which are situated in Hill Tracts and they are not still used for power generation.

5.4.5 Biomass Fuels

Biomass fuels include tree biomass, agricultural residues and animal wastes and it has been recognized that they play a very important role in energy scenario of Bangladesh.

It is believed that the yearly yield of agricultural residues will not increase substantially any more. The same is true with the animal wastes like cow dung. In fact, the yearly cow dung production will remain more or less static in future. If the population growth rate is taken into account, the yearly per capita biomass fuel availability is expected to deteriorate. Before proceeding towards alternative uses of biomass in Bangladesh, one must contemplate very deeply about it, as various types of biomass now maintain a precarious balance in the rural fuel supply and demand pattern. Any unplanned change may be disastrous for the vast rural people.

The complete transition from traditional to commercial fuels which is common to the history of the developed countries, will in all likelyhood not occur in Bangladesh. It is likely that traditional biomass fuels will remain large in absolute qunatity and will primarily cater the needs of the rural poor.

In the rural areas, cooking is done mainly by biomass fuels. But the traditional stoves are higly inefficient (about 10% efficient). There are scopes to increase the heat utilization efficiecny to about 22%. This means that biomass requirements for cooking will be halved. So, improve cooking stoves projects should be launched immediately.

Now-a-days, biogas from cow dung is often recommended for cooking and household lighting. It has been fairly established that 4-5 cow dung is necessary to meet the requirement for an average size rural household and almost all the households do not possess so many cows.

5.4.6 **Animal Muscle Power**

Traditional ploughs, bullock carts and other agricultural implements drawn by draught-animals are going to stay in Bangladesh for many years to come. In fact, the total animal muscle power potential is estimated at 3500 MW and this exceeds the present electrical generating capacity of about 2200 MW. Improvement in the designs of the traditional implements will lead to better and more effective use of the existing draught animals.

5.5 ACTIONS TO BE TAKEN IN ENERGY SECTOR OF BANGLADESH

1. Adaptation of rational pricing policing policy for all the commercial energy sources.
2. Introduction of efficient burners and Kupis to save imported Kerosene fuels.
3. Introduction of improved biomass fuel stoves for urban and rural households.
4. Implementation of energy conservation projects for industries.

