Chapter 1

INTRODUCTION

1.1 Energy and Economic Development

Energy is required to make anything happen. It is an essential component of human life and its socio economic development. It is so indispensable to human beings that without it one cannot think of survival of civilization. It is good to see that the world is fast progressing in technologies. These technologies have impacted a lot to improve the quality of life. However, there are still more than two billions people in the world who are yet to access the commercial source of energy. In India alone there are about 400 millions, who do not have access to commercial energy and not been able to utilize the available technologies [4].

As such they are still struggling for the energy to fulfill the basic needs like cooking, lighting etc. Hence there exist a huge gap between demand and the supply of energy. Every human being has equal right to access the equal amount of energy. However, this seldom happens. Therefore, there is a pressing need of studying the various energy sources, supplying of energy to the consumer in a more efficient and effective way so that people do not suffer.

In rural India the people depend upon firewood for cooking and kerosene for lighting due to lack of commercial energy. The excessive use of firewood for cooking, results in deforestation and health hazard. The deforestation causes environmental degradation. Also the use of firewood for the cooking, results in respiratory diseases to the users specially women and children because of the production of carbon monoxide and carbon dioxide.

Further, the excessive use of energy also affects the economy of the people. In rural areas where electricity is not available, people use kerosene for lighting purpose. As per public distribution system (PDS), a household is entitled to get 2-3 litres of kerosene per month. However, the same is insufficient for the people to make their livelihood for whole month. This finally encourages the black marketing of kerosene which unnecessarily put extra economic burden to the rural folks. Also during rainy season when firewood is wet, the rural folk use kerosene for cooking. This excessive use of kerosene results in poor economy of the people. Hence, energy has a direct linkage with economy and environment. Therefore, there is a huge need for integrated energy planning for the rural areas which can address the issue of energy, economy, and environment for the sustainable development of rural people of India.
1.2 Indian Energy Scenario

India has a population of about 1.3 billion constituting over 17% of population of the world. Geographically, it is seventh largest country and has a land area of 328 million hectares. Over 75% of Indian population live in rural areas. India witnessed a fast pace of economic reforms and growth in the early part of last two and half decades followed by a period of stabilization. International turbulence and unfavourable international economic environment also had its impact on economy [52].

Coal and hydroelectric resources is mainstay for India’s primary resource support for secondary energy purposes. Oil and natural gas resources of the country are limited and nuclear resources are modest. The coal resources are of poor quality with high ash content. The distribution of the primary resources in the various regions is rather skewed. The eastern region accounts for 70% of the total coal resources, the western region accounts for over 70 percent of the hydro carbon resources. The north east India has large potential of hydro power. Recently hydro power plants are being set up in Arunachal Pradesh, Meghalaya and Sikkim. Still more such hydro power plants can be set up to fully exploit the hydro power generation potential of the various rivers like Brahmaputra and its tributaries, Teesta and its tributaries etc.

In the coastal region of southern India there is a huge potential for harnessing wind and tidal energy. Apart from these abovementioned energy distribution patterns, government has installed few nuclear power plants also; the latest one is Kudankulam in Tamil Nadu.

Even after having huge potential for energy supply, the country is suffering from acute shortage of electricity throughout the year and the condition becomes worst especially during summer. As India has limited amount of hydrocarbon resources, it mainly imports hydrocarbons from Arabian countries and coal from Indonesia.

1.3 Energy Sources in Rural India

As per consumption pattern in India, the uses of non-commercial energy compared to total energy demand have been declining with time. Generally biomass is used as a source of energy in India. It has been seen that in the last fifty years biomass usage has decreased from 63% to 24%. The decline in its usage is attributed to change in the use of energy pattern by urban households. The rural and urban households have different energy consumption patterns. From 1981 to 2011, 65% of the urban population switched over to LPG but only 11.4% switched over to LPG in the case of rural households. In the urban area 92% of
households are using electricity for lighting while only 55% households in rural area are using electricity for lighting. Though, access to electricity has improved over the past 20 years from 36% to around 56% from 1994 to 2011 in rural households in India. However, still about 74 million rural households do not have access to electricity. Despite significant growth in electricity generation, power shortages continue in rural households in the country. In India electricity deficit is around 8 to 10% over the last few years and the rural consumers have suffered the most due to this deficit. If one goes by the statistics, it is seen that almost 90% of all villages stand electrified.

If a comparison is made of rural electrification at the state level, there exists a great disparity across states in household level electrification. The states like H.P., Punjab and A.P are much ahead of states like Assam, Bihar, Jharkhand Orissa and Uttar Pradesh. Table 1.1 enlists the status of household electrification of all states of India as per National Census Data 2011 [14].

1.4 Energy Consumption Pattern in Rural India

The pattern of energy consumption of rural India is enlisted in Table 1.2. In rural India fuels used for cooking and lighting are mainly firewood, LPG, electricity and kerosene. As per the 55th survey of national sampling survey organization (NSSO) firewood consumption is observed to increase from 1999-2000 to 2004-05 and then there was a marginal decrease in 2009-10 [14]. However, it has been observed that the total consumption of firewood was higher in 2009-2010 than in 1999-2000.

There was 7.5-8% overall increase of firewood consumption in the last decade and 25-30% overall increase in case of electricity consumption. While for the LPG, there had been nominal changes in consumption pattern in the last few years which can be observed in Figure 1.1.

There are basically three types of households that one finds in rural India namely low income, medium income and high income. The energy consumption pattern of each type varies one from the other. In the succeeding section, the various types of energy available in rural India and their consumption pattern shall be discussed in sequential manner.

1.4.1 Firewood Consumption

Table 1.1 enlists the details of the firewood consumption pattern across various income groups in rural India. It is observed that the firewood consumption for low income groups has been observed to increase from 95kg/month in 55th round of NSSO to about 102 kg/
month in 66th round of NSSO. Amongst the medium income group, it is found that there is a remarkable increase from 107 kg/ month (55th round, NSSO) to about 125 kg/ month (61st round, NSSO) and then declined to about 115 kg/ month (66th round of NSSO). It has been observed that there is an increase in consumption of fuel wood from about 112 kg/ month (55th round, NSSO) to about 120 kg/ month (66th round NSSO) in high income group. The households which fall in high income group consume higher level of consumption of fuel wood [11].

1.4.2 Electricity Consumption
A significant increase in electricity consumption for all income groups has been observed in the three rounds of survey. The household from low income group recorded a 2 % increase in consumption of electricity i.e. from 33kWh in 55th round of NSSO to 37 kWh in 66th round of NSSO per month. Amongst the medium income group households, a remarkable increase in electricity consumption has been observed in the same rounds of NSSO survey. Households of lower income group recorded a 12% increase while in medium income group recorded a 21% increase in electricity consumption. However, the households in higher spectrum recorded an increase of 48%. It is observed that from 55th to 61st round of NSSO survey there was a nominal change in electricity consumption pattern. However, the last five years i.e. from 61st to 66th rounds have recorded an increase of 28% in energy consumption. It is seen that the highest income households consume about 80 kWh per month when the trend of last three rounds put together [11].

Though across all income groups, there was an increase in electricity consumption, the increase in consumption of electricity for low income households was not significant. It is observed that the effect of improved electricity access is more amongst the middle income and high income households in rural India.

1.4.3 LPG Consumption
LPG consumption has some interesting observation if one observes at the various NSSO rounds over time as can be observed in figure 1.1.

It has been seen that there is no increase in consumption of LPG amongst all income groups from the 55th to 61st round of NSSO while from the 61st to the 66th round of NSSO, there is a decreasing trend in LPG consumption. It has been observed that the LPG consumption remains almost constant in the past decade. Contrast to other fuel consumption, LPG has not reached well to rural India and the demand of LPG is also not very significant. This raises
the issues of access and service delivery of LPG in rural India. If one observes the low income households, the LPG consumption is almost same and its quantity varies from 6-8 kg per month in all rounds of survey of NSSO; the medium household consumes about 10 kg per month. This shows that there is no remarkable change in LPG consumption though it is a clean form of fuel. It is observed that the improvement in LPG consumption has not taken place as expected in the past 10-12 years but electricity shows considerable improvement over time [11].

