CHAPTER 2

LITERATURE SURVEY

An ON-LINE search of computerized data has been conducted on topics relating to energy modelling, economy and environment. Global energy models and national energy models that link energy with environment, and energy models for policy decisions are collected. It has been found that at the national level time series and econometric models with two or more variables are being used to predict future energy consumption. A few researchers have worked on optimization models linking energy with economy or energy with environment. The significance of GNP-energy ratio has been realized. Uncertainty analysis has been used to determine the extent of confidence of the predictions. The scope and viability of Delphi methods and applications have been collected for determining the social acceptance of non-conventional energy sources.

2.1 GLOBAL ENERGY MODELS

The global models on energy have been developed for predicting the energy demand and to analyse the impact of energy consumption on the environment.

In the Energy Policy Project (EPP 1974) United States energy position is determined under various scenarios of reduced energy consumption.

The Project Independence Evaluation System (PIES) model (Federal Energy Administration 1974, 1976), initiated soon after the oil crisis, is a comprehensive model which linked supply with econometric demand model using linear programming. Future requirement is determined and is adjusted with the available resource using linear programming.
A combination of Energy Technology (Manne 1976) and macro economic
growth model has been carried out by Ford Foundation (1977) to study the role
of nuclear power. Supplies, demand and price are matched through a dynamic
non-linear programing model. The model assumes that as price increases, supply
increases and greater is the need to conserve energy. The macro economic
production function provides for substitution among inputs of capital, labour and
energy use.

Yet another model developed for finding the United States energy
demand is determined by Committee On Nuclear and Alternate Energy Systems
(CONAES 1977) using assumptions regarding energy prices, income, population
and public policies. CONAES determined the energy requirement in different
sectors.

The Workshop on Alternative Energy Systems WAES (1977) did not rely
on any energy-economy models. It found the oil supply and demand globally
under certain conditions. Future economic growth and oil price are determined.
Oil substitution by coal and nuclear are studied. Sensitivity analysis is carried out
to find the implications of uncertainty in the assumptions. Global requirements are
broken down to national level and the national supply and demand are then
analysed. This model is not based on past data, but the past is analysed to
develop future scenarios. In this case econometric models are not developed for
projecting the future. Hughes et al (1978) has analysed WAES model using World
Integrated Model (WIM). Computer simulation is carried out between major
regions of the world. Energy production, consumption, oil price, oil depletion and
energy conservation are included in the model.

The Brookhaven National Laboratory developed a Brookhaven Energy
System Optimization Model (BESOM) which evolved into a number of variants and
successors including a time step model (TESOM) and a dynamic model (MARKAL).
BESOM combines a programming model of energy supply with a long run macro
economic growth and input-output model (Groncki and Marcuse 1980). Economic
impacts of fuel scarcities are analysed. Fuel mix is determined by varying the input-output model coefficients. The two models are then balanced using iterations.

Hoffman et al (1982) have pointed out the uncertainties associated with energy policy as the rate of growth of energy supply, investment in more efficient energy utilization, appropriate strategy for research and development and causes and methods of dealing with environmental problems. It has been suggested that a model should try to answer these questions to remove uncertainties. Hoffman reviews the various energy models - BESOM which evolved into TESOM and MARKAL. MARKAL is a linear programming market allocation model developed for long term research and development, planning and analysis, and contains a large number of new energy technologies. LEAP has been used for similar purposes and includes a rather complete set of new technologies. It uses a dynamic network to balance energy flows and prices. MEFS is a linear programming supply model linked to econometric demand models, developed and used by the Energy Information Administration of the United States Department of Energy for mid-term forecasting and policy analysis. MEFS concentrates more on regional energy market than on new technologies. FOSSIL II emphasizes dynamic transitions in energy supply using the systems dynamics approach and has been used extensively in policy analysis. IIASA models are developed on these foundations and ETA-MACRO model developed a linear programming supply model (MESSAGE) and an accounting model of demand (MEDEE). All the models addressed long term energy requirements.