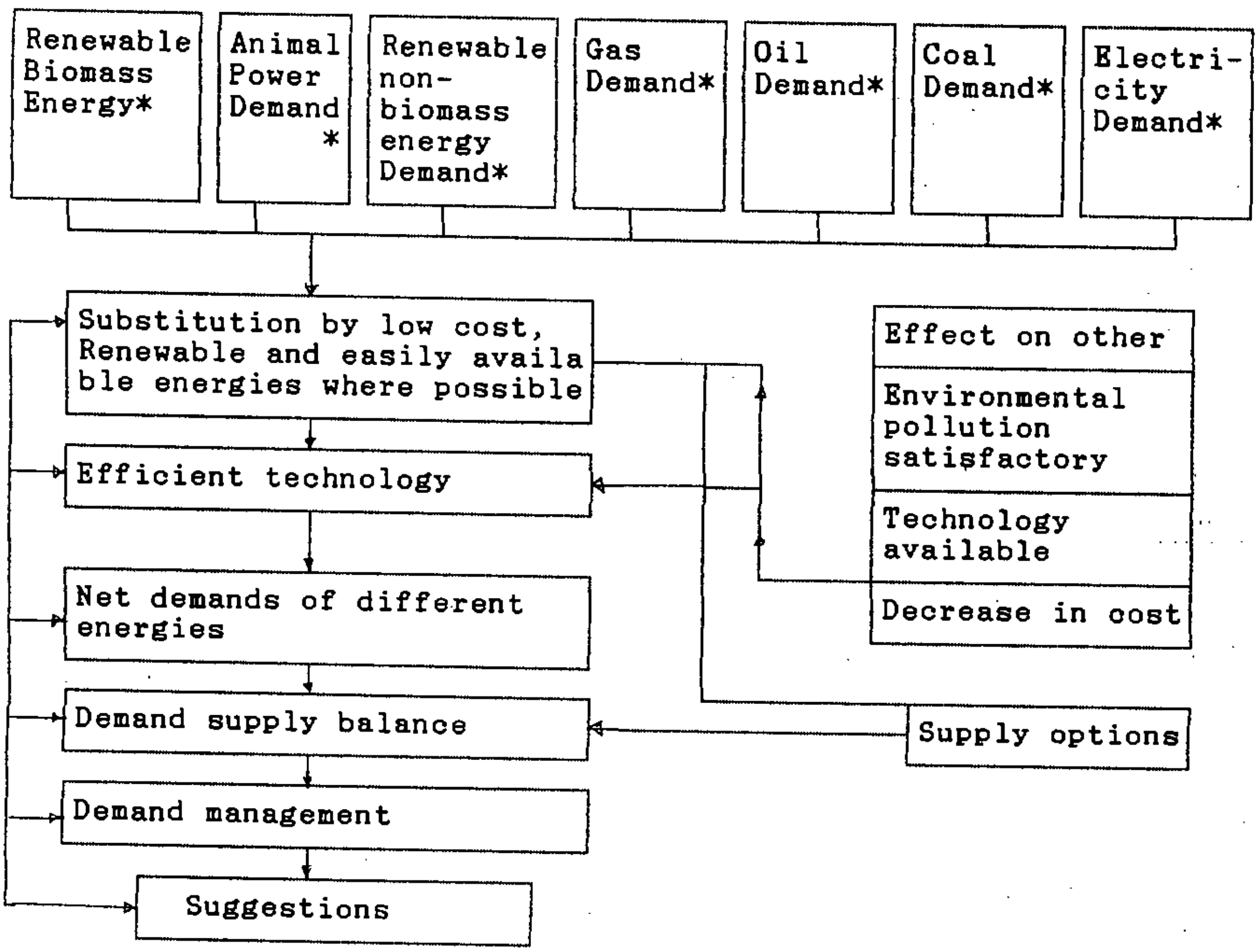
5. Implementation of system loss reduction project in electric power supply.
6. To increase the production of LPG
7. Dissimination of Renewable Energy Technologies.
8. Exploration of oil and gas in west zone.
9. Development of Barapukuria and Peerganj coal in west zone.
10. Development of coal based power plant in west zone.
11. Development of second East West electrical interconnector.
12. Development of energy in west zone.
13. Completion of gas pipeline in East zone and expansion to west zone.
14. Extension of Rural Electrification programme.
15. Tree platation to Augment the supply of fuel wood.
16. Establishement of hydropower plant at Sangu and Matamuhuri.

Some of these action may be taken as short term programmes and some are to be taken as long term programmes. Whatever it is we are to pay attention to these actions [7,8].

5.6 A SIMPLE BLOCK DIAGRAM FOR ENERGY MODELLING

The first step of modelling is to predict the demand of different types of energy. This prediction is usually done on the basis of part performance. So this reflects the suppressed demand of poor people and does not indicate their subsistence energy need. To

SIMPLE BLOCK DIAGRAM FOR ENERGY MODELLING



Demand*: Demand predicted for the period of modelling.

overcome this a minimum energy level may be established for the near future period for modelling and the energy demand may be calculated on this basis. However, it is the policy of the Government whether the people will meet the suppressed demand or they will enjoy a level of predetermined minimum energy. It is not so easy to determine a reasonable minimum energy level because it needs increase in per capita income and overall development of the country. Whatever it is according to the Government policy first a modeller requires to predict the demand of different types of energy. Then he suggests substitution of low cost for higher cost fuels if possible with if overall efficiency increase. A modeller also has to suggest efficient end-use technologies and proposes for less energy intensive life style. If the overall cost decreases and other factors are satisfactory it will reduce the actual amount of energy needed.

A block diagram may be drawn on the basis of following assumptions:

1. Supply of gas will be available according to the demand.
2. Petroleum and coal will be available in the world market with reasonable prices.
3. Energy demands predicted for the period of modelling are reasonable.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY AND CONCLUSIONS

For the development of this country prime emphasis should be given on energy sector and this require an appropriate and efficient energy model. In this thesis energy consumption model for electricy, gas, petroleum and total energy have been investigated. Linear regression analysis is used to forecast the above mentioned consumption based on past information. A more recent technique using artificial neural network has also been used for electrical energy forecasting. Due to scarcity of data some models have limitations, specifically petroleum consumption model.

In particular the contibutions of this thesis by chapter are as follows,

Chapter 1 described a brief introduction information about energy interaction, end use of energy, purpose of energy modelling and factors considered for energy planning etc.