1.4.4 Kerosene Consumption

It has been observed that the consumption of kerosene has fallen significantly over time across all income groups. The factors accountable for this fall are the increasing popularity and access to electricity and LPG. Also the consumption of kerosene has fallen sharply amongst the higher income group because they are not only keen but also can afford other sources of energy. The people have access to kerosene through the public distribution system (PDS) which provides a fixed amount at a subsidized rate every month as well as in the open market where the rates are higher. The Government of India provides a subsidy of more than 50% on kerosene supplied through the PDS chain.

As kerosene is primarily used for lighting purpose in rural areas, the availability of electricity will lead to reduced kerosene consumption in rural households. Further, it is seen that there is about 30% and 41% decrease in kerosene consumption amongst higher income households from 1999-2000 to 2009-2010 in both PDS and open market respectively. This trend is also observed among the low income group of households but the fall in kerosene consumption is about 10%. At the same time kerosene consumption for non PDS mechanism is pegged at 30% for the period from 1999-2000 to 2009-2010. Further, amongst the medium income households, the decrease in kerosene consumption through PDS is around 17% and non-PDS is around 20% for the same period [11].

1.5 Gap between Energy Demand and Supply of India.

As on April 2013, total installed capacity of power generation in India was about 223 GW, but still it is struggling to meet its increased power demand. Central government came up with the Electricity Act in 2003 to reform unorganized power sector in India. This act has helped to improve efficiency and bring some required changes in power sector. However, country is still facing acute power shortage in several regions in India. It is expected that after some time the reforms that has been made recently in the power sector will show the result. The supply-demand gap and financial systems constraint to support subsidies are
expected to put pressure to increase the power tariffs in the short to medium term. The various reasons for low power generation in India are;

(i) Coal is the base for electricity generation in India. India has enough coal reserves in forest area, however, due to strict forest protection regulations; it cannot be used for power generation.

(ii) The quality of coal available in the country is not up to the mark and is not suitable for power generation.

(iii) The major supplier of coal for power plants in the country is Coal India Limited; hence it has a market monopoly. Growth in supply by Coal India has suffered major setback due to high ash content, poor calorific value, etc. However, the demand of coal has increased exponentially in the country.

(iv) The increase in price of imported coal frequently and reduction in gas production in the Krishna Godavari basin by more than 60% has resulted in either low or no power generation.

(v) Low power generation from Hydro power plants is also due to droughts or less rainfall. In April 2012 demand supply gap of electricity was 8.2% as per the report of Central Electricity Authority, CEA. This was little higher by 0.2% in April 2011 and lower by 2% in March 2012. CEA reported that the total shortfall in electricity generation during 2011-12 was 8.5% with a demand of 9, 37,199 million units (MU) and the actual generation was 8, 57,886 million units (MU).

The total shortfall of electricity generation was 79, 313 million units. As per CEA data the highest shortfall was in Meghalaya at 28.1% which corresponds to 146 million units of generation in April 2012. In 2011-12, this state had the highest shortfall of electricity generation of 25%. The Western region had the highest shortfall of 11.4% during 2011-12. Southern India had the highest demand supply gap in April 2012 at 15.5%, little higher by 0.5% during the previous corresponding period. The gap between demand and supply of energy is enlisted in Table 1.3 as obtained from CEA [12].

1.6 An Overview of Rural Energy Technology

In rural area, people need energy not only for cooking and lighting but for thermal comfort during cold season and pumping water for drinking and irrigation purposes. Electricity is used primarily for lighting and running electronic gadgets like TVs, radios, and telephones for information, communications and entertainment. However, the supply of electricity to the rural area is still limited and erratic. In some cases due to geographical locations the grid
power supply is not economically viable. Hence many villages are still un-electrified. Hence, there is a huge need to supply the energy using off-grid energy technologies to the rural areas. Having understood the importance of these technologies, this section presents an overview of rural energy technologies which have the potential for improving the energy supply of rural India.

(i) Improved Chulha: The poor families in rural areas generally used energy mainly for cooking. They use the cooking stoves made of mud and brick and their efficiency is only 10-15%. Thus, improved chulha which burn firewoods with efficiency as high as 30% on an average was used as a first technology for improved access to energy in rural areas in India. The figure of the improved chulha is shown in Fig. 1.2. Today, a number of efficient and economical wood-fueled improved chulha (ICs) have been developed, with improvements based on the minimization of heat losses, maximization of heat transfer to the pot and efficient combustion. Apart from being more efficient it also leads to reduce the pollution. The relevance of this technology is important as making a sudden change in the use of energy from traditional way to modern way is not possible. Further as per the report of International Energy Agency “for poverty alleviation, employment generation and expansion of rural markets, there is huge need of development of more energy efficient biomass technologies as biomass will dominate energy demand in developing countries like India for quite sometime”.

(ii) Thermal Solar Cooking: Thermal solar cooking is one of the improved technologies for cooking, deriving the energy from the sun. The efficiency of solar thermal cookers is more by about 30% to 70% than traditional cooking stoves and comparatively, the production cost is also quite low. However, the main disadvantage of using solar thermal energy is the the people’s acceptability due to drastic differences with traditional uses for cooking.

(iii) Biogas Digesters: Biogas digesters are also promising technology in making the changes in the life of people in rural areas due to the availability of large number of cattle in rural India. The generation of biogas from animal and human waste is done through anaerobic digestion. The marsh gas (methane) produced is used as fuel for cooking in place of biomass or even kerosene and LPG. India has the large potential for biogas production as lot of animals in India are available. Hence, biogas can be produced at low cost. Further, the slurries obtained after the production of gas from the plant is considered as very good manure and has the potential to increase the agricultural productivity.
(iv) **Other uses of Biomass:** Other modern uses of biomass in India may also be an alternative for the replacement of traditional forms. Alternative biomass consists primarily of agricultural residues, like sugar bagasse, rice, coffee, and paddy husk. However, the major difficulty with agricultural waste for energy production is the low energy per volume making it difficult to handle and transport. This problem can be tackled in many ways, like by making briquettes (pieces of compressed agricultural residues). The major advantage of agricultural residues is that they can directly replace traditional fuel wood.

(v) **Solar Photovoltaic:** Solar Photovoltaic (PV) Panels is a popular choice to cater the need of energy supply in lesser privileged areas. PV panels are exceptionally good for stand-alone systems for electricity generation like street lighting, community facilities and solar home systems (SHS). The PV panels are reliable, durable, has low maintenance cost, and can be used up to thirty years. However, few drawbacks are also associated with this technology such as high initial investment and operating cost as the battery used in the system requires to be replaced in every four to five years. Further the other spare parts are also costly. Although it is quite costly but the large size PV panels can be employed for feeding the electricity in micro grids.

(vi) **Wind Energy:** Wind energy has also been proven as the promising technology for energy supply in rural areas. The wind energy systems may be utilized for both household and integrated grid. Similar to PV installation, more windmills generate more energy. However, its disadvantage is that it is intermittent and hence the systems are not very reliable. The high replacement cost of batteries makes wind energy expensive. The wind energy systems are highly beneficial for applications like water pumping. The other advantage of this system is that its structure can be locally fabricated with wood, plastics, and steel for the tower, so, the rural people have to buy the generator and gearbox only from outside. However, its application is limited to the coastal areas of India.

(vii) **Micro Hydropower:** Micro hydropower has a great potential in India for generating micro-grids electricity. Small hydropowers (SHP) with the generation capacity of 5 kW to 100 kW takes the water from a river through a small channel to a settling basin and then to a forebay tank for storing water at a higher head to gain the potential energy. The water is then fed to the power house through penstock where the kinetic energy of the water rotates turbine resulting in generation of electricity. The major advantages of SHP
are time tested technology, maintainance is easy, reliable and low running cost. The main limitations are high capital costs, feasible for micro-grids only.

(viii) **Biomass gasification**: Biomass gasification is another technology that can be utilized for electricity generation and has a huge potential in India. In biomass gasifiers the biomass is converted into producer gas by means of thermo-chemical process. The producer gas thus obtained is properly cleaned, and is utilied in IC engine for power generation. This technique is particularly suitable for small capacities electricity generation in kilowatt range. The advantages of biomass gasifiers are that they use local resources economically, though the operation and maintenance costs are high and the technology is still at the research level.

