CHAPTER 4

MODIFIED AND MPEEE MODEL

The Modified model that has been developed determines the commercial energy demand based on economic, technological and environmental factors. The output is then fed into the Mathematical Programming Energy Economy Environment (MPEEE) model which determines the optimum allocation of commercial energy resources based on environmental and practical limitations.

The present work involves the collection of data regarding the consumption of commercial energy sources like coal, oil and electricity for various sectors such as industrial, transportation, domestic, agricultural and commercial, for India from 1953 onwards. The variables involved in the model are the national income, energy price index, technological efficiency and emission factors for carbon dioxide, sulphur dioxide, nitrogen dioxide, total suspended particulates, carbon monoxide and volatile organic compounds from coal, oil and electricity and the required data have been collected. With these data base, the Modified model for forecasting and the MPEEE model for optimization of distribution pattern have been developed and the methodology adopted is explained in the following sections.

4.1 MODIFIED MODEL

Several econometric models that have been built to predict the energy requirement, either consider national income or energy price or both as variables. In a few cases, previous year's energy consumption has also been used to improve the accuracy of the predictions. In some cases, GNP is used as such or GNP per
capita and population are separated and the impacts of these variables on energy consumption are studied. In all cases a log-linear function is used, since it directly gives the elasticity coefficient. Literature survey indicated that technological and environmental factors have not been used in the energy demand econometric model. Modified model incorporates energy, economic and environmental factors.

4.1.1 Energy-Economic Variables used in the Model

Energy in common use can be classified as commercial and non-commercial energy. During the early fifties, the major contributors to the energy requirement in India have been the non-commercial sources. In the past decade the trend has changed. This is clearly visible from Fig.4.1. Use of commercial energy is growing at a faster rate as compared to non-commercial sources of energy. The consumption pattern of coal, oil and electricity during the past four decades is given in Fig.4.2. It could be seen from the figure, that since the oil crisis of 1973, there has been a steep rise in the energy consumption pattern. The reason being, the seventies witnessed a rapid industrialization. Prior to 1973, the coal and oil consumption pattern has been almost flat with a small growth rate. But after the 1973 crisis, oil consumption increased at a faster rate as compared to that of coal. This indicated that change in energy price because of the crisis did not have any major consequence on consumption. In the case of electricity, there has been a steady rise and the present consumption lies between coal and oil. The percentage consumption in the different sectors for coal is given in Fig.4.3. It is found that in the case of coal, industrial sector is the major consumer, around 83%. Transportation and domestic sectors consume only around 16.5%. This indicates that the bulk of coal goes only for industrial use. The percentage distribution for oil is given in Fig.4.4. About 61% of oil goes to the transportation sector followed by 17% which is consumed in agricultural sector. The remaining percentage goes to the other sectors. Transportation sector is thus the major consumer of oil. In the case of electricity shown in Fig.4.5, industrial sector is the biggest consumer followed by agricultural and domestic sectors. It is thus evident that coal and electricity features predominantly in
FIG. 4.1 PERCENTAGE SHARE OF COMMERCIAL AND NON-COMMERCIAL ENERGY IN TOTAL ENERGY REQUIREMENT.
FIG. 4.2 CONSUMPTION PATTERN OF COMMERCIAL ENERGY RESOURCES IN INDIA

YEAR: 1950-51 to 1980-81

- COAL
- OIL
- ELECTRICITY

CONSUMPTION (MTCM)
FIG. 4.3  COAL DISTRIBUTION PATTERN IN DIFFERENT SECTORS IN 1988-'89
FIG. 4.4 OIL DISTRIBUTION PATTERN IN DIFFERENT SECTORS IN 1988-'89

TRANSPORT 61%
AGRICULTURE 17%
DOMESTIC 14%
COMMERCIAL 3%
INDUSTRIAL 5%
FIG. 4.5 ELECTRICITY DISTRIBUTION PATTERN IN DIFFERENT SECTORS IN 1988-'89

- INDUSTRIAL: 56%
- AGRICULTURE: 18%
- COMMERCIAL: 2%
- TRANSPORT: 3%
- DOMESTIC: 21%
industrial sector and oil in transportation sector. A slight variation in the consumption pattern of these three will have a major impact on the energy scene of these two sectors.

The major commercial energy sources of India are coal, oil and electricity. Also these are non-renewable in nature which are getting depleted rapidly. Analysis is required for using these resources in a judicious manner and thereby prolonging its availability. To compensate for its reduction, other non-conventional energy sources which are renewable in nature have to be used. India has abundant reserve of such non-conventional energy sources.

The administrative prices on one hand and the rise in national income due to inflation on the other have made the energy problem opaque. Hence to have a clear picture, the price index of energy and national income are calculated at 1980-'81 prices, the base year price. The price index of energy helps in finding the actual rate of increase and it is found that the price index of coal, oil and electricity has remained almost constant till 1972-'73 as shown in Fig.4.6. The increase in coal price since 1972-'73 is around nine times, while for oil and electricity, it is around five times, the 1972-'73 value. The overall energy price represents the average price and in 1988-'89 it lies between oil and electricity price index. Inclusion of energy price in the model indicates its effects on consumption. Also the optimum amount that needs to be used from a national perspective is determined so as to obtain maximum benefits.

