MODELLING OF DECENTRALIZED INTEGRATED ENERGY SYSTEM

A THESIS

Submitted in fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

By

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For revised

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **MODELLING OF DECENTRALIZED INTEGRATED ENERGY SYSTEM** in fulfilment for the award of the Degree of The Doctor of Philosophy and submitted to the **Alternate Hydro Energy Centre (AHEC)** at **Indian Institute of Technology (IIT), Roorkee**, is an authentic record of my own work carried out during a period from January 7, 1999 to December 15, 2002 under the supervision of **Dr R.P. Saini**, Scientist, AHEC, IIT Roorkee, and **Dr. V. Devadas**, Assistant Professor, Department of Architecture and Planning, IIT Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any degree of this or other institute/university.

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ABSTRACT

The economic progress of any country is reflected as an increase in its energy consumption within the population. Conversely, if economic progress is desired, then an increase in the per capita energy consumption is an inevitable consequence, which needs to be given due consideration by Planning Bodies. Developing nations like India are largely rural in composition. Much of the country's economic growth is thus dependent on the suitable growth and development of its rural segment vis-a -vis the urban segment. The oil crisis beginning in the 70's has necessitated the general policy that oil and petroleum imports be judiciously utilized for achieving productivity that is conducive to national growth and development. Much of the productivity related to the gross national product occurs in industrialized areas of urban sectors. By contrast, there is a low level of productivity in the rural sector due to the poor and often unstable agricultural practices currently adopted. It is therefore evident that the major supply of available commercial fuels imported at the cost of precious foreign exchange are more likely to be diverted to the urban than the rural sector, since better levels of productivity are assured in such areas. In view of this, the rural sector is unlikely to receive the required amount of commercial energy for its development. It must thus make up for this energy deficiency by augmenting its available energy reserves with alternative resources that are available locally on a renewable basis.

India is predominantly rural in composition, it is therefore clear that the overall development of the country will be benefited by improving the level of economic growth in its rural sector. The concept of integrating various energy resources for meeting the total energy requirements of a rural area is popular in developing countries. The

commonly available renewable energy resources at the rural area can include: solar energy, wind energy, biomass energy and energy of flowing/captive water reserves. These resources are supplemented with other conventional/commercial resources in the rural area.

The end use of the required energy demand in the rural areas ranges from basic and subsistence needs of cooking, heating and lighting to productive activities ranging from farm mechanization to rural industries, irrigation etc. For each end use, there could be a range of energy options viz. commercial/non-commercial/renewable, which can be used in a manner depending upon the resource endowment of the micro region, the annual resource availability, the energy needs and their priority for the given population. Since energy utilization scenario would differ from one micro region to another, it becomes necessary for rural planners to conduct independent studies for each micro region instead of generalizing for the whole region encompassing a cluster of micro regions.

Energy planning for different regions in the rural Indian segment is thus a challenging task. In the literature, several researchers have attempted to design and evaluate energy plans for different cluster of regions and thus provide in a piecewise manner a picture of the energy scenario in different pockets of the Indian sub-continent. Despite the numerous studies reported, several rural regions have yet to be explored in regard to their existing energy scenarios. The scope for extensions of the reported work is therefore encouraging.

For the present work, it was proposed to take up energy studies for a village in the district of *Pauri Garhwal*, in the newly created state of *Uttaranchal (India).* There are very little studies reported for this region, and, the present work was therefore directed to fill a part of this need. *Kanvashram*, a rural hilly village in the district was chosen for the purpose. This village has recently been identified by the *Garhwal Mandal Vikas Nigam*, a planning body for the district, as a promising site for development into a tourist/pilgrimage centre. It is therefore expected that in view of this proposal, the village of *Kanvashram* is likely to experience rapid development in the near future. Hence the village appears to be ideally suited for the purpose of energy studies and planning. Accordingly, the present study attempts to address the objectives of assessment of the energy consumption trends of the rural population, estimation of the level of inequality in energy resource consumption in different segments, development of an integrated energy planning model involving the major energy end use applications, application of the developed energy planning model for subsequent simulated studies and evolving effective policy measures in relation to energy planning for the study area.

These objectives can be realized using appropriate methodology of analysis. The data needed for the study is by and large of a primary nature.