**1.7 Linkage between Energy, Economy and Environment**

In our today’s society people especially economists seem to be growth oriented, even growth obsessed. For them, growth in a country’s economy is always good news and decrease in the economy or even stability are regarded as the worst news ever. It seems that people believe that the growth of an economy equates with the well-being of a society; but growth cannot go on forever. In order for an economy to grow, people need resources. People tend to have the illusion that resources are infinite or substitutable, but that is not true. As our population and consumption grow, we are depleting the Earth’s resources more and more and soon nothing will be left. Technological improvements have pushed back the limits on growth many times, but that is not enough in the long term. If population continues to increase at the present rate, the Earth will no longer be able to sustain it. So, abiding with strict laws and rules people can put limits on population growth. Looking back to history it reflects that the growth in population is exponential, and not linear; It was one billion until 1800 AD and the population reached two billion by 1930 AD and it jumped to three billion in just another 30 years. As per recent data it is estimated that approximately seven billion people are living at present in the world.

The more the population increases, the more the consumption increases, and the more the consumption increases, the more the energy resources are depleted by people. But the problem is many of the resources do not exist in endless amount, they are finite. People have made the mistake to rely heavily on fossil fuels such as coal, natural gas and oil over the years, but these resources will soon come to an end. Fossil fuels are not evenly distributed around the Earth; some regions have substantial reserves of fossil fuels, whereas others have little. How much each country’s fossil fuel reserves will last depends on how much the
country extracts, how much it consumes, and how much it imports and exports from other countries. It is important to keep in mind that people from developed countries consume much more energy than people from developing countries. Our most used fuel is oil with an energy consumption of 35% worldwide. It is essential to remember that it takes energy to make energy. For example, drilling for oil needs a huge infrastructure of roads, vehicles, pipelines, all of which we need to use energy. Apart from this, it gets harder and harder to extract oil from the ground as time goes by, and for this reason some oil companies are not willing to extract it, because the extraction of oil tends to cost more than what they would receive from selling the oil.

Besides the fact that the above mentioned types of energy resources are limited, they can also be very harmful for the environment. Water for example is polluted, when massive oil spills from tanker ships or drilling platforms foul coastal waters and beaches. The air is polluted from the CO₂ emissions from cars and airplanes or from the smoke of coal coming from ovens. Fossil fuel emissions also drive changes in global climate. Methane, for example, is a potent greenhouse gas that drives global warming. So, the time has come for us to find alternative energy sources, since fossil fuels are not a sustainable long-term solution to our energy needs and their use has negative impact on our environment. The alternative energy sources such as solar energy, wind energy, geothermal energy and ocean energy are renewable energy sources that are not finite. So, people should start using renewable energy sources and avoid using finite energy sources, in order to reduce negative environmental impact and health problems.

Thus, it is clear that the economy, energy and environment are interconnected, because if we protect the environment by using new energy sources our economy also boosts. People often tend to think that the protection of the environment runs counter to the economic well-being, but that is wrong. When thinking in the long-term, it is evident that the degradation of ecosystems feeds back to harm economies. It is totally wrong to equate environmental protection with economic sacrifice, because human economies are connected to the environment and rely on its goods and services. Thus, it is necessary for people to recognize the need to build an environment-friendly economy that relies on renewable energy sources [15].

**1.8 Need of Sustainable Energy Planning in India.**

Energy is the backbone of any country in the world as it is the basis of determining the economic status of the country. Energy consumption by any country determines the per
capita income of the country. The energy is basically of two types namely commercial and noncommercial. The non-commercial energy is mostly utilized in rural India which constitutes about 70% of India. The non-commercial energy is mostly derived from firewood i.e. biomass, animal dung and agricultural waste. The commercial energy is mostly derived from hydrocarbons such as coal, petroleum products, nuclear power and hydropower plants etc. The commercial energy is mostly imported from other countries. Therefore, any economic activities are predominantly dependent on commercial form of energy.

India being a highly populated country having about 1.3 billion population should devise a sustainable energy planning for maintaining its growth. There is a huge imbalance between demand and supply compounded with high aspirations of the people. The government should now seriously think of developing a strategic model for sustainable development through sustainable energy planning. Otherwise it will fail to strike a balance between demand, supply and sustained economic development. Thus in this research study, it is felt that the need of sustainable energy planning for India is the need of the hour.

1.9 Need of Sustainable Energy Planning in Sikkim

As discussed in the preceding section that the energy is the basic requirement to sustain life in any society and per capita consumption of energy determines the economic status of any country/state/region. Sikkim being a hilly state having biomass in abundance with less coming avenues for the people. As such there is need of sustainable energy planning in Sikkim so that the rural people can avail adequate amount of energy without much hardship, investing less money and maintaining a sacrosanct balance between the energy economy and environment so that the people of this tiny hilly state can become self-reliant and more or less get rid of commercial fuels for at least cooking and lighting to some extent.

1.10 Literature Review

In 1983, an advisory board on Energy was formed with an aim of providing guidelines and directions to the energy policy of India. The measures prescribed by the board were highly appreciated and were brought into practice and implementation by different ministries and planning commission.

One of the major models adopted by the board was the TEESE model (TERI Energy Economy Simulation and Evaluation) which was developed by TERI (The Energy and Resources Institute, Pachauri et al 1988) this model is further scattered into three component sub models. They are:
i. A reference energy system
ii. An output input model
iii. A linear programming model.

This model discusses all those issues and alternatives which are possible in the global economy and energy field. The most significant assumption behind the structure of this model is that the useful energy or energy services for any given sector which consumes energy, is required for the mobilization of service which are provided by that sector. Eg: the cooking needs, heating needs and lighting needs help in measuring the demand for energy.

Agrahari and Tiwari [2014] presented a design and the performance of portable floating type biogas plant of capacity 0.018 m³ made of plastic for outdoor climatic condition. The authors made a comparative study of the cow dung and kitchen waste of 30 kg slurry capacity in batch system for production of biogas. The authors measured the different parameters like temperature, solar radiation and relative humidity along with the composition of biogas, pH and volume. Further they analyzed the rate of biogas production at different temperatures on day-today basis. Through the physio chemical analysis of biogas and slurry, the authors identified kitchen waste as the best alternative to generate the biogas at community level.

Sarkar [2014] studied the five year plans of the Government of India for the Rural Development in India. He observed that the planning, implementation and monitoring of various centrally sponsored schemes were carried out by rural development department for rural poverty alleviation. The author found that the main issues of the five year plan in India is to create self-employment opportunity for the people of below poverty line which can improve overall quality of life in the rural areas and women empowerment in socio-economic and politics. He also suggested that for the improvement in rural areas it is necessary to participate in policy making.

Dhass and Harikrishnan [2013] presented a low cost hybrid energy system utilizing solar-wind-biomass for rural electrification. The authors developed a new methodology to find out the unit cost of energy of SPV, wind and biomass hybrid system. They analyzed many hybrid renewable energy systems like solar-biomass, solar-wind, and solar-wind-biomass for rural electrification purpose and arrived to a conclusion that the LCC for solar to (wind + biomass) = 1: (0.25 + 0.75) which was the lowest value from all sets of combinations. Hence, they recommended the implementation of proposed hybrid system in remote areas, where installation of grid power is not viable due to high cost.
Suberu and Bashir [2013] presented a review of electricity generation through renewable energy and micro grid implementation in rural villages. They brought out some important issues with regard to efficient DG implementation applicable to rural energy planning procedures. Lastly they suggested the suitable frameworks in planning and design of rural energy. Further they concluded that RE distributed generation in MG would be beneficial in remote places and also highlighted the advantages of connecting distributed generators smooth for operation of MG.

Khambalkar et al [2013] presented the assessment of biomass available in three villages of Maharashtra for finding out the self generating nature of the villages. They determined the impact of the self energy generation over time, which resulted in direct saving of the money and generated the employment of rural people. The authors selected bio-energy as the source of energy available in rural villages through forestry, agriculture waste and residue etc and animal waste (animal dung) for self-sustainable development and made their assessment of consumption and exact quantification of the bio-energy generation capacity in the villages for domestic and other activities. From the research study, they found that the villages had tremendous potential of bio-energy and its proper exploitation can help the villages to become self power-generating. Finally, they analyzed the biomass conversion technologies such as biomass gasifier and biogas energy generation system for the overall benefit of the studied villages.