Energy consumption per capita is a little ambiguous. Some countries have low energy consumption per capita, but their standard of living is considered high. Sweden has lower energy consumption per capita compared to United States while New Zealand has half the consumption per capita compared to that of United Kingdom and West Germany, though with comparable economic standards. The variation in consumption per capita between countries with the same standard of living may be due to the nature of the economy such as rural or industrial or it may be due to the social values that would emphasize activities
FIG. 4.6 VARIATION OF COMMERCIAL ENERGY PRICE INDEX IN INDIA
which are not energy intensive in nature. The aim of the model is to provide a consumption per capita that results in higher standard of living through efficiency improvements. Hence GNP is included in the model.

The change in consumption per capita and income per capita over the years is plotted in Fig.4.7. From the figure, it could be observed that the commercial energy consumption per capita for all forms of energy shows an increasing trend. However, though the absolute value is increasing, it is very low as compared to developed countries. To increase the income per capita it is essential to utilize the available resources efficiently so as to obtain a higher income. The variation of energy consumption per capita and national income per capita over the years indicate that income is rising at a lesser pace compared to energy consumption in India. Obtaining a higher income at a minimum consumption of energy resource should be the main objective of any energy plan.

4.1.2 Enumeration of the Modified model

Energy planning deals with energy-economy interactions. Energy planning has to consider several factors like GNP, population, environment while planning for demand. The model developed in this work links these factors while predicting the future requirement of commercial energy. It involves two stage least square technique.

Seven time series regression equations have been used. Past consumption data with time are considered. The linear fit is given by the following equation,

\[ X_t = a + b l_t \]  \hspace{1cm} (4.1)

The constant a and slope b are determined from matrix developed using least squared error principle.
FIG. 4.7 COMMERCIAL ENERGY CONSUMPTION PER CAPITA AND GNP PER CAPITA IN INDIA
Once the unknown parameters are determined they are used to form the model,
\[ X_t = a + b I_t + e_t \quad \ldots \quad (4.5) \]
where \( t = 1, 2, \ldots, n \) years corresponding to
- 1970-'71 to 1988-'89 for ST models
- 1953-'54 to 1988-'89 for LT models
\( e_t \) is the error present in the prediction of the model.

The power fit and the exponential fit are given by the following equation,
\[ X_t = a I_t^b \quad \ldots \quad (4.6) \]
\[ X_t = a \exp \left[ b I_t \right] \quad \ldots \quad (4.7) \]

After taking 'ln' on either side, the equation is solved in a similar manner as for a linear model. The quadratic fit is then built which is of the form

\[
\begin{bmatrix}
    n & \Sigma I_t \\
    \Sigma I_t & \Sigma I_t^2
\end{bmatrix}
\begin{bmatrix}
a \\
b
\end{bmatrix}
= 
\begin{bmatrix}
\Sigma X_t \\
\Sigma X_t I_t
\end{bmatrix}
\]

\quad \ldots \quad (4.2)

\[
\begin{bmatrix}
    \text{MAT-A} \\
    \text{MAT-B}
\end{bmatrix}
= 
\begin{bmatrix}
    \text{MAT-C}
\end{bmatrix}
\]

\quad \ldots \quad (4.3)

\[
\begin{bmatrix}
    \text{MAT-B}
\end{bmatrix}
= 
\begin{bmatrix}
    \text{MAT-A}
\end{bmatrix}^{-1}
\begin{bmatrix}
    \text{MAT-C}
\end{bmatrix}
\]

\quad \ldots \quad (4.4)
\[ X_t = a + b \log l_t \quad \text{... (4.9)} \]

After taking log the parameters \( a \) and \( b \) are solved using a 2 x 2 matrix, similar to equation (4.2).

The presence of noise and randomness in the data are removed by using the smoothing methods. Simple exponential smoothing which is suitable when past data remains constant has not been included in this study since it is found that all data, be it, consumption or price or income, has an increasing trend. Hence only double and triple exponential smoothing has been undertaken. The double exponential smoothing is of the form,

\[ X_{t+T} = a_t + b_t T \quad \text{... (4.10)} \]

where

\[ a_t = 2 S_t^{[1]} - S_t^{[2]} \quad \text{... (4.11)} \]

\[ b_t = \frac{\phi}{1 - \phi} \left[ S_t^{[1]} - S_t^{[2]} \right] \quad \text{... (4.12)} \]

and \( T \) represents the future time.

\( S_t^{[1]} \) refers to the first difference and \( S_t^{[2]} \) refers to the second difference which are found using the following equations,

\[ S_t^{[1]} = \phi X_t + (1 - \phi) S_{t-1}^{[1]} \quad \text{... (4.13)} \]

\[ S_t^{[2]} = \phi S_t^{[1]} + (1 - \phi) S_{t-1}^{[2]} \quad \text{... (4.14)} \]
The initial values $S_o^{(1)}$ and $S_o^{(2)}$ are determined using the equation,

$$S_o^{(1)} = a_{est} - \left[ \frac{1 - \phi}{\phi} \right] b_{est}$$ \hspace{1cm} \ldots (4.15)

$$S_o^{(2)} = a_{est} - \left[ \frac{2 (1 - \phi)}{\phi} \right] b_{est}$$ \hspace{1cm} \ldots (4.16)

where $a_{est}$ and $b_{est}$ are the $a$ and $b$ values obtained using the linear model. $\phi$, the smoothing constant is varied from 0.01 to 0.3 in steps of 0.01. The best smoothing constant is selected using the least squared error principle and the best fit is selected as the one with the least squared error, as explained in the error analysis later. The triple exponential smoothing is built of the form,

$$X_{t+T} = a_t + b_t T + c_t T^2$$ \hspace{1cm} \ldots (4.17)

where

$$a_t = 3 S_t^{(1)} - 3 S_t^{(2)} + S_t^{(3)}$$ \hspace{1cm} \ldots (4.18)

$$b_t = \frac{\phi}{2(1-\phi)^2} \left[ (6-5\phi) S_t^{(1)} - 2(5-4\phi) S_t^{(2)} + (4-3\phi) S_t^{(3)} \right]$$ \hspace{1cm} \ldots (4.19)

$$c_t = \frac{\phi^2}{2(1-\phi)^2} \left[ S_t^{(1)} - 2 S_t^{(2)} + S_t^{(3)} \right]$$ \hspace{1cm} \ldots (4.20)

and $T$ represents the future time.
Si1! and S[2] are similar to equation (4.13) and (4.14) respectively. S[3] is given by the following equation.