Detailed analysis relating to the energy consumption trends among the rural population was carried out using statistical measures, Lorenz curves and Econometric inequality indices. The energy consumption patterns were analyzed for three categories viz. *Joint households, Nuclear households and All households* in relation to the commonly used energy resources available in the study area.

Linear programming models were developed for the end uses of the area and an integrated model was designed that could be used for subsequent simulation studies. The integrated model was used to examine the impact of certain scenarios in the projected year 2005 A.D., for which the energy planning exercise is being carried out.

The findings of the study reveal that the energy consumption of the *Joint* family household differs from that of the *Nuclear* household in regard to magnitude, inequality levels and pattern of use for different decile groups. This was found to be true for the major energy resources i.e. electricity, kerosene, LPG and fuel wood. The implication of these findings is that an energy plan based on extrapolation of current trends must make suitable provision while allocating energy resources for future energy demand in the region under planning.

The integrated energy planning model developed for arriving at the most suitable mix of energy resources needed for meeting the demands in the study area shows that the optimal solution cost obtained from the model is highly reduced in comparison to the cost employing the existing consumption pattern in the study area. The use of the optimization methodology for energy resource planning is therefore to be recommended. The projected energy allocation model for the year 2005 A. D. is accordingly prepared after allowing for changes in demand and supply constraints.

Hypothetical scenarios, introduced as outcome of policy moves, are also examined by the simulated application of the model for the projected year. The findings helped in deciding the effectiveness of the scenario as a policy measure for implementation. The results showed that certain policy moves are effective, some were break even, while others are to be rejected. Based on these and other major findings, recommendations are made for policy measures suitable for the study area and other areas sharing common characteristics.

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NOMENCLATURE

C_T = Total cost of providing energy for all end uses

C_{ij} =Cost/unit of the i^{th} resource option for j^{th} end use[Rs/kWh]

X_{ij}=Optimal amount of i^{th} resource option for j^{th} end use[kWh]

D_j = Total energy for j^{th} end use[kWh]

S_{ij} = Availability of i^{th} resource option for j^{th} end use[kWh]

η_{ij} =conversion efficiency for i^{th} resource option for j^{th} end use

C_i = Cost of ith energy resource in Rs/kWh (see table of costs of energy resources)

W_i= Weightage of ith energy resource

$RA_{i\,scenario}$= Resource allocation for the ith energy resource in accordance with the model allocations for scenario

$RA_{i\,base}$ = Resource allocation for the ith energy resource in accordance with the model allocations for the reference case (year 2005 A.D.)

W_i = Weight of energy resource with respect to agro waste, the lowest energy resource "rung "of the "*energy ladder*".

CHAPTER–1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Economic development in a growing nation is inextricably linked with the growth of energy consumption among the population. As the economic prosperity of the nation improves, it is accompanied by an increasing energy consumption trend among the people. Energy thus occupies an important position in improving the standard of living and comfort of the people. However, the problem that most developing countries face is one of ensuring a regular supply of energy for meeting their major energy needs in relation to economic growth, which is essential for global survival.

In a developing nation like India, the rural segment is predominant and accounts for a major say in dictating the overall economic prosperity of the nation. To ensure a uniform and sustainable economic growth, attention must be paid to the provision of adequate energy for such segments. However, as it presently stands, a severe energy crisis exists in most parts of the Indian rural segment. This situation has forced the rural energy planner to evolve optimal planning strategies for sustainable development.

The existing centralized planning strategy lays emphasis on industrial growth and development in the urban segment. It is assumed that, the benefits of the urban growth would gradually diffuse into the rural segments in close proximity, and, that the rural segment would eventually reap the extended benefits of the urbanized growth. However, the short sightedness of this policy became apparent only after several years, when it was realized that the rural segment was receiving a mere trickle of the benefits that urban segment was enjoying. The last five decades have witnessed a rapid economic growth in the urban segment, which can be sharply contrasted with the falling economic prosperity of the rural segment. Severe economic recession, rampant poverty, unemployment and the ever increasing exodus of the rural youth into the already over crowded urban areas in search of better employment prospects is posing a threat to the population control of both segments. In fact, the disparity in the economic levels within the two sectors is fast rising to dangerous levels that can have damaging repercussions on the socio-economic stability of the nation as such. This critical situation can be averted or minimized to a great extent if timely measures are taken to encourage a more balanced growth in the rural segment, and, rejuvenate the fallen rural economy by employing more effective policies and planning strategies.