Suzanna and Cudney [2012] studied the relationship of environment and energy and explored its value in evaluating energy and environmental processes through a management system for waste water treatment plants. They proposed an integrated model of energy and environmental management as an instrument for achieving a balance between these two complex systems. The authors claimed that the proposed integrated model would minimize the energy consumption maintaining the environmental efficiencies. The important factors which contribute to both energy and environment were found by the authors and the model was validated through a case study.

Chowdary et al. [2012] presented a detail study of the renewable energy scenario of Bangladesh. They proposed a hybrid system connected to grid by employing five different alternative energy resources to fulfill the ever increasing electricity demand for both domestic and commercial sectors in remote areas, where grid connected electricity supply is not possible. They proposed a novel, effective, convenient and robust hybrid system
utilizing the various energy technologies such as biomass (rice husk), photo voltaic generator, wind generator, biogas and micro-hydropower.

Mohammed and Oyeniyl [2012] studied the role of women in rural households energy management. They identified their specific tasks and decisions making roles at their family level in sourcing and use of household energy sources. The authors also discussed the various constraints faced by rural woman in an efficient household energy management. The qualitative and quantitative data collected at the household level were analyzed and indicated that the role of rural women are culture derived. Further, in rural household, women were found responsible for sourcing, processing and use of biomass resources for cooking.

Aggarwal [2011] studied the fuel consumption pattern in rural areas by conducting a study in three different zones depending upon their geographical and socio-economic conditions, based on the four parameters, namely- (i) Caste, (ii) income, (iii) land holdings and (iv) Family size of each family. The author found the present level of use of fuel wood by households (95.2%) along with other fuels like kerosene (38.4%), LPG (70%), crop residues (94.5%), dung cakes (4.1%) and biogas (1.5%). In 99.5% households, electricity was used for lighting.

Ghosh et al. [2011] presented a design of solar artifact. They studied the challenges with regard to solar energy scenario of rural areas of West Bengal, state of India and proposed low cost solar devices to cater the energy needs in the areas which are scarcely electrified. They identified the renewable energy scenario of interior rural area of Sundarban and proposed appropriate low cost technology devices. They reported that the proposed eco-friendly and low cost renewable energy devices, suitable for the rural people has the potential to compete with other available solar products in terms of cost and utility.

Hiremath et al. [2011] presented the implications of Decentralized Energy Planning for rural India. They developed a mathematical model for the appropriate utilization of sources of renewable energy in India. They presented various appropriate objectives functions and limitations to be considered for the DEP. The developed model was successfully applied in Kunigalm, a typical Indian block unit which comprises many villages and they found that for meeting the energy needs of the entire block considered in the study, biomass based energy systems have the potential.

Mallick et al. [2011] presented a diffusion model to establish green house gases reduction potential in rural India comprising of large number of villages, where people use the energy
sources such as fuelwood, kerosene oil and gas for cooking and lighting needs. They used diffusion models to forecast the electricity demand and recommended the measures to be implemented to meet the daily demand. They identified solar photovoltaic fuel cell based lighting system as the best alternative to cater the need of proper lighting of the rural households.

Murugan [2011] studied the different forms of energy used and their consumption in rural household in Kanyakumari district of Tamil Nadu. He observed that the consumption pattern is dependent on the various available sources of energy and the income level of the people. It was also observed that most of the people use cow dung for cooking in larger quantity due to its easily availability and not affordability to bear the cost of LPG. In spite of larger availability of cow dung in the selected district of study, its use for the production of biogas is negligible due to higher installation cost of biogas plant.

Zamfir [2011] presented European experiences and suggested the techniques in the field of renewable energy management for regional development. He presented the overview of the issues of renewable energy in European region and recommended the various measures and actions to manage the development of region based renewable energy considering the financial allocation through the energy policy for energy efficiency and renewable energy.

Dave and Mahesh [2010] analyzed the impact of a Sujala watershed project on rural energy management in selected villages of micro-watershed areas of Hosadurga taluk in Chitradurga district of Karnataka. They presented the need of improvement in agricultural productivity and production to ensure the drinking water availability, fuelwood and fodder to increase incomes and employment opportunities for marginal and small farmers, landless labours and also socially marginalized groups. Further, they emphasized on the integration of income generation agenda along with watershed development programmes to improve the livelihood of the rural people.

Singh et al. [2010] presented a photo voltaic-DG hybrid energy device control strategies for a remote village of Jharkhand. To reduce the electricity consumption by hybrid system initially they suggested drawing power from the diesel engine generator for a short span of time till it achieves the optimum point of operation. The PV system was integrated with DG (Diesel Generator) system using soft computing technique based on fuzzy logic for planning of control strategy. Introduction of a fuzzy logic controller helped to optimize the DG set.
running time and this led to fuel economy, reduction of electricity cost and less environmental pollution.

**Singh and Bajpai [2010]** surveyed energy consumption pattern in various sectors such as domestic, agriculture, transport, rural industries and miscellaneous uses for a cluster of 3 villages in Eastern UP. They discussed the current energy scenario, preferred energy options and potential of various renewable energy systems in rural areas for creating sustainable livelihoods. They also planned for the decentralized energy options to cater energy security in villages to fulfil the need of energy for cooking, lighting and motive power from available renewable energy sources.

**Ojha [2009]** presented a review of the various decentralized renewable energy options and discussed about the current power policy and highlighted the benefit of decentralized energy potential in India. The author emphasized on the importance of setting up of independent rural power producers (IRPPs) for promoting the development of sustainable and socially equitable rural power sector. The author highlighted the urgency of initiating new innovative initiatives in framing new national energy policy in current power scenario in India to expedite social and economic development of rural areas. For productivity and promoting the goal of sustainability these new initiatives should be mainly focussed on the agenda of national development requiring substantial increase in energy requirement. For new development strategies, IRPPs may be one of the instruments that can simultaneously promote social and industrial development, meet market demand and ensure sustainability.

**Akella et al. [2007]** presented the optimum utilization of integrated renewable energy system for rural electrification of remote areas and carried out their research study in Jaunpur block of Uttaranchal state of India. They estimated the resource potential as 807MWh/yr and energy demand as 808 MWh/yr based on the field data. Their results indicated that for meeting the energy requirements of the area, the proposed optimized model would be the best option. Contribution of renewable energy sources to the total energy demands was observed as: MHP 16.81% (115465), solar 2.27% (15588), wind 1.78% (12201) and biomass energy 79.14% (543546) kWh per year for meeting the requirement of 687 MWh per year at 15% reduced level of 808 MWh per year load.

**Gupta and Kohlin [2006]** estimated the demand for domestic fuels. The authors surveyed 500 households having four alternatives for the source of energy such as: Fuelwood, Coal, Kerosene and LPG. They used two-stage process to estimate the demand, where the first and
second stages investigated the choice and the quantity used respectively. The authors also analyzed the option of the primary cooking fuel in terms of rankings of six fuels stated by the households for five considered attributes. Further their policy discussion highlights that provision of subsidies has less impact on the use of polluting fuels such as coal and fuelwood because of weak cross-price elasticities. However, increased availability of LPG and creating public awareness of indoor air pollution would have greater impact for lesser usage of coal and fuelwood in the rural households.

Polatidis et al. [2006] developed a systematic framework to provide insights with regard to the suitability of multi-criteria methods for renewable energy planning. The authors presented main features of the decision-making process employed in their research, the major multi-criteria analysis techniques and discussed the needs of the methods for renewable energy planning. Finally authors developed a comparison matrix by utilizing various suitable multi-criteria methods and their performances.

Vinodia and Najamuddin [2006] presented the potential of renewable energy in rural India. The authors highlighted the importance of renewable energy and reported that the renewable energy sources especially in remote villages is the best way to solve the inadequate energy supply. The authors suggested various strategies to promote renewable energy sources in rural India and highlighted its various technologies to fulfill the requirement of rural people in India.

Modi [2005] examined the scenario of the rural electricity and suggested recommendations for possible reforms in India mainly focussing Uttar Pradesh and Madhya Pradesh. Author made an attempt to address the policy reforms which has political, institutional and financial acceptability so as to provide benefits of electrification to rural population. The initial assessment of recent initiatives was carried out by the authors and certain recommendations were proposed to improve the electricity services in rural India.