Environmental analysis and least cost energy models are applied to United States Energy structure (OECD 1983). Regional/national energy mix and environmental impact scenario evaluations are determined for energy systems. Torrens (1983) has addressed the energy environmental problem from an end-user perspective. Direct and indirect emission, air pollution, impact of conservation are studied. The case studies include a local energy-environment model, a
regional environment-energy analysis using a computer optimization model and a
national environment-energy analysis, using an economic energy model.

MARKAL model has been developed for Australia (De L. Musgrove, 1984)
to determine the fuel options available under a variety of realistic constraints and
objective functions since it addresses fuel switching, technology substitution, energy
conservation and emission abatement.

Thode et al (1985) have fitted a regression model within the Brookhaven
Energy System Optimization Model (BESOM) where oil use is a function of coal
use and gas use. This is expressed in log form. The BESOM's linear programming
investigates alternate imports, capital requirements, environmental effects and
natural resource uses. All these relate to energy factors. Economy has not been
mentioned. Environmental effects have been included.

The efficiency of sectors and fuel is maintained constant and the
aggregate energy supply, demand and price forecasting are analysed for different
policies by the Department of Energy, Mines and Resources (EMR) energy demand
and price modelling system for Ontario, Canada (Halliwell et al 1985).

Baldwin and Prosser (1988) have simulated the world oil markets based
on standard commodity models. They can be classified as simulation and
optimization models.

Hamilton (1989) has used MARKAL models for controlling emission and
finding alternate fuel options.

Most of these models have used econometric models with linear
programming. The combined linear programming econometric system provide the
capability to represent structural changes in the energy system in an explicit
manner, while maintaining the overall economic and behavioural relationships
captured by econometric model. These global models are studied to determine the significant parameters that need to be used in national energy modelling.

2.2 GLOBAL ENERGY MODELS LINKING CARBON DIOXIDE (CO₂)

Leinweber et al (1980) developed a model to assess the environmental effects of different energy policies and gauge the validity of such assessments. The model calculates the amount of air pollutants and nuclear wastes.

The uncertainties involved in assessing CO₂ in the atmosphere are the behaviour of the natural carbon cycle, rate of uptake by the oceans and biomass of anthropogenic CO₂, the accuracy of general circulation models that simulate the atmospheric response to an increased loading of CO₂ and the expansion, conservation and fuel switching in the energy supply (Schware 1981). Because of such uncertainties, the models try to stabilize the atmospheric CO₂, by reducing the CO₂ emission from fossil fuel.

In the energy-CO₂ models reviewed by Keepin (1986), it is found that IIASA (1981) scenarios involve an iterative procedure. Economic parameters and population are fitted into the energy demand model and projected. The demand is then fed into the supply model to find the least expensive strategy. This strategy is then used to calculate the economic and environmental impacts. The procedure is repeated until internal consistency is obtained. The IIASA is criticized because of the iterative procedure and the key results are found to depend on uncertain costs and resource estimates. It is a global model involving economic, demographic, geographic and resource data from all regions. Despite robustness, sensitivity analysis showed the analytical structure to be highly unstable. Lovins et al (1981) starting with the low scenario developed by IIASA emphasize a strategy for energy conservation, efficiency improvements and alternate energy sources. It finds a method to reduce energy consumption and eliminate CO₂ emission. The results of the model establish the fact that economic growth is not tied to energy demand growth. Nordhaus and Yohe (1983) determine global GNP
as a function of labour productivity, population and energy consumption. Substitution of fossil fuel by non-fossil fuel is considered. Probabilistic scenario analysis is carried out. Ten variables whose value are uncertain is given a high, medium and low value. The model is then used to analyse CO₂ emissions for these scenarios. In addition to sensitivity analysis, Nordhaus and Yohe attempted model validation. Though model validation gave positive results, Nordhaus and Yohe model did not consider income and end-use efficiency which are found to be sensitive parameters in other models. Their omission in Nordhaus and Yohe model is significant.