\[ S_i^{[3]} = \phi S_i^{[2]} + (1 - \phi) S_{i-1}^{[3]} \]  

... (4.21)

The initial values S[1], S[2] and S[3] are obtained using the equations,

\[ S_0^{[1]} = a_{est} - \left[ \frac{1 - \phi}{\phi} \right] b_{est} + \left[ \frac{(1 - \phi) (2 - \phi)}{\phi^2} \right] c_{est} \]  

... (4.22)

\[ S_0^{[2]} = a_{est} - \left[ \frac{2 (1 - \phi)}{\phi} \right] b_{est} + \left[ \frac{2(1 - \phi) (3 - 2\phi)}{\phi^2} \right] c_{est} \]  

... (4.23)

\[ S_0^{[3]} = a_{est} - \left[ \frac{3 (1 - \phi)}{\phi} \right] b_{est} + \left[ \frac{3(1 - \phi) (4 - 3\phi)}{\phi^2} \right] c_{est} \]  

... (4.24)

where a_{est}, b_{est} and c_{est} are the parameters a, b and c obtained from the quadratic model. The parameters a_i, b_i and c_i are obtained for different values of \( \phi \) from 0.01 to 0.3 in steps of 0.01 and the \( \phi \) which best fits is selected from among them, using least squared error technique.

Having obtained the parameters of the seven time series equations, they are then fitted into the model and the predictions are made in each case. The error is then determined for each model.

\[ e_t = x_t - \hat{x}_t \]  

... (4.25)
where $x_t$ is the actual and $X_t$ is the predicted. The squared error is obtained using the equation,

$$SE = \sum_{t=1}^{n} e_t^2$$  \hspace{1cm} \text{... (4.26)}

The model with the least squared error is selected as the best fit time series model. The concise flow chart for the computer program is given in Appendix 1. Logistic model has not been used since in India since the growth is expected to continue till the forecast period 2010-'11. Oil consumption is expected to reach saturation by 2050 and nuclear is expected to contribute to a large portion of electricity generation during that period. As the analysis has been carried up to 2010-'11, consumption is expected to grow steadily till that year. After 2050 the flattening of the curve is expected. Hence logistic model may not be suitable for Indian conditions.

As time series models are used as first approximations, more sophisticated econometric models with previous year's energy consumption, energy price and national income have been used by many researchers. Hence such an econometric model can be developed for India. Since GNP and energy price involve monetary terms, they are adjusted for their inflation by converting the values to a common 1980-'81 price. The variables are then converted to an index with a base year as 1980-'81. The energy demand using econometric model may be expressed as

$$Y_t = K \left[ Y_{t+1} \right]^{\theta} \left[ \frac{P_t}{P_0} \right]^\alpha \left[ \frac{G_t}{G_0} \right]^\beta$$  \hspace{1cm} \text{... (4.27)}

$$Y_t = K \left( Y_{t+1} \right)^{\theta} \left( P_t \right)^\alpha \left( G_t \right)^\beta$$  \hspace{1cm} \text{... (4.28)}

The time response parameter $\theta$, elasticities $\alpha$ and $\beta$, and constant $K$ are determined after taking 'In' on either side.
\[ \ln Y_t = \ln K + \theta \ln Y_{t-1} + \alpha \ln P_{t} + \beta \ln G_{t} \quad \ldots (4.29) \]

\[ \bar{Y}_t = \bar{K} + \theta \bar{Y}_{t-1} + \alpha \bar{P}_{t} + \beta \bar{G}_{t} \quad \ldots (4.30) \]

The unknown parameters $K$, $\theta$, $\alpha$ and $\beta$ are determined using least squared error principle.

\[
\begin{bmatrix}
    \sigma V_{t} \\
    \sigma V_{t}^2 \\
    \sigma P_{t}V_{t-1} \\
    \sigma G_{t}V_{t-1} \\
\end{bmatrix}
= \begin{bmatrix}
    \Sigma V_t \\
    \Sigma V_t^2 \\
    \Sigma P_tV_{t-1} \\
    \Sigma G_tV_{t-1} \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
    \bar{K} \\
    \theta \\
    \alpha \\
    \beta \\
\end{bmatrix}
= \begin{bmatrix}
    \Sigma \bar{V}_t \\
    \Sigma \bar{V}_t \bar{V}_{t-1} \\
    \Sigma \bar{P}_t \bar{V}_{t-1} \\
    \Sigma \bar{G}_t \bar{V}_{t-1} \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
    \text{MAT-D} \\
    \text{MAT-E} \\
    \text{MAT-F} \\
\end{bmatrix}
= \begin{bmatrix}
    \text{MAT-D}^{-1} \\
    \text{MAT-D} \\
    \text{MAT-F} \\
\end{bmatrix}
\]

Once the unknown parameters are determined they are fitted into the econometric model. The concise flow chart for the computer program is given in Appendix 2.