Realizing the necessity for appropriate corrective action, the Indian Government made attempt to tackle the problem by increasing supply of commercial energy inputs. The general impression was that if the rural segment was provided with sufficient commercial energy inputs, then productivity (and consequently the standard of living of the rural population) could be raised. This would head the fallen rural economy towards the path of a slow but sure recovery. The central planning policy that is currently in operation has attempted to resolve the issue by allocating an increased supply of commercial energy inputs (oil and electricity) to the rural sectors. Plans have been approved by the state and central government planning sectors in revamping rural sectors to combat the existing energy crisis. While some success has been reported in the implementation, the efforts would bear more fruit if the projects were better regulated and organized. It appears that the projects aimed at introducing commercial energy inputs into the Indian rural areas are basically large-scale ventures, modelled in imitation of Western consumption trends. Such projects fail to take into consideration the peculiarities in characteristics and consumption trends associated with Indian villages which shows that the intensity of consumption is much lower in these areas as compared to urban areas. This is because in urban segment, the industrial energy sector is the major energy component of the demand, while in the rural segment, it is mainly the domestic sector. The average rural consumer, on account of the general low standard of living can ill afford electrical energy above his basic needs. Such needs are mostly restricted to lighting energy needs. Hence, the economics of supplying energy to such areas is not attractive. Further, the technical feasibility of projects aimed at the extension of the existing grid supply to distant villages, appears to be a waste in terms of the small population being served, and, the poor financial returns recovery on the instrument. [Singh 2000] Nonetheless, despite these glaring shortcomings in the project ideals, the centralized planning strategy continues to be patronized. This is largely because the key planners, who are of urban elite origin, favour the system of planning with which they are more conversant and comfortable. Such planners have little exposure to the ground realities and requirements of the rural energy system and are not likely to settle for decentralized planning with which they may not be familiar.

Another reason responsible for favouring the centralized planning strategy is that such a strategy meets the approval of the international aid agencies responsible for funding the projects. Such organizations confine their loans/capital only for schemes that are patterned on the centralized planning strategy, which, appears to provide quicker returns on the investment.

These two reasons imply that the central planning system will continue to be in force that and it is unlikely that rural areas will be much benefited as a consequence.

Rural areas must then either resign themselves to the allocation of resources in accordance with the centralized planning strategy in force, or else fend for themselves by evolving alternative strategies to combat the inevitable energy crisis.

Recently, there has been a renewal in the perspective of rural planners. The rising cost of commercial energy procurement and the possibility of using renewable energy inputs, so abundant on a local basis, has caused the government to seriously consider exploring the feasibility of setting up decentralized energy systems for rural areas. Such systems, have the major energy inputs derived from renewable/non-commercial energy resources, while a relatively small proportion of the energy requirements are satisfied using commercial energy inputs.

A three pronged strategy has been contemplated in regard to the implementation of decentralized energy planning for rural areas as follows:

(i) The first goal is to increase the commercial energy supply in country which will assist in the projected increases in GDP (Gross Domestic Product) and ultimately result in the improvement of the standard of living of the rural population.

(ii) The second objective is to ascertain the causes of inefficient energy utilization and prepare rural areas for more efficient ways of using energy.

(iii) The third objective is to analyze the energy consumption pattern and devise a suitable strategy involving an energy resource mix for different sections viz. domestic/agricultural/industry/transport, etc. In the context of the third objective, it must be mentioned that Indian villages utilize both commercial energy resources like oil products and electricity as well as non-commercial age old resources like fire wood, agro -waste animal dung etc. A vast potential of energy is additionally available for new technologies that employs energy resources like solar energy, wind energy, biogas and biomass energy and the energy associated with flowing water in streams and rivulets. Rural India is blessed with an abundance of these renewable energy resources which offer ample scope for generating an adequate energy pool sufficient for meeting most of the energy needs of the rural segment.