There is considerable debate over the issue that the presence of CO₂ in the atmosphere causes the temperature to increase. Keeling and Bacastow (1978) has carried out research and found the concentration of CO₂ to be steadily increasing and state that this in turn will increase the average atmospheric temperature. Brooks (1989) states that the temperature and CO₂ concentration have remained almost stable over the past hundred years and unnecessary caution is imposed on energy usage. But he agrees that there may be a small percentage of rise in temperature.

Darmstadter and Edmonds (1989) have studied the impact of technological innovation with reference to energy models. In this global model the world is divided into nine regions and studied. The CO₂ emission is then determined after balancing the energy demand with energy supply.

Diepstraten et al (1989) state that the only short term option available to reduce CO₂ emission is to reduce fossil fuel utilization. They are of the opinion that the problem cannot be solved either by energy conservation or fuel tax, but energy efficiency should be improved and henceforth energy analysis concept has to be used in policy making.

Harvey (1989a) has found out how the atmospheric temperature would vary for different scenarios. His results indicate that the air borne fraction of CO₂
falls rapidly once emission begins to decrease, so that the total emission can be
reduced to half the present value to stabilize atmospheric CO₂. Hence to stabilize
atmospheric CO₂ it is sufficient to reduce 50% of the existing value. Also
deforestation has a disproportionately large effect on net emission. The changes
in temperature, CO₂ concentration in the terrestrial biosphere are analysed
(Harvey 1989b). He agrees that CO₂ emission can be reduced by improving
efficiency, by replacing fossil by non-fossil fuels; nuclear may be counter productive
(Harvey 1990). He states that natural gas can be used profitably to replace coal.

Boyle (1990) feels 60% reduction in CO₂ emission and significant
reduction in other greenhouse gases may be required to stabilize the climate.

It is found by vector optimization that the application of energy saving
technologies together with CO₂ removal techniques may reduce the overall
emission of CO₂, by more than 70%. This will increase the costs of energy system
by 100% and reduce energy consumption by 25% (Groscurth et al 1990). Alfsen
et al (1990) have calculated the CO₂ emission for power plants, industry and
transport as a function of consumption, fuel efficiency and emission coefficient.

2.3 ENERGY POLICY MODELS

Barnett (1950), Cottrell (1955), Cook (1971) and Odum (1973) have
concluded that higher GDP per capita requires higher energy consumption per
capita.

A computer model has been developed by Schweizer et al (1973) to
analyse the supply, demand, energy price based on future policies and technology
changes.

Cooper (1975) reports about the California laws and regulations, dealing
with energy policy analysis and forecasting, and the requirements and
methodology necessary to fulfill these policies.
Econometric and process analysis models are developed to quantify the impact of alternate energy policies on future energy prices, energy utilization and economic growth in United States (Hudson and Jorgenson 1978). Four cases are analysed and it has been found that substantial reduction in energy can be achieved from adjustments in the pattern of energy use and in the structure of economic activity.

Laurmann (1978) has recommended policies for reducing CO₂ emission resulting from fossil fuel utilization. Econometric models are used to predict the future energy requirement.

A simulation model is used for energy planning (Scholer et al 1978). The model will provide consistent projections about energy demand, energy conservation, alternate energy development strategies and, economic and ecological consequences of these alternates.

Holoday (1979) states that though the use of energy models is increasing, quantitative modelling has had little impact on either policy making or on oil and gas exploration. Models are of high technical quality and high credibility and hence they should be used for policy decision making.

It is felt that unless the energy input to agriculture in rural areas is increased, the socio-economic condition of the villagers will suffer (Brisco et al 1979). However, Revelle (1980) feels that the reason why people live in poverty in villages is that they are not in a position to use the available energy efficiently. There are several renewable energies available like biomass, agricultural and animal wastes, biogas and solar. Electricity can be generated at mini stations which use renewables. Efficient utilization of energy will help energy to last longer.