Since this econometric model does not include technological efficiency and environmental quality, Modified model is developed using the two stage least square principle.
The best fit is obtained using Ordinary Least Square Error (OLSE) principle and is taken to the Modified model for the second stage analysis. Any randomness, noise or outliers are removed by going in for this technique. The error is drastically reduced at the second stage as compared to the first stage time series model.

Technological factor depends on several parameters such as age of the equipment, load factor and operating conditions. Different methods of measuring technology have been dealt with by Zaidman and Cevidalli (1989). In all those methods, technology is characterized as an yielded output (product or service) and is expressed by a technical parameter or a cluster of parameters.

The end-use efficiencies of the various systems in India taking into account new technology introduction over the years are fitted into the model. Sourcewise efficiency over the years is calculated based on weighted average method.

The efficiency based on the first law of thermodynamics, of the coal fired boilers used in industries is considered to be 76% over the years 1953-'69, 82% from 1969 to 1980, 85% during 1980-'85 and 90% from 1985 to 1989 because of the use of fluidized bed boilers, while for coal furnaces used in industries, the efficiency is considered to be 30% during 1953-'74 and 40% from 1974 onwards. The efficiency of steam engines used in transport is considered to be 37% during 1950-'70 and 39% over the years 1970-'89. The efficiency of stoves using coal is considered to be 40% from 1950 to 1970 and 60% during 1970-'89. The efficiency of oil fired boilers used in industries is considered to be 82% during 1950-'82 and 85% from 1982 to 1989 while the efficiency of oil furnaces is considered to be 40% over the years 1953-'72 and 45% during 1972-'89. The efficiency of diesel engines used in transport is considered to be 30% from 1950 to 1968 and an increase of about 6 percent is noticed by the year 1989, with proper plant operation. The efficiency of oil stoves used in domestic sector is considered to be 40% from 1950 to 1970 and 70% during 1970-'89. The efficiency
of diesel pumpsets used in agriculture is considered to be 50% over the years 1950-70 and 70% from 1970 to 1989. The efficiency of lighting in industrial and domestic sectors is 25% during 1950-72, 75% from 1972 to 1987 and 90% over the years 1987-89 while for heating it is considered to be 60% from 1950 to 1970, 70% during 1970-72, 80% over the years 1972-87 and 85% from 1987 to 1989. For oven the efficiency is considered to be 70% from 1950-70 and 80% over the years 1970-89. The efficiency of electric vehicles is considered to be 60% during 1950-61, 70% over the years 1961-70 and 75% from 1970-89. The efficiency of pumpsets over the years 1950-70 is considered to be 60%, while during 1970-81 it is considered to be 65% and from 1981 to 1989 as 75%. These informations were collected from industrial users, product manufacturers and the following literatures (Ashok 1990, Durgesh et al 1990, Duffy 1972, Faber 1961, Mitchell 1983, Perry 1950, Romer 1976).

The large scale utilization of fossil fuels to generate heat and electricity for a growing population has increased the level of carbon dioxide in the atmosphere. This has resulted in global warming. Hence to constrain the rise of CO₂, it has been included in the energy consumption model. The CO₂ emitted per ton of coal and oil is multiplied by the energy consumption figures to obtain CO₂ emission. About 65% of the total electricity generation is at the thermal power station and this results in tremendous quantity of CO₂ emission. Hence CO₂ emitted at the thermal power plants is taken as the CO₂ emission from electricity. If CO₂ emitted from energy sources is curtailed, the amount of energy that needs to be utilized sourcewise can be determined. The effect of efficiency improvements, emission reductions on energy consumption is studied.

In the Modified model, refined energy consumption (Y) at time ‘t’ is a function of energy consumption (X) at time ‘t’ obtained using regression analysis, price (P) at time ‘t’ corresponding to a base year, GNP at time ‘t’ corresponding to a base year, technological efficiency (TE) at time ‘t’ and CO₂ emission (EQ) at time ‘t’. Modified model can be represented as
\[
Y_t = K \left( \frac{X_t}{P_o} \right)^{\theta} \left( \frac{G_t}{G_o} \right)^{\beta} \left( \frac{TE_t}{EQt} \right)^{\delta} \left( \frac{EQ_t}{EQt} \right)^{\tau}
\]

\[Y_t = K (X_t)^{\theta} (P_l)^{\alpha} (G_l)^{\beta} (TE_t)^{\delta} (EQ_t)^{\tau}\]

... (4.35)

The constant \( K \) and the parameters \( \theta, \alpha, \beta, \delta \) and \( \tau \) are determined after taking 'ln' on both sides.

\[
\ln Y_t = \ln K + \theta \ln X_t + \alpha \ln P_l + \beta \ln G_l + \delta \ln TE_t + \tau \ln EQ_t
\]

... (4.36)

\[
\bar{Y}_t = \bar{K} + \theta \bar{X}_t + \alpha \bar{P}_l + \beta \bar{G}_l + \delta \bar{TE}_t + \tau \bar{EQ}_t
\]

... (4.37)

The unknown parameters are determined using least squared error principle.

\[
\begin{bmatrix}
\Sigma X_t \\
\Sigma X_t^2 \\
\Sigma P_l \\
\Sigma P_l^2 \\
\Sigma G_l \\
\Sigma G_l^2 \\
\Sigma TE_t \\
\Sigma TE_t^2 \\
\Sigma EQ_t \\
\Sigma EQ_t^2
\end{bmatrix}
\begin{bmatrix}
K \\
\theta \\
\alpha \\
\beta \\
\delta \\
r
\end{bmatrix}
= 
\begin{bmatrix}
\Sigma Y_t \\
\Sigma Y_t X_t \\
\Sigma Y_t P_l \\
\Sigma Y_t G_l \\
\Sigma Y_t TE_t \\
\Sigma Y_t EQ_t
\end{bmatrix}

\]

... (4.38)
Using the parameters obtained from the matrix the Modified model is developed. The concise flowchart for the computer program is given in Appendix 3.