The energy plan for the rural segment should aim at arriving at a suitable mix of all these resources for meeting the various energy resources with specific objectives as targets. Such a plan aims at optimal development in which greater stress is to be laid on non-conventional energy resources than on commercial energy. It is envisaged that such an energy plan will improve the economy and life style in the village and check the growing emigration rate of the rural population into the urban zones. To achieve these objectives, the Government has initiated the ***Integrated Rural Energy Program (IREP)*** in the 6^{th} five-year plan, which has expanded ever since then.

The objectives of the IREP are to provide energy for meeting the basic needs of cooking, heating and lighting especially for the weaker sections of the rural society. It does so by utilizing locally available resources to the maximum extent possible which not only satisfies the basic energy needs, but also creates several benefits like new employment opportunities, increased productivity, improved incomes apart from accelerating the process of decentralized development. The end use of energy in the rural areas ranges from basic and subsistence needs of cooking, heating and lighting to productive activities ranging from farm mechanization to rural industries, irrigation etc. For each end use, there could be a range of energy options viz. commercial/non-commercial/renewable, which can be used in a manner depending upon the resource endowment of the micro region, the annual resource availability and the needs and their priority for the given population. Since the energy resource availability and utilization scenario would differ from one micro region to another, it becomes necessary for rural planners to conduct independent studies for each micro region instead of generalizing for the whole region encompassing a cluster of micro regions.

1.2 DECENTRALIZED ENERGY PLANNING AND THE IREP

Decentralized Energy Planning (DEP) was initiated by the Government of India with the understanding that a more efficient and equitable allocation and utilization of available resources could be fostered in rural areas [Sinha et. al. (1997)]. The necessity of DEP arose due to the limited foresight of centralized planning exercises that ignored the effects of socio-economical and eco-cultural factors governing the success of planning for rural areas. It is now being realized that DEP at local levels can help in bringing about the desired results. The key factor for a successful implementation of a DEP program lies in galvanizing local participation. Several agencies have, emerged which engage in mobilizing the rural population by means of awareness camps that focus on the necessity of DEP schemes, their proper implementation and their overall contribution to the growth and development in the region.

In the Indian context, the DEP is structured with the rural family and village characteristics in mind. They are executed from the developmental block level (of which the rural area is a part), supervised from the district level monitored at the state level and ultimately formulated at the national level. At the block level, the DEP is executed as the IREP, which is co-ordinated by the Energy Cell of the planning commission of the Indian Government. At the village level, the programs are executed in the form of local *Energized Village Models* or "Urjagrams" and these are co-ordinated by the *Ministry of*

Non-Conventional Energy Sources (MNES). Monitoring of DEP at the district level is currently under consideration and some plans have been tried for certain Indian states. For example, DEP in Wardha district (Maharashtra) [Operations Research Group (ORG) report (1989)] and Almora district in Uttranchal (Erstwhile Hilly region of Uttar Pradesh) [Hossain et. al. (1988)].

As stated earlier, the implementation of the DEP at the block level is accomplished with the help of the IREP. It would be pertinent to review briefly the history of the origin of the IREP, its scope of activity and its subsequent progress.

The IREP was initiated during the 6^{th} Five year plan on a pilot scale in selected Indian states. The objectives of the IREP are the provision of energy inputs for various uses to rural areas using an optimal mix of all types of energy sources. The program involves plans framed for rural development that were subsequently translated into field exercises, and implemented with the aid of state government assistance. The schemes proposed at the micro level were intended to be operated in decentralized manner with independent energy planning activity controlled by the governing state. Initially four Indian states were identified in 1981 in which IREP's were to be introduced. Subsequently, five more states were inducted by 1984-85. In each of these states, the development of the program was carried out in three phases. [Chopra (1987)]

In the first phase, state level working groups consisting of representatives for the different concerned departments were entrusted with the task of preparing an approach paper on the rural energy problem in the state, and, developing strategies for the coordination of the IREP in terms of area based project implementation.

In the second phase, districts and pilot blocks (each block consisting of up to 100 villages) were selected in which it was feasible to initiate IREPs.

In the third phase, the actual implementation of the IREP was carried out. By the end of the 6th plan period, 20 block level IREP projects were in progress at different stages of implementation within the selected states.