Chapter 2, dealt with statistical approach of curvefitting by linear regrassion.

In chapter 3, using linear regrassion energy consumption of different sectors has been forecasted also results and discussion are in chapter 3. In chapter 4, electrical energy has been forecasted by using a recent technique named artifical neural network.

In chapter 5, environmental issues in energy modelling has been described.

Bangladesh's thrust towards fast growth through enhanced activities in the agriculture, industry and the service sectors calls for an increased demand for energy, particularly, the commercial energy.

In this thesis, consumption model for the year 1993-2000 A.D. of total energy, electricity, gas and petroleum are prepared using the past consumption from the year 1981-1992. Here observation is that energy modelling should be for area based, and for long term, medium terms and short term basis. The supply of energy source is limited, so a better projection is necessary to meet the increased demand of energy at the most economical and efficient way. The results obtained by this research work conforms the energy consumption forecasted by Bangladesh Bureau of Statistics.

6.2 SUGGESIONS FOR FUTURE WORK

Steady state behavior/forecasting of different sectors of energy has been forecasted for Bangladesh. Further study may be done in the area of dynamic response of different parameters of energy forecasting of different forms of primary energy sources e.g. electricity, gas, petroleum etc.

As electricity should not and cannot be used to meet all types of energy needs, there is a need to pay attention for the planned development of all types of energy sources for both rural and urban areas.

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APPENDIX

APPENDIX

SOME IMPORTANT DEFINATIONS

Some important definitions about the types of energy and energy resources are described in this appendix. Bangladesh is very poor in mineral resources. But its main mineral consumptions are in eneregy sector. All types of energy resources of Bangladesh are described in this appendix.

A.1 DEFINITIONS RELATING TYPES OF ENERGY

Primary Energy

The energy available from energy sources extracted from a stock of reserve under the ground (e.g. coal, crude oil, natural gas) or captured from a flow of resources on or above the ground (e.g. water, wind or solar power) before they undergo any process other than seperation and cleaning.

Secondary Energy

The energy available after transformation of a primary energy source (e.g. petroleum products, electricity)

Final Energy

The energy made available to the consumer before its final utilization or energy consumed by the final user for all energy purposes. Final energy excludes all energy lost in the transformation of primary to secondary energy, energy used within the transformation industries, and energy lost in the distribution process.

Useful Energy

The amount of heat, light or work actually made available to a final user of energy (domestic, industry, transport etc.) on the output side of the user's equipment and appliances.

Commercial Energy

Energy sources that pass wholly or almost entirely through the market system are defined as commercial energy (e.g.coal, oil, gas, electricity). Commercial energy sources are considered under national accounting system. Fuelwood extracted from reserve forests are also considered under national accounting system but they donot constitute commercial energy.

Non-Commercial Energy

Energy which is derived from traditional sources such as wood fuels (e.g.fuel wood, sawdust), agricultural residues (e.g. husk, straw, jute sticks etc.), animal dung and shrubs are known as non-commerical energy.

Renewable Energy

Energy sources which are constant or regenerated after a regular time cycle are commonly known as "renewable sources of energy" e.g. solar radiation, wind energy and bio-mass fuels.

Renewable Biomass Fuels

Biomass is generally defined as the organic matter produced by photosynthesis process. Biomass resources which are used as fuel are woodfuels, agricultural residues, animal dung etc. These fuels are also termed as traditional fuels. Biomass fuels are renewable upto the limit of its sustainable yield.

Renewable Non-Biomass Energy

Energy sources such as solar radiation, wind energy, tidal energy etc are examples of Non-Biomass renewable energy sources.

A.2 DEFINITIONS RELATING RESOURCES

Resources

A more general term referring to the geological endowment of minerals in the earth's crust in such concentration that commercial extraction is either presently or potentially feasible.

Reserves

A subset of resources which can be extracted at a profit under the present mineral price or production cost conditions.

Proved Reserves Recoverable

The fraction of proved reserves in place that can be recovered (extracted from the earth in raw form) under the above economic and technological limits.

A.3 DIFFERENT ENERGY RESOURCES OF BANGLADESH

Coal

Coal resources have been discovered in locations: Jamalganj (Bogra), Barapukuria (Dinajpur), Peerganj (Rangpur).

Coal resource estimated at Jamalganj is 1000 million tonnes and is located at a depth of about 1000 metres. Extraction of coal at Jamalganj has not yet been possible due to existing technoeconomic reasons.