4.1.3 Validation of the Model

The model is validated by comparing with other models, the squared error (SE), square of correlation coefficient ($R^2$) and the Durbin Watson (DW) statistic. The square of the difference between the actual and the predicted is called the squared error. The model which has the least squared error will hence mean that the deviation of the predicted from the actual in that model will be the least. Square of the correlation coefficient $R^2$ explains the strength of the relation of the independent variable with the dependent variable. If $R^2$ is near the value of 1, the independent variable will explain a large part of the variation in the dependent variable. When there is a natural sequential order in the error term, the correlation is referred to as autocorrelation. Autocorrelation occurs when a variable is omitted in the model on the right hand side. In such cases, a cluster of errors is noticed. Presence of autocorrelation is always checked by the Durbin Watson statistic.

4.1.3.1 Error Analysis

The error is determined using the equation

$$e_t = x_t - Y_t \quad \ldots (4.41)$$
The SE as per equation (4.26) is determined. For validation $R^2$ and DW value is also determined using the equation

$$R^2 = 1 - \frac{\sum_{t=1}^{n} (x_t - x_m)^2}{\sum_{t=1}^{n} (y_t - \hat{y}_t)^2}$$  \hfill (4.42)$$

$$\text{DW} = \frac{\sum_{t=2}^{n} (e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}$$  \hfill (4.43)$$

where $x_m$ is the mean value. Validation is then carried out for time series model and the econometric model using equations (4.26), (4.41), (4.42) and (4.43). The concise flow chart for the computer program is given in Appendix 4.

The best model is selected as the one with the least squared error, highest correlation coefficient and highest DW statistic. The Modified model is then used to make predictions.

### 4.1.3.2 Uncertainty Analysis

Uncertainty analysis is then carried out to determine the effect on consumption because of changes in the independent variables. The confidence limits are then determined for $Y_t$ with confidence coefficient $\mu$ using the following equation,

$$Y_t \pm St_{(n-p-1), (1-\mu/2)} \hat{SE}(Y_t)$$  \hfill (4.44)$$
where \( St \) is the tabular Students 't' value for \( [(n-p-1), (1-\mu)/2] \) degrees of freedom. 

\[ \text{SE} (Y_t) \] is determined using the equation,

\[ \text{SE} (Y_t) = \sqrt{V(Y_t)} \] ... (4.45)

\[ V(Y_t) = \sigma^2 \left( 1 + \frac{1}{n} \right) + \sum_{i=1}^{p} (v_{it} - v_{im}) V(b_i) \]

\[ + 2 \sum_{i=1}^{p} \sum_{j=i+1}^{p} (v_{it} - v_{im}) (v_{jt} - v_{jm}) C(b_i, b_j) \] ... (4.46)

\[ \sigma^2 = \frac{\text{SE}}{n - p - 1} \] ... (4.47)

\[ V(b_i) = \text{Variance of } b_i \]

\[ = \sigma^2 C_{ii} \] ... (4.48)

where \( C_{ii} \) is the \( i^{th} \) diagonal element of the inverse of the corrected sum of squares and product matrix.

\[ C(b_i, b_j) = \text{Covariance between } b_i \text{ and } b_j \]

\[ = \sigma^2 C_{ij} \] ... (4.49)

where \( C_{ij} \) is the element in the \( i^{th} \) row and \( j^{th} \) column of the inverse of the corrected sum of squares and products matrix.

The effect of price, efficiency and population on energy consumption is studied using the long term Modified model. To study the effect of population the GNP in the Modified model is calculated as per capita GNP and the Modified model with 5 variables is then multiplied by the 6th variable population and is then used in the 7x7 matrix equation.
4.2 MATHEMATICAL PROGRAMMING ENERGY ECONOMY ENVIRONMENT MODEL

Energy economics is helpful in developing energy policies that allow the economy to produce and consume energy more efficiently thereby maximizing net output and growth. Economic efficiency includes both efficient consumption and production of energy. Mathematical Programming Energy Economy Environment (MPEEE) model, an optimization model, has been developed so as to use energy more efficiently while trying to meet the energy requirement and curtail the pollution. The two issues though conflicting in nature, try to balance within themselves while maximizing the GNP-energy ratio. Maximizing the ratio helps in maximizing the income while minimizing the energy consumption. The constraints limit the six major emissions resulting from fossil fuel utilization. The optimum values for the variables $y_1$, $y_2$, and $y_3$ are determined at various percentage reductions of the emissions. The values indicate the quantity of coal, oil and electricity that need to be utilized for obtaining reductions in the emission levels.

4.2.1 Significance of Energy-GNP ratio

The energy-GNP ratio gives an indication of several parameters. Using the ratio, the energy price can be predicted. It also depicts several factors like the prosperity of a country, its prevailing economic conditions and technological breakthroughs.