Singhal and Varun [2005] presented the potential of non-conventional energy sources in India along with various renewable energy technologies (RET) and their advantages. The authors reported that renewable energy sources in India have the potential to provide the energy security. It may reduce the burden of importing the petroleum products in India. The authors argued that if a part of national budget for the purchase of petroleum products is utilized for development of renewable energy technologies, the renewable energy source may fulfill the energy demand in a cost effective manner.
Reddy [2004] analyzed the nitty-gritty of energy use in household sector in India and the associated social and economic factors which are responsible for changes in household energy use and type of fuel selection. The author also analyzed the energy-poverty relation, effects of household energy use on livelihood and gender based issues. The author has also discussed the positive impacts of energy efficiency, the needed policies and the specific proposals for government intervention to achieve the required energy efficiency.

Batliwala and Reddy [2003] presented the challenge of engendering energy and empowering women. In this research paper, the authors have presented how the involvement of women can change the energy consumption pattern of Pura village in South India. The results indicated that women work for longer hours than men in Pura village. Due to agricultural mechanization women are now involved in back-breaking tasks. It is observed that women spend more labour hours as they contribute a vital 42% for gathering fuel, 80% for fetching water, 15% for grazing livestock and 44% for agricultural work of the labour hours respectively.

Belgiorno et al. [2003] presented the gasification process to harness the energy from solid wastes. The authors described the current status of gasification technology, pre-treatments, energy recovery systems and advantage of syngas use mainly focussing attention to the various process cycles and impacts of solid wastes gasification on environment. The authors reported that the gasification process helps in energy recovery considerably and curtail the emission of pollutants. For the thermal treatment of solid wastes, this technique is considered as an alternative to the conventional technology.

Ravindranath and Ramakrishna [1997] examined the energy options for cooking in a part of south India. The authors carried out experimentations on 12 fuel device combinations taking into consideration thermal efficiency and controlled cooking tests in order to study their viability. They evaluated various fuel device combinations so as to compare various available options for fulfill cooking energy requirements and compared the cooking energy options available. In their study they found that there exists a correlation between percentage heat utilization and specific fuel consumption. The authors also discussed the health, environmental and economic aspects of the various available options.

Barker [1996] studied the economical aspect of advanced biomass power generation technologies from the conceptual stage to commercialized stage. They reported that biomass can be the largest source of sustainable renewable energy in the UK and other parts of the Europe. The author narrated that to generate electricity from biomass in full potential, a good
amount of effort is required to develop technologies with maximum efficiency for power generation from biomass.

Malik et al. [1994] carried out study for Wardha District in Maharashtra State, India, and presented an approach for planning of integrated energy system, and exhibited an ideal blend of incipient/traditional energy technologies utilizing a PC predicated linear programming model using mixed integer. The planning at district level was accomplished at two stages viz. statistical method of extrapolation procedure for movement from village level to the block level energy scenario and was predominantly based on reviews. The same model was scaled up for studying the district level energy scenario.

Ramanathan and Ganesh [1994] performed a multi-target examination about the energy used for cooking including its options by employing the procedures of goal programming with nine goals under thought factoring the energy, environmental system, and prudence. The scholars stated that lignite, natural gas, LPG, biogas, decentralizing electricity production, and solar thermal, gasification of fuel wood show to be favored origins whilst soft coke charcoal, coal, grid electricity, PV, and biogas or diesel based electricity generation are not all that favored because of the high cost or low productivity of use.

Ramnathan and Ganesh [1994] broke down this decentralized power production opportunities accessible to downtown families by adopting some methods from goal programming furthermore recommended that the electricity provisioning from PV and diesel should be acclaimed for household devices. Moreover, all further urged that electricity from the grid and one obtained by gasification of fuel wood can be encouraged barely after the efficiency of electricity generation is made more advanced.

Sinha and Tiwari [1994] ventured into the conservation of customary fuel through the reception of energy obtained from the sun. The contributors highlighted the significance of solar energy for water heating purposes and also recommended that utilizing a solar hot water method for residential applications incorporating cooking can conserve a substantial measure of conventional fuel. For a vibrant commercial setting, men numerically figured the payback span of the solar hot water system as 4.98 yr for comprehensive replacement of electricity round the year. In any case, the figure turned out to be 10 yr for fuels viz. cooking gas, firewood, and lamp oil. Subsequently, they perceived the solar water heater being a profoundly sensible strategy for round the year residential applications.
Byrne et al [1994] presented a study on two PV-DSM applications involving a water heater and an air conditioner. The authors connected a single 55-W PV module to an electric water heater and observed an increase in temperature of 2°C in water at the end of the afternoon compared to the standard DLC (grid-disconnected) case. A conservatively sized PV array without storage could meet the house air-conditioning load over 97% of the time from noon to 3 p.m., but only 69% from 3 p.m. to 6 p.m. The authors reported that PV system combined with an air-conditioning cycling program, resulted in increased success rates for supply of an air-conditioning load, meeting almost 100% of the load between noon and 3 p.m. and 85% during 3 p.m. to 6 p.m. Furthermore, based on the experimental results, they suggested that a modest-size PV array with storage could significantly shave peak air-conditioning loads during 3 p.m. to 6 p.m., thus reducing the peak demand faced by a utility at the economic rate.

Zhen and Fang [1993] developed a liner optimized energy model at village level to design the cheapest energy supply system and the best energy supply structure. To study and predict future changes in the system, a system dynamic model was built. After combining the two models and implementing in village of North China plains, which predicted that if energy-transformation devices were properly installed, the cost of the supply system would reach the lowest level while meeting the demand and also saving some amount of energy at the same time.

Srinivasan and Balachandra [1993] presented a case study on micro level energy, which considered both, the conventional as well as the new alternative technologies. According to their results, the energy savings of approx 27% and cost savings of approx 16 % are quite achievable by proper planning. Energy planning at micro-level (district/taluk) becomes pragmatic under these circumstances to pursue the goal of sustainable development and to harness available local energy resources. They also suggested that the energy consumption pattern in Bangalore North taluk in 1987–88 is considered and projected the demand for energy in 1995–96. The different energy sources are used to provide different end-use services through different end-use devices.

Ramanathan and Ganesh [1993] presented and applied a GOAL Programming which is a multi-objective programming model for household sector of Madras city. This multi-objective programming model consisted of a total of eight objectives which are oriented towards economy, energy conservation, balance of payments, employability and greenery, consistently. They allocated the various energy sources to various energy end usages by
incorporating social and environmental objectives. Also, it becomes cleared from the results of the original model and alternative scenarios that solar thermal energy, natural gas, LPG, fuel wood, kerosene and lignite should be promoted for cooking and water pumping or other irrigational works should be done by using grid electricity or diesel. As far as solar PV system is concerned, it is best for operating domestic appliances.

Joshi et al [1992] developed a linear programming model to minimize the cost function for an energy supply system. They successfully implemented the model in the domestic and irrigation sector of a village and suggested to use wood and agricultural wastes as fuels in the stoves of efficiency level 18-16 %. Further, they identified electricity as the best and most efficient option for lightening. For the agriculture purpose, diesel power pumps were found more suitable than electric ones for irrigation. Furthermore, biogas was observed to be feasible for cooking only with plants of capacity 8 cubic meters and for lighting only when the biogas conversion efficiency in the mantel was considered to be 4%.

Kermanshahi et al [1992] proposed an algorithm on the basis of reliability and security indices to determine the optimal and allocation of small scale decentralized energy resources. The total installation capacity was determined in this algorithm, considering the capacity and outage rates of the small scale decentralized energy resources with an intention of maintaining the supply reliability within the permissible level. They used a chance reliability constraint to ensure that for each period, the new unit additions together with existing units used, provide a level of system reliability that does not exceed a user specified loss of load probability. The values of capacity as a function of the maximum load incorporation of decentralized power sources were used to express the power supply reliability of the system.