Barapukuria and Peerganj coal resources have been reported to the 250 million tonnes and 400 million tonnes respectively and located at depths of about 160 metres. Feasibility study of Barapukuria coal is now completed. Proved reserves in place and proved reserves recoverable of coal at Barapukuria and Peerganj are not yet released. Feasibility study of Peerganj coal has been initiated.

Peat

Total peal resources of Bangladesh is reported as 600 million tonnes, of which 133 million tonnes are located in Faridpur and Khulna regions. Average depth of peat layers in Faridpur and Khulna regions vary between 2-2.5m with the overburden layers of 1-1.5m. For peat resources, proved reserves in place and proved reserves recoverable are not yet known.

Oil

Haripur oil field is the only known oil deposit in Bangladesh. It has a resource of 40 million barrels (5.47 million tonnes), of which only 30 percent (1.6 million tonnes) is reported as recoverable. Proper assessment of oil resources has not yet been made. At present, the field is producing 350 barrels of crude per day.

Most of the petroleum energy need of the country is met by import. For example, total amount of primary supply of petroleum (crude petroleum products) in 1990 is reported as 1.995 million tonnes of which 64,000 tonnes (3 percent of total), is obtained from local sources (crude oil and natural gas liquid).

Natural Gas

It is reported in the plan document that the toal estimated reserve of natural gas in 15 gas fields (14 on shore and one off shore), is around 13 TCF of which about 1.35 TCF has already been extracted upto June 1990. It is estimated that a total of about 30 million barrels of natural gas liquid is recoverable of which nearly 2.5 million barrels have already been extracted upto June 1990. Existing 10 producing gas fields have a total production capacity of 1070 MMCFD comprising 39 Nos. of wells. The present day production is around 600 MMCFD (1990), supplied from 7 fields.

On the basis of IDA assisted hydrocarbon habitat study appraisal drilling projects and CIDA assisted reservoir study, it is reported (PETROBANGLA) that total reserves in place in 15 gas fields is 37.08 trillion cubic feet of which 25.66 trillion cubic feet is recoverable.

Hydropower

Total hydropower potential of Bangladesh is reported (PSMP 1985) as 1500 GHh per annum; located at Kaptai (1000 GWh), Matamuhury (300 GWh) and Sangu (200 GWh). Total electricity generated in 1990 was 7700 GWh, of which 925 GWh (12 percent) was generated by

5 hydro units installed at Kaptai (2 x 40 MW+3 x 50 MW=230 MW). Power generation capability of the installed hydropower plants depends on the availability of water (intensity and duration of rain in the water shed area as of the Kaptai reservoir. Average yearly power generating capacity of installed hydropower plants is reported by power development board as 750 GWh.

Biomass Fuels

Biomass is defined as all organic matters produced by photosynthesis process. Depending upon their characteristics and quality biomass resources are used as food, fodder, building materials, fuel and manure. Only a fraction of total biomass produced by photosynthesis process is used as fuel.

In Bangladesh, biomass fuels are obtained from three sources, tree, field crops and livestock.

Land is the ultimate resource base that supports the production of total biomass resources. Various data needed to estimate the supply of biomass fuels are, land use analysis, yield of biomass produced in each catagory of land and the fraction of total biomass used as fuel. Among the above mentioned data, land use data are available in statistical year book. But it is a difficult task to have reliable data on sustainable yield, actual extraction rate and fraction of biomass used as fuel.

Some of the observation on biomass fuels supply from different catagories of land in 1981 are presented below:

a) Reserve forests occupying 15 percent of total area supplies 2 percent of biomass fuel (only 46% of total reserve forest area was reported as productive).

b) Village forest, occuping 2% of total area, supplies 14% of total biomass fuel.

c) 59% of total area was under agricultural crop and supplies 60% of total biomass fuel. If the contribution of animal dung and recycled biomass fuels are attributed to agricultural crop land, then its contribution would be 82%.

d) 98% of total biomass fuel was supplied by privately owned agricultural cropped land and village forests, only 2% by reserve forests.

e) The composition of total biomass fuels were as follows: Agricultural residues 66%, wood fuels 18% and animal dung 6% (small share of woodfuel was an indication of their scarcity. Moreover wood fuels were consumed by over cutting resulting depletion of growing stock).