The energy-GNP ratio can be maintained stable, or more preferably it can have a declining trend over the years. If the energy-GNP ratio is increasing, it invariably means that energy is being consumed at a faster rate and hence there will be a problem of energy scarcity in future. Energy-GNP ratio can also have a declining trend if both energy and GNP decline at a faster rate. To determine the rate of change in the ratio with reference to energy and GNP, their variation is studied independently along with the energy-GNP.
India meets the growing demand by importing tremendous quantity of oil from the Gulf countries. If this quantity of oil had been supplied indigenously the national income of India would have been higher.

4.2.2 Energy Environment Nexus

Over 95% of the energy demand of the industrial world is met by burning fossil fuels. India’s commercial sources has contributed to a large extent to environmental degradation. The emissions that result from the utilization of these sources are discussed below.

4.2.2.1 Carbon Dioxide Emission (CO2)

Accumulation of CO2 in the atmosphere increases the atmospheric temperature resulting in global warming. The average temperature has risen by 0.5-0.7 degree Celsius with an accompanying rise in sea level of around 1 cm per year. It is estimated that if the present trend continues for another 50 years, the temperature rise would be around 1.5-4.5 degree Celsius and the sea level will increase by 0.3-1.3 metres. The effects of global warming are already being felt - increased occurrence of flooding in coastal areas, general temperature increases, northerly shifts of climatic patterns, hot dry regions becoming hotter and drier, warm, wet regions becoming warmer and wetter, increased severity and violence of weather patterns and greater fluctuations of temperature, wind and precipitation. The amount of CO2 emission from various energy sources in India is given in Fig.4.8. About 1550 million tonnes of CO2 was added to the atmosphere during the year 1988-'89 in India. To reduce the addition, curtailment of fossil fuel usage and afforestation measures are required. Growing of trees not only helps reduce CO2 emission but also helps generate bioenergy. The quantity of fossil fuel to be utilized for various percentage reduction in CO2 is determined by including it in the model.
FIG. 4.8 EMISSION OF CO$_2$ FROM COMMERCIAL ENERGY SOURCES
4.2.2.2 Sulphur Dioxide Emission (SO\textsubscript{2})

About 90% of the SO\textsubscript{2} emitted into the atmosphere is because of fossil fuel combustion. The SO\textsubscript{2} emission in India is given in Fig. 4.9. Usage of low sulphur containing fuels would result in lesser sulphur emission. Sulphur content in the atmosphere can be controlled by going in for coal washing, coal gasification and oil desulphurization. These techniques have to be made cost effective if they are to be utilized. Policy decisions are mostly based on cost. To reduce the SO\textsubscript{2} emission, it has been included as a constraint in the Modified model.

4.2.2.3 Nitrogen Dioxide Emission (NO\textsubscript{x})

Of the total Nitrogen Oxides (NO\textsubscript{x}) present in the atmosphere, only 50% is because of natural consequences. Of the remaining, 75% is due to fossil fuel combustion. NO\textsubscript{x} combines with CO, resulting in ozone formation which causes photochemical smog. NO\textsubscript{x} reacts with the water vapour forming nitric acid which leads to acid rain. NO\textsubscript{x} is formed because of inadequate supply of air during the usage of oil stoves, gas appliances and other combustion process. The NO\textsubscript{x} emission in India is plotted in Fig. 4.10. The usage of catalytic converters will help reduce NO\textsubscript{x} emission from vehicles. Emission from other sources can be reduced by going in for flue gas treatments or by using low NO\textsubscript{x} burners. To restrict NO\textsubscript{x} emission from fossil fuels particularly from that used in vehicles, it has been included as one constraint in the model. For a certain percentage reduction of NO\textsubscript{x} the quantity of coal, oil and electricity that can be used is determined.

4.2.2.4 Total Suspended Particulates (TSP)

Particulate matter arises from different sources. The major contributors are from the industrial and agricultural sectors. These minute particles are blown by the wind and remain suspended in the atmosphere. Sometimes sand particles that are blown into the air get accumulated. Around 5 to 50% of TSP in the atmosphere is caused by human beings. The TSP emission in India is given in
FIG. 4.9 EMISSION OF SO$_2$ FROM COMMERCIAL ENERGY SOURCES
FIG. 4.10 EMISSION OF NO$_2$ FROM COMMERCIAL ENERGY SOURCES
Fig. 4.11. Coal washing, usage of natural gas where possible will help reduce this emission. Installation of particle removal equipment in power stations along with efficient combustion techniques will bring down the TSP emission to a large extent. TSP is found to cause several hazards. Its presence in the atmosphere needs removal. It has been hence decided to include it as a constraint in the model.

4.2.2.5 Carbon Monoxide Emission (CO)

Incomplete combustion of carbonaceous fuels in industries and vehicles results in CO formation. CO is emitted from the stoves because of the absence of sufficient quantity of air. Forest clearing results in tremendous amount of CO in the atmosphere. Also burning of fuelwood and hydrocarbons oxidation result in CO emission. Of the total prevalent CO in the atmosphere 60% is because of these above factors. The CO emission from various commercial energy sources in India is given in Fig.4.12. Reduction in CO emission is carried out by reducing the vehicular CO emission, through improvements in engine design and exhaust emission controls. CO is found to cause several harms. To reduce its effects, its accumulation in the atmosphere has to be removed and hence it has been included in the model as a constraint.