Sinha and Kandpal [1992] described a linear programming based approach for arriving at optimal mix of energy technologies for cooking, lighting and irrigation. These models and their various applications have optimized the cost of using energy resources for different end requirements. The most cost effective option after collected wood is found to be biogas (for fulfilling the total energy needs of a particular area of rural regions). However the solutions corresponding to this model are site specific. The mechanized devices for irrigation like stand-alone PV system and pumping sets, water pumping windmills, gasifier systems and biogas units are attached or coupled with dual fuel mode devices, electric pump sets or diesel motors separately. They found that there are many solutions corresponding to the mathematical model which have been obtained for specific conditions existing in India and
also observed that there are sets of conditions which correspond to alternative energy sources making an economic sense or contributing to the economy.

**Sinha and Kandpal [1991]** described a linear programming based approach for arriving at optimal mix of energy technologies for cooking. In these models they optimized the cost of using energy resources for different end requirements. The most cost effective option after collected wood is found to be biogas (for fulfilling the total energy needs of a particular area of rural regions). However the solutions corresponding to this model are site specific. When fuel wood is used in a dual fuel mode gasifier, it authenticates the fact of fuel wood being the cheapest energy source for irrigation purposes. They found that the gas produced from the combustion of wood in dual fuel mode gasifier is further burnt in dual fuel mode diesel pumps to save the diesel quantity required on daily/weekly/monthly basis and thus the costs associated with different technologies and devices show a sharp rise if there is no fuel wood available in the village.

**Sinha and Kandpal [1991]** described a linear programming based approach for arriving at optimal mix of energy technologies for lighting. These models and their various applications have optimized the cost of using energy resources for different end requirements. The most cost effective option after collected wood is found to be biogas (for fulfilling the total energy needs of a particular area of rural regions). The most commonly used devices/sources of light in rural areas are of two types; fuel based and electricity based. Some of them are, chirag, hurricane lantern (both hot blast as well as cold blast), petromax, mayadeep, alcohol noorie light, incandescent and fluorescent cool daylight. They found that the cost of grid electricity and kerosene are nearly same for meeting the normative lighting energy requirement. They also suggested that noorie which is an advanced version of a normal kerosene lamp is the most cost effective source of light.

**Sinha and Kandpal [1991]** developed a linear model for determining the cost-effective technology options in the field of irrigation. By using this model they estimated the energy required for irrigation. The authors also discussed the techno economics of different energy resource and technology options for the irrigation sector. The technologies include solar photovoltaic, water pumping windmills, gasifier and biogas plants coupled to diesel engines operating in the dual-fuel mode, electric pump sets, and diesel pumps in the independent mode. The developed model is solved for typical conditions that exist in India, and they found that there are conditions in which alternative energy technologies make economic sense.
Joshi et al [1991] developed a simplified linear model which attempts to optimize the cost function of an energy supply system which consisting of a mix of energy resources and conversion devices. They applied this model to three villages, from three different physiographic zones of Nepal and analyzed the data. Their results showed that the optimized use of different energy sources in different regions is strongly dependent on demographic and climatic parameters. They suggested that for hill villages, hydropower could become the cheapest source of energy if technical options were provided, but until then more efficient use of wood is the only viable solution. They also suggested that the use of biogas is economically most feasible in Terai village.

Jain et al [1991] developed an open charcoal gasifier in 1991 and tested on a Briggs and Start on spark ignition engine which has a power of 10 HP and found that it could yield an output of 1.98 Kw cwith charcoal consumption rate of 1.54 Kg/KWh. Biomass gasifier in cogeneration with gas-turbine in pulp and paper manufacturing sector. Open core throat less gasifier cum gas clean up system designed and tested for fuelling a 3.5 Kwan diesel engine generator set (Jain et al 1991). This diesel engine was operated for more than 400 hours and it was seen that when the load was around 2.8 Kwan, it yielded an average replacement of 70% consuming the husk at a rate of 8.8 Kg/hour.

Necsulescu and Ramkrishna [1990] formulated a linear programming discrete time model and an optimum control continuous time model with the purpose of using the large amount of input output data for assisting energy planning decisions. Their models used in energy planning by calculating the energy production required to meet a given final demand of various commodities over time. These two models are combined and applied to a village in north china Plains which predicted that if the devices of energy transformation were properly installed then the cost of the supply system would reach the lowest level while meeting the demand and saving some energy.

Alam et al [1990] presented the Huq’s model of integrated rural energy system in revised form which is based on the system dynamics methodology of Forrester for policy planning. Their model is constructed to integrate the crop production, biogas production, rural forest and agro-based industries with the aim of optimizing edible, saleable and inflammable outputs to improve the quality of life. They applied this revised model for a village in Bangladesh and discussed the simulated results for policy changes.
Ashkenazi and Ramkumar [1990] developed a computer program IRES on the basis of power supply probability, for designing integrated renewable energy system with the minimum initial capital investment. This program converted the energy available from each resource into a common unit basis (kWh). The objective of this program or model was to minimize the initial capital investment for the constant supply of energy needs at a particular reliability level. From the result obtained, it was observed that biogas is the most promising energy source to cater the energy needs of rural people with the minimum capital investment.

Jayashankar et al [1989] presented a very simple model for an optimal mix of different renewable energy technologies for catering the energy needs in rural areas. This model considered the various important factors such as: the rate of escalation, inflation, availability of resources, demography, rate of interest etc.. They carried out the economic analysis of the fixed dome type biogas plant of size 8 cubic meters and burnt a part of gas produced after glazing and black coatings in order to achieve an optimum level of temperature. Their analysis showed that the optimum area to be blackened and to be coated with glaze would have a radius of 1.5 times larger size than that in the digester of the biogas plant.

Chetty et al [1988] developed a mathematical model and applied with an aim to minimize the cost and use of non local resources and to maximize the overall system efficiency. The authors applied this model in an electrified village and recommended the use of biogas for lighting in place of kerosene. They also recommended the use of firewood for cooking in the highly efficient stoves. Under the condition “single source for single task”, it was found that firewood for cooking and biogas for lighting were the most preferable and profitable options for the village considered in the study. However, in other villages or rural areas, the use of electricity for lighting and firewood for cooking in increased efficiency stoves were found to be the best options from the point of cost minimization.

Samarkou and Subramanium [1988] analyzed two optimization techniques on an hour-by-hour simulation of a combined wind and solar power plant. The system also includes a battery storage system as well as a group of diesel generators. The two optimization techniques are: simplex from the package of MINUITS written at CERN and a modified steepest descent algorithm. They found that both techniques are suited to hour-by-hour simulation for the above system since the function being minimized is monotonically decreasing towards a minimum. The comparison results showed that the steepest descent algorithm converges slightly faster than the simplex one. Moreover, the application of the
techniques for two different sites with different load profiles let us conclude that the results are stable.

Kumar et al [1988] developed a mathematical model to predict the heat losses and gains from various mechanisms in a KVIC-type biogas plant as a function of slurry temperature and other parameters. The developed model also predicted the transient performance of the conventional KVIC-type biogas plants covered by a greenhouse. They also made the numerical calculations to predict the monthly performance of biogas plants of different sizes having digester volumes ranging from about 4 to 220 m$^3$ for the climate of Delhi, India. Their results indicate that the heat losses from the slurry to ambient through the annular space left between the gasholder and the digester are very significant for smaller plants, whereas charging represents the largest single component of heat losses for larger plants.

El-Shibini et al [1989] presented an analysis of operating pattern of the power system of the thermal plant to minimize its operating cost. They developed and demonstrated a very practical method to establish mathematical models for the fuel cost of thermal power stations in electrical power systems. The developed technique utilized the operating records of the power stations, stored on a computer. These records were utilized to estimate and continuously modify the fuel cost functions of the power stations.

Groumpos and Papageorgiou [1987] developed an optimal sized algorithm for dispersed stand alone PV system to obtain the monthly average insulation difference for both the array and battery size. This algorithm was implemented to the world’s first ever PV system powered village in the state of Arizona, USA and a saving up to 22 % was observed during the calculation of economic life cycle costing. Further, it was observed that the total life cycle cost of the dispersed stand alone PV system depends on the loss of load probability value (LOLP), which is inversely proportional to expected life cycle cost.

Jain [1987] analyzed a case study of villages to signify the relevance and importance of economic factors of the concept of renewable energy centers. He proposed a concept whose aim is to meet all energy needs for all the inhabitants rather than making only electricity available to those who can afford it. His concept is based on an appropriate combination of solar, wind and bioconversion systems. He proved the relevance and economic viability of the concept and the results, which have been so far very encouraging.