Hogan (1980) reviews energy models in terms of major energy policies. Models selected deal with price controls, import reduction,
environmental cost, investment capacity and employment effects. The shortcomings and future directions to be taken are summarized.

A comparative analysis of seven leading models concerned with forecasts of worldwide energy demand is discussed (Allen et al 1981). The difference in projection is attributed to differences in assumptions about economic growth and energy utilization rates.

Optimal policies are determined using a multiple objective linear programming model in Netherlands (Kok 1987). The limits of this approach are also analysed.

Cepros and Samouilidis (1988) present an overview of the methodology used in energy policy analysis. The quantitative approaches used for energy supply analysis, energy demand analysis and energy economy interactions are surveyed. New directions for improving the modelling approach are proposed.

To improve the standard of living, energy consumption should be increased (Gilland 1990). These arguments indicate that energy consumption and economic growth are strongly correlated.

2.4 TIME SERIES MODEL

Time series models are used in several countries since they are easy to apply in any situation. However, as they are argued to be crude approximates, time series models can be used as first approximations.

Wolde_Ghiorgis (1991) has found the energy utilization pattern in three industries - cement, textile and food processing industries in Ethiopia. The models used for determining the energy utilization are linear, parabolic, exponential and logarithmic. He has stated that linear models give maximum value while parabolic,
exponential and logarithmic models give realistic value and can be used for developing countries. These models give simple extrapolation of the past.

Supply models are always fitted using logistic fit. It is a 'S' shaped curve where demand stabilizes after a certain period of exponential growth. Logistic model - a life cycle model tends to focus on the supply side, in particular the effect of depletion on productivity (Davidsen et al 1990).

Bodger and Tay (1986) have predicted the electricity requirement in New Zealand for three horizons- 5, 10 and 15 years. They have compared logistic model with linear, exponential, double exponential, exponential inverse, Weibull and Gompertz model using the sum of squared errors, correlation coefficient and Durbin Watson statistic. They have stated that logistic curve gives the best result. The forecasting precision and accuracy are tested using the variance analysis and the confidence interval. The optimal asymptote is found using Fibonacci search technique. Later Bodger and Tay (1987) have used a logistic model to predict the electricity requirement in New Zealand for various sectors. The model is then used to evaluate the substitution process among the various energy forms - coal, oil, electricity and gas.

Due to the oil crisis of 1973 and 1979, Bopp and Sitzer (1988) have developed time series model to study the future behaviour of oil markets.

Sterman et al (1988) have used logistic model to determine the energy resource in United States in five sectors - exploration and discovery, production, price, revenue and investment, and technology and demand. The oil demand is determined by real GNP, oil intensity and price. An average lag of 15 years is assumed between a change in price of oil and its full effect on demand. In another model, TREND, developed by Sterman (1988), the time lag is determined through simulation of past consumption data.
Thus logistic model is used to find how substitute products are developed as demand of one fuel stabilizes. Demand for a certain fuel stabilizes under three conditions - when the reserve is depleted or when Government enforces a ban on the usage of the fuel, or when substitutes are developed. The fuel position in India is such that the reserve will last for another sixty years and the Government is more concerned in making available all energy sources to the people that any ban seems improbable. Hence logistic models have not been tried for India.

Another important frequently used technique is the Box Jenkins (BJ) technique. Electricity demand on a daily basis or oil market behaviour can be studied using BJ technique. Pesper (1985) has used BJ technique to study oil-market behaviour while the growth of electricity demand in United States is studied by Uri (1981). He has compared BJ model with an econometric model. A combined BJ and econometric model has also been developed by Uri and it has been found that the combined model gave the best results for fluctuating data. Thus it is decided that this model may be useful where there are inherent fluctuations in the dependent variable. The energy consumption data in India has a steady increase which indicates that BJ technique may not be suitable for India.