4.2.2.6 Volatile Organic Compounds (VOC)

VOC results from inefficient combustion of hydrocarbons (HC). HC are the essential ingredient of photochemical smog. The VOC emission in India over the past four decades is given in Fig.4.13. Most of the HC emission are from vehicles and hence reduction is carried out by controlling vehicular emission. To reduce the content of VOC in the atmosphere it is included in the model as a constraint.
FIG. 4.11 EMISSION OF TSP FROM COMMERCIAL ENERGY SOURCES
FIG. 4.12  EMISSION OF CO FROM COMMERCIAL ENERGY SOURCES
FIG. 4.13  EMISSION OF VOC FROM COMMERCIAL ENERGY SOURCES
4.2.3 Characteristics of the MPEEE Model

MPEEE model is an optimization model which links energy, economy and environment. The objective equation maximizes the GNP-energy ratio. In other words, the program tries to maximize the national income at a minimum consumption of energy. This is made possible through efficiency improvements and conservation measures. The constraints limit the emission of the six major emissions from fossil fuels - CO₂, SO₂, NO₂, TSP, CO and VOC.

The predicted coal, oil and electricity requirements from the Modified model is used as input in the MPEEE model. The GNP-energy ratio \( A_t \) for coal, oil and electricity is predicted for a certain year 'T' at which the optimum values \( y_{IT} \) are going to be determined. It is then used in the equation

\[
\text{Maximize } Z = \sum_{t=1}^{3} A_{IT} y_{IT} \quad \ldots \quad (4.50)
\]

In the case of electricity, emission occurs at the thermal power station. The emission factor in the case of CO₂, SO₂, NO₂, TSP, CO and VOC is multiplied by the coal used at the thermal power station over the years to obtain the emission from electricity. The emission factor is for emission at the power station and hence if used as such in MPEEE model, the variable 'y₃' for electricity will give the optimum coal to be used at the thermal power station and not optimum electricity requirement in 2010-'11. Hence the emission factor from electricity is determined in each case using the equation,

\[
\text{Emission factor for electricity} \times \begin{bmatrix} \text{Predicted coal use at the thermal power station in time } T \\ \text{Electricity requirement in time } T \end{bmatrix} = \frac{\text{Emission factor of coal used at thermal power station}}{\text{Electricity requirement in time } T} \quad \ldots \quad (4.51)
\]
The emission factor obtained is used in the MPEEE model. The constraints used in the MPEEE model are

\[
\sum_{t=1}^{3} \left[ \begin{array}{c} B_{tk} \\ \end{array} \right] \left[ \begin{array}{c} y_{tk} \\ \end{array} \right] \leq \left( 1 - m \right) F_{kT}
\]

\[
\sum_{t=1}^{3} y_{t} \geq 0
\] ... (4.52)

'k' represents the emissions and m the percentage reduction of emission. Since there are 6 emissions and 3 sources it will be a 3 x 6 matrix. B represents the emission factor in time 'T'. The y_t gives the optimum requirements of coal, oil and electricity based on the six constraints.

The model is analysed for various percentage reduction of emissions obtained using the equation,

\[
\begin{bmatrix}
\text{Emission at m\% reduction of pollutants} \\
\text{in time 'T'}
\end{bmatrix}
= \begin{bmatrix}
\text{Emission of pollutants in time 'T'} \\
\text{Emission of pollutant in time 'T' in 88-89}
\end{bmatrix} \cdot m\% \begin{bmatrix}
\text{Pollutant emission in 88-89}
\end{bmatrix}
\] ... (4.53)

It is not viable to remove 100% emission which would require complete termination of fossil fuel use.

When the model is analysed, it is found that electricity generation from coal gets the minimum allocation because of extensive pollution. A constraint is hence introduced which indicates electricity generation should be greater than the existing thermal power stations which cannot be terminated. The constraint used is,

\[
y_{3} \geq 235.96
\] ... (4.54)
CO₂ emission being the largest in India, detailed analysis is carried out for CO₂. The installed capacity for electricity is planned at 175,000 MW in 2000-'01 (Thirteenth EPS 1990) which is equivalent to 636.6 BU electricity generation capacity approximately. Since already work has been started to reach this plan level, the program is run at various y₃ values ranging from 235.96 to 636.6 MTCR. The optimum y₁, y₂ and y₃ are determined at various percentage reductions of CO₂ in 2000-'01, 2005-'06, 2010-'11, 2015-'16 and 2020-'21. The emission factor Bₖ and the total emission Fₖ of equation (4.52) and the objective function of equation (4.50) will vary for each year.

Similar constraints are developed for individual sectors and the optimum demand for coal, oil and electricity is determined in the various sectors. In the case of electricity, the emission is determined at the thermal power station. This is then categorized into different sectors based on the consumption pattern over the years. The emission factor for electricity is then determined in each sector as per the equation previously explained. The model is very flexible. It can also be used for minimizing or maximizing consumption, in which case the objective function becomes

\[ \min/\max Z = \sum_{t=1}^{3} y_t \]

The constraints will remain the same.

4.3 DELPHI METHODOLOGY

The Delphi study is conducted to arrive at a decision, based on quantitative values with regard to social acceptance and percentage allocation of the non-conventional energy sources. A simple survey will only give the awareness of the public on the different options available, but to determine the social acceptance and the possible percentage allocation, a consensus needs to be arrived at, which validates the use of Delphi. The method helps to process
information that looks haphazard and unsystematic on a scientific basis. Participants arrive at a consensus of opinion without being forced to follow a certain viewpoint.

4.3.1 Delphi Process

The Delphi questionnaire has been framed and given to ten experts as a pretest to check for its reliability and validity. The Round one questionnaire is then prepared taking into consideration the alternatives suggested by experts. A copy is given in Appendix 5. The first round questionnaire is mailed to 200 participants and in addition to that 100 participants are met in person. The participants are managers in industries, officers in transports, corporations, agriculturists, professors, policy makers and the general public. The questionnaire is designed to take up only a few minutes of each participant's time.