Ramkumar et al [1986] proposed integrated renewable energy systems (IRES) which utilize different manifestations of solar energy to satisfy various energy needs in the the remote
rural areas of developing countries. For finding the methodology of the design of IRES they employed a linear programming approach. They found a method which is quite general and it minimizes an objective function of total annual cost, subject to a set of energy and power constraints. Also they have given a numerical example to illustrate the design procedure.

Samarakou and Hennet [1986] developed a computer model to simulate the electrical system of a Mediterranean island incorporating a wind power plant, a photovoltaic power plant and a storage system. They incorporated a number of diesel generators to obtain an overall view of the system performances. They found that it is a very attractive solution to generate electricity by wind and solar energy for isolated regions with high levels of yearly wind energy and insulation. They calculated various parameters which can be used in the simulation to improve the configuration of the system and to estimate the cost of the electrical energy unit.

Hennel and Samarakou [1986] optimized the active areas of PV conversion system, group of electricity generating wind machines, optimal capacity of a battery storage system, for combined wind cum solar power plant by minimizing the total life cycle cost of the system. Minimization of is the criterion to obtaining the optimized parameters of the system is to minimize the total life cycle cost of the system. The algorithm for generating the system costs corresponding to various values of the parameters and to use these costs in a search procedure to determine the minimum. Each point is generated by a simulation program describing the system behavior.

Amto et al [1985] used a linear programming model (MARKAL) to assess the approximate potential of solar, thermal and biogas technologies under various circumstances. Solar water heaters which are used in the private and commercial sector and biogas systems which are mainly used in the agricultural sector are the most competitive technologies for minimizing the load on economy due to the purchase of energy from other countries. From an estimation they found a saving of 450 PJ (1 PJ=10^{15} J) from a non renewable sources (assuming constant cost) for 20 years.

Bansal et al [1985] introduced a new concept by using a greenhouse for enhancing the biogas yield from a conventional biogas system in the winter months. The rate at which anaerobic digestion takes place in order to produce biogas, is a function of slurry temperature. In order to increase the output of biogas in the months of winter, the greenhouse concept is used so that, the temperature or the warmth required for smooth anaerobic
digestion is maintained and there is no effect of winter on the system. When the conventional biogas system is glazed, the trapped solar energy can be used to raise the temperature of the slurry which generally goes low enough to reduce the gas yield. Numerical calculations have been performed corresponding to the meteorological data on a typical winter day, i.e. 19 January 1981, at New Delhi (India).

**Bartoli et al [1984]** discussed a simple analytical method which allows one to predict the fraction of the load covered by a photovoltaic plant as a function of the dimensions of its components (i.e. area of the photovoltaic array and battery storage capacity), of the meteorological parameters and of the user's load. Then they used this method to perform an economic analysis for standalone plants and for fuel-assisted plants.

**Samouilidis et al [1983]** applied a large linear programming model to the national energy conservation policy options and cost benefit models of investment decisions to the localized microeconomics behavior of individual consumers. The compatibility of the two models showed that optimum decisions for individual consumers were significantly different from optimum centralized ones. They made comparative analysis of the results which shows significant divergence between the optimal solutions of the two models, indicating that no real coincidence of interest exists under the given conditions. To narrow the gap between the two perspectives, it is proposed that the government should take into consideration the economic criteria of the individual consumers, defining appropriate policy measures such as pricing and incentives.

**Reddy and Amulya [1982]** reviewed the condensed version of the final report of a detailed field study of rural energy consumption patterns in six villages located west of Bangalore in dry belt of Karnataka State in India and they also carried out their work in two phases; first a pilot study of four villages and second is the detailed study of six villages. The aim was carry out a census survey rather than a sample study. In the end 560 households out of 578 (97%) were surveyed. The ranking was found for the various energy sources in order of average percentage contribution to the annual total energy requirement: firewood, 81.6%; humanenergy, 7.7%; animal energy, 2.7%; kerosene, 2.1%; electricity, 0.6% and all other sources (rich husks, agro-wastes, coal and diesel fuel), 5.3%.

**Reddy [1970]** presented goals, strategies and policies for rural energy. The author focused primarily on cooking and rural electrification in villages with the objective of providing better quality of life, poverty alleviation. The author argued the importance of transparent,
accountable and democratic institutional arrangements at the rural level for monitoring and running rural energy systems. Finally, the author reported the requirement of a clear policy for encouraging and supporting rural institutions for maintaining transparent records, accounts and its smooth functioning.

Ramkumar et al [1969] discussed the feasibility of fabrication, installation and operation of wind energy conversion and storage system in a small rural community in a developing country. The authors conducted preliminary analysis of the economics of the energy package and observed the encouraging results. They fabricated a prototype model and presented the experimental results.

1.11 Problem Definition

Having gone through the various literatures available with regard to rural energy planning in Sikkim and understanding the energy demand and supply of rural Sikkim, it is felt that there is an urgent need to study and explore the ways and means of rural energy planning for Sikkim for its sustainable development. Hence the researcher will make an attempt to study the integrated rural energy planning for rural Sikkim in this thesis work. Based on this problem definition the researcher has outlined the objectives and scope of the present research work in next section.

1.12 Objectives of the Present Research Work

From the literature review of the past researches presented in the preceding section, it is observed that there is no systematic research study carried out at village level for meeting energy demands of the rural people without affecting existing environmental scenario. The basis of such research study is the primary data of energy consumption, availability of various energy resources and socio-economic condition of the people. An effective and systematic analysis depicting potential advantages of switching on of households from energy inefficient devices (both cooking and lighting) to energy efficient devices is also largely missing in the literature.

Thus present research work attempts to steer clear of these limitations and remaining in the same front, the objective of this research work has been module as follows;

(i) To study the energy scenario of rural Sikkim.

(ii) To categorize the households of rural Sikkim based on land holdings and occupations so as to assess the energy needs.
(iii) To enumerate the energy consumption pattern in cooking and lighting sectors in rural Sikkim.

(iv) To estimate the potential of locally available energy sources and to develop a model for optimal mixing of renewable energy sources for sustainable development of Sikkim.

(v) To explore the decentralized energy option through optimal mixing of renewable energy sources.

(vi) To assess the implementation of energy efficient devices through substitution model for developing the linkage between energy and socio economic development of villages and to study the integrated rural energy planning for sustainable development of Sikkim.

1.13 Methodology
The methodology for carrying out the present research work is exploratory in nature. The data has been collected through interviews and prepared questionnaire. This collected data has been analysed for cooking and lighting sectors. Further, optimal mixing of renewable sources have been carried out either to supplement or compliment the present energy supply pattern to provide clean and cheaper energy. Also study on energy efficient devices have been carried out to replace the existing traditional devices so that rural people of Sikkim can available required energy maintaining a balance amongst energy, environment and economy.

1.14 Organization of the Thesis
The present thesis is organized in nine chapters as follows;
Chapter 1 deals with the introduction of energy and related economic development. Also it highlights the Indian energy scenario, energy consumption pattern of rural India, various sources of energy in rural India and brings out the gap between demand and supply energy of the country. It also gives a synoptic view of rural energy technologies, tries to show the linkage between energy, economy and environment and finally outlines the need of sustainable energy planning both for India and Sikkim. Further an exhaustive literature survey is presented followed by the objective of the present thesis.
Chapter 2 discusses about the rural energy scenario of Sikkim, rural energy demand, energy consumption pattern and lastly presents the identification of gap between demand and supply.
Chapter 3 discusses on the various rural energy technologies suitable for Sikkim and also highlights some of these technologies namely micro-hydel power plant, solar photovoltaic system, biomass and biogas plants.

Chapter 4 deals with decentralized energy options namely TERI, and sunderban models and their relevance with respect to Sikkim. This chapter also deals with decentralized energy planning for Sikkim. Lastly it presents planning of available energy sources and discusses about alternative energy supply to fulfill the energy demand.

Chapter 5 presents the survey methodology, analysis of surveyed data and energy consumption pattern of surveyed villages of Sikkim.

Chapter 6 presents the energy supply by optimal mix of renewable energy sources. This chapter also deals with methodology of mixing of renewable energy sources and also discusses about life cycle cost of photovoltaic, biogas and biomass based generation systems.