The Central Electricity Authority in India uses three different approaches for forecasting electric power requirement. The average electricity requirement is then found from the three values. The three methods are trend, end-use and Scheer’s formula (ABE 1987). The trend approach involves time series models while in the end-use method, energy consumption for each category is projected based on expected changes in production. This does not include the price fluctuations of various energy sources or the national income. The third approach, the Scheer’s formula is based on the hypothesis that for every one hundred fold increase in per capita generation, the rate of growth of power generation will be reduced by half. Such hypothesis will only give approximate value rather than true estimates.
Various attempts have been made in India to predict the future energy requirements by employing modelling techniques such as Development Oriented approach (Reddy et al. 1977).

2.5 ECONOMETRIC MODELS

Friedlander (1973) feels that developed countries have increased their energy consumption rate, so that their standard of living will improve.

Energy consumption and economic growth are found to be closely related (Smil 1980). He emphasizes that energy is the driving force behind economic growth and development (Smil et al. 1980). The link between energy and economy has been established.

At the national level two and three variable models are being developed to predict the energy requirement after the oil crisis of 1973. Since price and income are mostly involved in these models, they are referred as econometric models.

Parikh (1976) and Tyner (1978) have developed energy demand model with single independent variable for India. In both cases energy consumption is found to be a function of national income.

Zucchetto and Walker (1981) have used linear and power fits for relating energy per capita with GDP per capita. Cross sectional regressions of GDP versus energy from 1950 to 1974 have been carried out. The results show that in the linear fit, the slope remains stable.

Harel and Baguant (1991) have found per capita annual electrical energy consumption to be a function of per capita annual Gross Domestic Product (GDP) for Mauritius. A log linear function has been fitted. The elasticity coefficient is the ratio of the percentage change in annual electrical energy consumption to the
percentage change in average annual GDP. The elasticity coefficient is determined based on past data. Using the elasticity coefficient, future electrical energy requirement is determined with the Harel- Baguant model.

Prior to 1973, analysts have been of the opinion that energy consumption is a function of income only. The oil crisis of 1973 led to a rise in price. The result has been a decline in demand. This indicated that energy consumption is a function of price also. The use of energy in industries for Singapore and Taiwan has been studied by Ang (1987). Electricity demand in industries is found to be a function of industrial output and electricity price. He has analysed the changes caused by shifting over to less energy intensive industries. He has found structural changes to have a major influence on industrial energy use.

Basile (1979) has projected energy demand as a function of income and price. The income and price elasticities are determined for high and low scenarios in 2000-'01. Similar projection for the demand of domestic petroleum consumption as a function of real income and exogenous wholesale price index of energy relative to the implicit GNP deflator is carried out by Thurman and Berner (1980). In this case only elasticities of demand are determined and compared. Electrical energy demand as a function of industrial output and electricity price has been done by Ang (1987). The impact of shifting to less energy intensive industries has been studied.

Rahman (1988) has linked energy demand with energy price, foreign earnings and capital flows, in a macroeconomic model for India. Non-commercial energy is excluded from this model. The energy demand equations are specified to show the effects of price and income on the demand for the three types of energy - coal, oil and electricity. Energy pricing policies are considered in the model.
Pachauri et al (1992) in their model developed for India indicate that future energy demand is dependent on economic growth, population growth, changes in industrial structure, planned and desired goals of consumption, and energy utilization efficiency.

In addition to price and income, previous year's consumption is also used in predicting energy demand. Verleger (1973) has found oil demand in United States to be dependent on previous year oil demand, price of oil, price of competitive fuels and consumption expenditure per capita. He has determined the standard error of estimation (SEE), square of correlation coefficient (R^2) and Durbin Watson (DW) statistic to validate the model.

Kaboudan (1989) has estimated the electricity consumption for Zimbabwe, in five sectors using ordinary least squares. The electricity consumption in domestic sector is found to be a function of previous year's electricity consumption in domestic sector, price of electricity in domestic sector and population. In the agricultural sector, instead of population it is capital formation, for mining sector, it is mining output and for industrial sector, it is employment. For other sectors, electricity consumption is a function of previous year's consumption and employment. In all cases, excepting the last, a log linear relation is used. The R^2 and DW value is determined. Long run and short run elasticities are determined.