The mean value of the responses is determined. The second round contains the mean value and their responses. The participants are asked to review their responses and remark on the reason for their deviation from the general response. Round two questionnaire is sent to 131 respondents all over India. A copy of Round two questionnaire is also given in Appendix 6. Out of 131 responses, 61 responses are received and statistical analysis is carried out to check whether stability and consensus have been obtained. It is found that in a majority of cases the results are positive.

The statistical tests and analysis are carried out after receiving the second round responses. In the first round, 43.7% response has been obtained and in the second round it is 46.6%. The analysis indicate the achievement of consensus and stability and hence the Delphi is stopped after the second round.
4.3.2 Delphi Analysis

The questionnaire is analysed to determine whether there has been a shift in their responses from round one to round two, whether uncertainty has decreased and whether consensus has been reached. The mean, standard deviation, confidence, group stability and individual stability of the participant in answering a question are determined. The responses are given scores either from 1 to 3, from 1 to 6 or in some cases 1 to 10 depending on the number of options. The scores are the weightages given to each option so that from the result it is easy to determine the category in which the general response lies.

4.3.2.1 Mean

The mean response is the average response of the participants. The responses are given a scaling and then the value is determined. The mean response nearer to a certain option is found and that option is taken to be the mean value.

\[
\text{Mean Score} = \frac{\sum \text{number of responses for option } i \times \text{Score}}{(\text{Total number of responses}) - (\text{questionnaires not answered})}
\]

where \(i\) indicates different options.

4.3.2.2 Standard Deviation

It gives a measure of the extent of the spread in deviation. From one round to the next the deviation from the mean response should decrease to indicate a decrease in dispersion. The standard deviation is obtained using the equation,

\[
\text{Standard Deviation} = \sqrt{\frac{\sum \text{number of responses for option } i \times (\text{Score} - \text{Mean Score})^2}{(\text{Total number of responses}) - (\text{Questionnaires not answered})}}
\]
4.3.2.3 Confidence

It gives a measure of the participants' confidence in answering a certain question. As the round goes from one to the next, the confidence in answering the question should increase.

\[
\text{Confidence} = \frac{\text{Questionnaires not answered}}{\text{Total number of responses}} \quad \ldots (4.57)
\]

4.3.2.4 Stability

Stability is the change in individual response from round to round. Stability is used as a measure to decide the number of rounds required for Delphi. A statement was considered stable when 80% or more of the participants did not change their responses (Nelson 1978).

Chi square ($\chi^2$) test has been used to determine individual and group stability (Chaffin and Talley 1980) in this Delphi study. Group stability is checked by forming a table for each question. The observed values are values obtained from the Delphi. In the observed value table, rounds form the row and options form the column.

<table>
<thead>
<tr>
<th>Observed</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
</tr>
<tr>
<td>Rounds</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>O_{11} O_{12} O_{13} RT_1</td>
</tr>
<tr>
<td>II</td>
<td>O_{21} O_{22} O_{23} RT_2</td>
</tr>
<tr>
<td></td>
<td>CT_1 CT_2 CT_3 GT</td>
</tr>
</tbody>
</table>

The expected value table is then obtained using the equation,

\[
E_{11} = \frac{RT_1 \times CT_1}{GT} \quad \ldots (4.58)
\]
The expected value table is given below,

<table>
<thead>
<tr>
<th>Expected</th>
<th>Options</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>E₁₁</td>
<td>E₁₂</td>
<td>E₁₃</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>E₂₁</td>
<td>E₂₂</td>
<td>E₂₃</td>
<td></td>
</tr>
</tbody>
</table>

The \( \psi^2 \) value for group stability is then obtained using the expression

\[
\psi^2 = \sum_i \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij}}
\]  

... (4.59)

where \( i \) represents the row and \( j \) represents the column.

Individual stability is then determined using the same \( \psi^2 \) formula. The observed value table is then formed as follows,

<table>
<thead>
<tr>
<th>Observed</th>
<th>Round I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Round I</td>
<td>O₁₁</td>
</tr>
<tr>
<td></td>
<td>O₂₁</td>
</tr>
<tr>
<td></td>
<td>O₃₁</td>
</tr>
<tr>
<td></td>
<td>CT₁</td>
</tr>
</tbody>
</table>
The expected value table is then formed using the equation (4.58).

<table>
<thead>
<tr>
<th>Expected</th>
<th>Round I</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Round II</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>E_{11}</td>
<td>E_{12}</td>
<td>E_{13}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E_{21}</td>
<td>E_{22}</td>
<td>E_{23}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E_{31}</td>
<td>E_{32}</td>
<td>E_{33}</td>
<td></td>
</tr>
</tbody>
</table>

These two tables are used to obtain the $\chi^2$ value for individual stability. This $\chi^2$ value for individual stability and group stability is then checked with the table value for the (i-1)(j-1) degrees of freedom (DOF), i and j being the number of rows and columns respectively. If the calculated $\chi^2$ value is less than the table value the null hypothesis is accepted. If it is greater than table value, alternate hypothesis is accepted. The concise flowchart for the computer program developed for solving the above is given in Appendix 7.

The results of the Delphi study are then compared with the Modified model predictions and MPEEE model optimum allocations to arrive at a percentage distribution of non-conventional energy sources.

The model developed has the following specific features: inclusion of technological and environmental factors in addition to energy price and national income in forecasting the energy demand, optimum allocation of energy sources for maximization of GNP-energy ratio and consensus of opinion for acceptance of non-conventional energy sources.