Chapter 7 presents the techniques for improving energy use in cooking and lighting sectors. Further it deals with energy consumption in cooking and lighting sectors and also deals with substitution model for energy devices.

Chapter 8 presents the strategy for sustainable economic development of rural Sikkim through implementation of improved renewable technologies.

Chapter 9 presents the general conclusions and future scope of work. This chapter is followed by references referred for carrying this thesis research work.
Table 1.1 Status of household electrification in India [NCD, 2011]

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Electrification Levels</th>
<th>States</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90% and above</td>
<td>Himachal Pradesh</td>
<td>96.6</td>
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<tr>
<td></td>
<td></td>
<td>Punjab</td>
<td>95.5</td>
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<td></td>
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<td>Chandigarh</td>
<td>97.3</td>
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<td></td>
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<td>NCT of Delhi</td>
<td>97.8</td>
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<td></td>
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<td>Sikkim</td>
<td>90.2</td>
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<td></td>
<td></td>
<td>Daman &amp; Diu</td>
<td>98.3</td>
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<td></td>
<td></td>
<td>Andhra Pradesh</td>
<td>89.7</td>
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<td></td>
<td></td>
<td>Dadra &amp; Nagar Haveli</td>
<td>91.7</td>
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<td></td>
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<td>Goa</td>
<td>95.6</td>
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<td>Lakshadweep</td>
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<td>Tamil Nadu</td>
<td>90.8</td>
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<td></td>
<td></td>
<td>Kerala</td>
<td>92.1</td>
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<td></td>
<td></td>
<td>Pondicherry</td>
<td>95.8</td>
</tr>
<tr>
<td>2</td>
<td>80-89%</td>
<td>Jammu &amp; Kashmir</td>
<td>80.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uttarakhand</td>
<td>83.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Haryana</td>
<td>87.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gujarat</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Karnataka</td>
<td>86.7</td>
</tr>
<tr>
<td>3</td>
<td>70-79%</td>
<td>Nagaland</td>
<td>75.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chhattisgarh</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maharashtra</td>
<td>73.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A&amp;N Islands</td>
<td>79.4</td>
</tr>
<tr>
<td>4</td>
<td>60-69%</td>
<td>Manipur</td>
<td>61.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mizoram</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tripura</td>
<td>59.5</td>
</tr>
<tr>
<td>5</td>
<td>50-59%</td>
<td>Rajasthan</td>
<td>58.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meghalaya</td>
<td>51.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arunachal Pradesh</td>
<td>55.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Madhya Pradesh</td>
<td>58.3</td>
</tr>
<tr>
<td>6</td>
<td>40-49%</td>
<td>West Bengal (%)</td>
<td>40.3</td>
</tr>
<tr>
<td>7</td>
<td>Below 40%</td>
<td>Uttar Pradesh</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bihar</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jharkhand</td>
<td>32.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assam</td>
<td>28.4</td>
</tr>
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<td></td>
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<td>Odessa</td>
<td>35.6</td>
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Table 1.2 Fuel consumption pattern over time in rural India

<table>
<thead>
<tr>
<th>Source of Energy</th>
<th>Low income</th>
<th>Medium income</th>
<th>High income</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Firewood</strong></td>
<td>Consumption increased from 95 kg- 113 kg from 1999-2000 to 2004-2005, but decreased from 113 kg- 102 kg from 2004-2005 to 2009-2010. However there was overall increase in the decade.</td>
<td>Remarkable increase of consumption from 107 kg-125 kg from 1999-2000 to 2004-2005. However consumption remains same i.e. 120 kg (approx) for low medium income group but observed to decrease from 124 kg-115 kg from 2004-2005 to 2009-2010 in high middle income group.</td>
<td>The consumption of firewood steeply increased from 112 kg -124 kg from 1999-2000 to 2004-2005. However there is a slight decrease in consumption i.e. 120 kg (approx).</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>Consumption increased from 33 kWh-37kWh from 1999-2000 to 2004-2005. However there was slight increase in the period from 2004-2005 to 2009-2010.</td>
<td>Consumption increases from 40 kWh-47 kWh over a period of time. The low medium income recorded nearly a 6 kWh more consumption than high middle income group.</td>
<td>Consumption increased remarkably from 61 kWh-80 kWh from 2004-2005 to 2009-2010. The consumption was nearly 80 kWh from highest income bracket during 2004-2005 and 2007-2010)</td>
</tr>
<tr>
<td><strong>LPG</strong></td>
<td>Consumption increases from 6 kg-8 kg from 1999-2000 to 2004-2005. However there is a slight change from 2004-2005 to 2009-2010.</td>
<td>In lower middle income group the consumption was varying from 7 kg-10 kg and in high middle income group there was no change in consumption and it was approximately 11 kg from 2004-2005 to 2009-2010.</td>
<td>In this category the consumption was 10 kg-11 kg approximately from 2004 to 2010</td>
</tr>
<tr>
<td><strong>Kerosene</strong></td>
<td>Consumption decreased from 3.17 lts-2.83 lts from 1999-2000 to 2004-2005. However the consumption was constant approx 2.82 lts from 2004-2005 to 2009-2010. Market purchased kerosene has also similar trend.</td>
<td>In PDS kerosene consumption there was a decline from 3.62 lts-3.0 lts during 1999-2000 to 2004-2005. Also there was a decrease in PDS kerosene consumption from 3.2 lts-2.98 lts during 2004-2005 to 2009-2010. Further similar trends for open market purchased kerosene have been observed.</td>
<td>Steep decrease in PDS kerosene consumption from 4.29 lts-3.35 lts in the period from 1999-2000 to 2004-2005. Also same trends in decrease of kerosene consumption from 3.35 lts-3.0 lts for the period 2004-2005 to 2009-2010 have been observed. Also similar trends were observed for open market purchased kerosene.</td>
</tr>
</tbody>
</table>
Table 1.3 Electricity demand and supply in India

<table>
<thead>
<tr>
<th>FY</th>
<th>Energy Demand (MU)</th>
<th>Availability (MU)</th>
<th>Shortage (MU)</th>
<th>%</th>
<th>Peak Demand (MW)</th>
<th>Demand</th>
<th>Met  (MW)</th>
<th>Shortage (MW)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-03</td>
<td>545,983</td>
<td>497,890</td>
<td>48,093</td>
<td>8.8</td>
<td>81,492</td>
<td>71,547</td>
<td>9,945</td>
<td>12.2</td>
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</tr>
<tr>
<td>2003-04</td>
<td>559,264</td>
<td>519,398</td>
<td>39,866</td>
<td>7.1</td>
<td>84,574</td>
<td>75,066</td>
<td>9,508</td>
<td>11.2</td>
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</tr>
<tr>
<td>2004-05</td>
<td>591,373</td>
<td>548,115</td>
<td>43,258</td>
<td>7.3</td>
<td>87,906</td>
<td>77,652</td>
<td>10,254</td>
<td>11.7</td>
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<tr>
<td>2005-06</td>
<td>631,024</td>
<td>578,511</td>
<td>52,513</td>
<td>8.3</td>
<td>93,214</td>
<td>81,792</td>
<td>11,422</td>
<td>12.3</td>
<td></td>
</tr>
<tr>
<td>2006-07</td>
<td>693,057</td>
<td>624,716</td>
<td>68,341</td>
<td>9.9</td>
<td>100,715</td>
<td>86,818</td>
<td>13,897</td>
<td>13.8</td>
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</tr>
<tr>
<td>2007-08</td>
<td>737,052</td>
<td>664,660</td>
<td>72,392</td>
<td>9.8</td>
<td>108,866</td>
<td>90,793</td>
<td>18,073</td>
<td>16.6</td>
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</tr>
<tr>
<td>2008-09</td>
<td>777,039</td>
<td>691,038</td>
<td>86,001</td>
<td>11.1</td>
<td>109,809</td>
<td>96,785</td>
<td>13,024</td>
<td>11.9</td>
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</tr>
<tr>
<td>2009-10</td>
<td>830,594</td>
<td>746,644</td>
<td>83,950</td>
<td>10.1</td>
<td>118,472</td>
<td>102,725</td>
<td>15,747</td>
<td>13.3</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1.1 Firewood, LPG and electricity consumption over time across income classes

Fig. 1.2 Improved chulha [Designed by IISC Bangalore]