Electricity demand in United States in the residential, commercial and industrial sector has been obtained using an energy model derived by Chapman et al (1973). The model has been estimated by ordinary least squares using both cross sectional data and time series data. The electricity demand is found to be a function of previous year's electricity consumption, price of electricity relative to a base year, price of natural gas relative to a base year, income per capita relative to a base year and population relative to a base year. The model determines long run and short run elasticities. Their analysis indicates that if increased environmental protection costs are passed on to consumers in the form of higher prices, then the rate of growth of demand is reduced. Comerford et al (1973)
have determined the price elasticity of demand in the industrial sector, using econometric methods similar to the work done by Chapman et al (1973). Roberts (1980) has used a similar expression to determine the fuel market share.

Ramesh (1987) has determined the energy demand in agricultural sector in India, using the previous year's energy demand, energy price and national income.

In the Sudanese energy demand model, energy demand is found to be a function of previous year's energy consumption, gross domestic product, population growth and energy price (Williams, 1990). The long term and short term elasticities are determined. Though these models have three important parameters price, income and previous year's energy consumption, technological efficiency and environmental quality, two vital parameters of the eighties have not been used in any of these models.

Chateau et al (1982) and Gowdy (1985), have reported a rising trend in technical efficiency of energy use in industry. Ostblom (1982) have reported that this effect is marginal in Sweden. Labys (1973) has found fuel demand to be dependent on prices, economic activity, prices of one or more substitute fuels and possible technological influences. Demand is represented as a function of previous year's demand, price of fuel, price of substitute fuel, income and technological influences. Labys et al (1979) have used this approach to forecast future levels of coal demand. Caldwell et al (1979) have used a set of efficiency standards for appliances produced after 1980 in the electricity model for United States along with the price and income variables.

A LBL Residential Energy Model (McMohan 1987) considers the future efficiencies of appliances and then projects the future energy consumption in residential sector. Though technological efficiency improvements are considered in this model, environmental factors are not included. In domestic sector, a considerable amount of pollution is found to be present.
Specific investment projects deal with short term decisions. Resource depletion, technological developments, carbon dioxide emissions are some problems associated with long term analysis (Manne et al 1984). The eighties saw the emergence of such long term models, that dealt with energy consumption, change in technology and emission, due to fossil fuel consumption.

Temperature change has been tried in the energy demand model in United Kingdom. Sourcewise energy requirement is projected by Wigley (1982) for two sectors - domestic and industrial. The industrial energy demand is found to be a function of demand at the previous period, change in output index, price of energy and change in temperature. For the domestic sector, instead of the output index, disposable income is used. Wigley states that using price and non-price components will result in incorporating technical efficiency in the system. His argument is, non-price components are output index, disposable income and temperature change. However, for technological change, though the repercussion may be felt in the income or output, it should be considered as a separate entity for its own importance. Only then improvements in efficiency, conservation measures could be studied.

A model for projecting residential natural gas demand has been carried out by Boncher et al (1988) and Bartlett et al (1990). Bartlett's model for Western Europe incorporates a climate variable which considers the number of heating days.

2.6 OPTIMIZATION MODELS

Optimization models have been developed linking energy with economy. Maximization of resource output, revenue or minimization of cost are some factors normally considered in the objective equation.

An optimization model has been developed to maximize the value of resource output - final demand of economic sectors and natural forest lands by
Zucchetto and Jansson (1981). It is constrained by production capabilities and land use and the requirement of economic sectors which should be within the availability.

Leung and Hsu (1984) have developed an input-output model for Hawaii where they try to maximize income, output or employment. Hsu et al (1987) have developed a multiobjective Non-Inferior Set Estimation Input Output model for Taiwan, where Input Output and Linear Programming techniques are used in combination. The model maximizes GDP and minimizes energy consumption. The same authors (Hsu et al 1988) have developed another input-output model among industries in Taiwan where they try to minimize the consumption and at the same time achieve a certain economic growth.

Sarma (1986) has developed a linear programming model for optimum allocation of energy resources for efficient utilization in India in 2000-'01, while minimizing cost.

WATEMS (Fuller and Luthra 1990) minimizes cost. It consists of supply - demand, retirement - production, resource limit and share limit constraints.

The optimization models linking energy and environment are reviewed. An air pollution emission control model has been developed for St. Louis, Missouri, United States by Kohn (1975). He minimizes the total annualized incremental cost of meeting the prescribed limits. The three constraints are, the total emission from different sources should be within the total prescribed limits of particulates, SO$_2$ and NO$_2$. A non-linear programming model has been developed (Holton 1981) which minimizes cost and controls HC and NO$_x$. Ellis et al (1985) have worked on ambient least cost model for eastern North America where the emission reduction can be greater than or equal to the greatest reduction in pollution concentration. The objective equation in all the models minimizes cost. The models link energy usage with environmental pollution. It has been established that energy and economy are the deciding factors in national policies. Models
linking energy and economy with environment will be helpful in taking a balanced decision. Also from a nation's point of view, least cost strategy need not always give the best results.

Luthra and Fuller (1990), proposed a linear programming model which calculates the least costly configuration and analyses the economic and air pollution impacts of several policies such as no nuclear development, higher insulation standards for homes and usage of wood or solar for home heating. For a given economic scenario the demand for the various fuels is determined. This demand is then linked to a supply model that translates secondary energy demand to primary energy demand.

2.7 IMPORTANCE OF ENERGY-GNP RATIO

Energy-GNP ratio is a reflection of several underlying factors such as state of the technology, GNP composition, demographic and sociological factors, price, environmental constraint and the level of activity in energy sector (Edmonds and Reilly 1985).

Hogan (1981) has compared the energy-GNP ratio for the period 1961-74 for United States, Sweden, Netherlands and West Germany. United States and West Germany have a stable trend and United Kingdom a declining one. For Sweden, from 1963 to 1966, there has been a rise and after 1966 the trend has remained constant. Netherlands exhibited an increasing trend. When compared between 1973 to 1985 (Nakicenovic et al 1987) Japan, United States, United Kingdom, Italy, West Germany, Netherlands, Turkey, Canada and Australia have a declining trend while Greece is found to have an increasing trend. United States and Sweden have the same standard of living but different energy-GNP ratio. When the ratio is observed over time, it gives an indication for energy conservation performance. Dunkerley (1979) is of the opinion that difference in ratio between countries is because of the difference in the structure of energy supply, economic activity and energy prices.
The Modelling Resource Group (MRG 1978) projected an increase in energy use and a decline in energy-GNP ratio for United States.

Sterman (1982) is of the opinion that a fall in energy - GNP rate is a reflection of the substitution potential. Also conservation, technological change and change in sectoral output will lead to a decline. When the actual energy-GDP is more than the estimated for a particular year, it is inferred that the country has been less efficient in its consumption of energy (Lebel, 1982) and there may be energy scarcity in the near future.

Dunn (1986) shows how the energy-GNP ratio has been changing over the years 1950-'75 for the various countries. For United States it remains stable. For West Germany there is a declining trend. In the case of developing countries like Brazil, Nicaragua and Mauritius the trend is seen to increase.

United States has maximum per capita energy consumption. New Zealand has half the per capita compared to that of United Kingdom or West Germany though with comparable economic standards (Chandra et al 1990).

Schipper et al (1990) state that the energy-GNP ratio is determined not only by changes in the efficiency of energy utilization, but also by changes in the growth of energy using activities relative to GNP. Hence the use of energy-GNP ratios as efficiency indicators is suspected on both theoretical and empirical grounds. But they agree that energy intensity or energy use per unit of activity or output (its inverse) is conceptually related to energy efficiency.

Kononov (1990) states that in the former United Soviet Socialist Republic, a decrease in the share of energy intensive sectors has led to a decline in energy-GNP ratio.
2.8 UNCERTAINTY ANALYSIS

The extent of uncertainty in predicted models is found to be an important issue and hence literature has been gathered on the work done on uncertainty analysis in energy models.

Roberts (1980) states that uncertainty in such models is because of three sources. Parameter uncertainty arises because parameters are found using fits and are hence not precise. Stochastic uncertainty arises because even though the parameters are fitted precisely, they are subjected to random variation. Structural uncertainty is present when the model is not a correct representation of reality. Confidence intervals are determined to detect the extent of uncertainty present.

Labys (1982) states that when models are formulated there is a certain amount of uncertainty and hence have to be checked for their predictive capability and validity.

Baltagi et al (1983) state that however accurate the model may be, inaccurate assumptions about exogenous variables may lead to poor forecasts. Sensitivity analysis deals with such errors in two ways - to obtain the likely set of values for these variables or to anticipate the likely range of its variation and its impact on the dependent variable.

Uncertainty arises because of randomness of certain elements or when the process is measured with uncertainty or when certain variables used as inputs may themselves be measured with uncertainty (Labys et al 1985).

Roberts has referred to three uncertainties, while according to Keepin (1986) there are two uncertainties involved in energy modelling. They are parametric, which refers to numerical values of input and structural, which depends
on the nature and formulation of equations. There are no methods for handling structural uncertainty while there are several methods for handling parametric uncertainty.

2.9 DELPHI STUDY

The conventional form of the technique is considered to be a procedure for polling a panel of respondents usually selected for their expertise - concerning the likelihood and probable date of occurrence of supposedly future events (Hill and Fowles 1975). In each round, the participants are asked to predict again in view of the opinion of a majority of participants from previous round. The objective is to arrive at a common goal acceptable to everyone.

Though there are several techniques to find the success of the experiment, stability, convergence and consensus, the value of the Delphi is not in reporting high reliability consensus data, but rather in alerting the participants to the complexity of issues by forcing, cajoling, urging and luring them to think and to have them challenge their assumptions (Coates 1975).

Despite its increasing acceptance, popularity and usage, very little is really known about the method and its applications. A study by Brockhaus and Mickelsen (1977) has revealed that Delphi is most successful when used for forecasting and planning purposes. Still, many have used it in other fields. Schoeman and Mahajan (1977) have used it to assess community health needs, Kruus (1983), to explore the long term aims of Carleton University, Cicarelli (1984), has used to predict the future of economics, Nelms and Porter (1985), to estimate the impact of information technologies on clerical work and Benarie (1988), for environmental standard setting.

The characteristics of Delphi are anonymity, iteration, controlled feedback and statistical aggregation of group response (Rowe et al 1991). Hence it is classified into two stages - the first stage involves the rounds and the second stage
calls for statistical analysis which gives the mean or median and the extent of the spread of participants’ opinion to give an indication of the consensus arrived at.

From the literature survey, it is clearly seen that very few have attempted to develop an econometric model with sourcewise allocation of energy taking into account, the price, income, technological efficiency and environmental factor in an integrated manner for a developing country. The optimization models, linking energy and environment indicate that in most cases only cost minimization is undertaken. The important parameter, GNP-energy ratio has not been considered in any models, though its importance has been highlighted. Maximization of the ratio in the optimization model will help to stabilize the GNP-energy ratio, in a developing country where there is a declining trend. Quantification of qualitative statements is made possible using Delphi. The survey indicates that it is a versatile tool for energy planning and forecasting. The development of such an energy, economy and environment model is likely to be useful for planners, for evolving suitable energy resource planning exercise to meet the future energy demands.

Precisely such an attempt has been made in the present work and what follows is a detailed presentation of the development of the model and its analysis.