The IREP focuses on using a mix of different energy resource inputs for meeting the energy needs of the population. The choices will depend on the availability of various resources in the region. Major thrust was placed on resources that included: windmills, solar cookers, water heating systems, biomass based improved *chulas* (stoves), improved kerosene stoves, etc. The progress was measured in terms of the targets fixed by the planning state. IREP Cells were set up for co-ordinating the program with different government departments. Also, project cells at the district and block levels were set up for help in the implementation. To encourage adoption of renewable energy schemes, subsidies were given by the government.

The experiences of the 6th plan in the area of renewable energy promotion showed that more effective objectives and monitoring were needed for a better rate of success in IREP program implementation. Subsequently, in the 7th plan that followed, the planning commission set up the following objectives:

(i) Augmentation of the fire wood supply through large-scale deforestation programs mainly on wasteland as the fuel wood demand is likely to increase.

(ii) Promotion of efficient use of fuel wood through large scale implementation of the improved *chula* program (wood stove).

(iii) A more efficient utilization of cow dung in the form of biogas fuel inputs instead of dung cakes. The slurry that remains after the digestion can be used as an organic natural fertilizer. Family and community biogas plants should be encouraged.

(iv) Replenishment as far as possible of commercial energy based devices with non-commercial energy operated devices like: solar cooker, solar heating systems etc.

(v) The promotion of energy saving devices and options like improved kerosene stoves, and rural electrification for illumination needs.

(vi) Promotion of non- oil based fuels like: soft coke, charcoal etc.

(vii) Improved use of agro waste as a fuel by compression into briquettes/pellets for biomass gasifiers.

To meet these objectives satisfactorily, the program control was divided into the following sub-components:

(i) Developing institutional mechanism in states implementing the IREP.

(ii) Training of staff/ villagers in the operation of the IREP. For this purpose it was proposed to set up national training centres.

(iii) Project preparation with the help of the planning commission.

(iv) Project implementation with the help of R&D institutions, academic institutions, industries and Non Government Organizations (NGO's).

(v) Provision of financial incentives and subsidies.

(vi) Monitoring of the physical and financial progress with regular guidelines to be given from time to time.

(vii) Development of a computer based model at the national level catering to the planning of the IREP policy and investment.

The objectives outlined attempted to improve the energy consumption habits and trends, but did not fully explore the trade offs involved in terms of energy economics in their implementation.

The IREP has had its share of teething problems. A variety of questions have been raised in regard to the confusion that prevails among some rural energy planners. These issues relate mainly to the administrative and control aspects that have created doubt and apprehension in the minds of these rural planners as regards the possible outcome of the scheme.

Nonetheless, the program has continued to grow substantially and presently there are 856 blocks in 25 states and 7 union territories under the control of the program.

Table 1.1 (a) shows the present status of the IREP projects in the rural sectors of different Indian states [MNES (2000) (Annual Report 1999/2000)] In order to provide the necessary training for manpower, Training–cum- R&D centres have been sanctioned at Bakoli (New Delhi), Lucknow (Uttar.Pradesh), Bangalore (Karnataka), Kheda District (Gujarat) and Shillong (Meghalaya). The centres at Delhi and Lucknow are already functional and have been active in conducting several programs since their commissioning. [Singh (2000)] Table 1.1(b) highlights some achievements of the MNES (up to the year 1997), showing the growing acceptance of renewable energy technology in the Indian energy sector.

Table 1.1 (a) : State wise coverage of blocks under Integrated Rural Energy Program (IRES)

State	No. of blocks	State	No. of blocks	Union territory	No. of blocks
Andhra Pradesh	32	Manipur	19	Andaman & Nicobar Islands	05
Arunachal Pradesh	10	Meghalaya	16	Chandigarh	01
Assam	21	Mizoram	11	Dadra & Nagar Haveli	01
Bihar	56	Nagaland	25	Daman & Diu	01
Goa	5	Orissa	45	Delhi	05
Gujarat	25	Punjab	40	Lakshadweep	01
Haryana	38	Rajasthan	36	Pondicherry	02
Himachal Pradesh	45	Sikkim	04		
Jammu &Kashmir	28	Tamil Nadu	21		
Karnataka	42	Tripura	06		
Kerala	44	Uttar Pradesh	115		
Madhya Pradesh	85	West Bengal	34		
Maharashtra	37			**Total**	**856**

Source: MNES 2000 Annual Report 1999/2000, New Delhi, Ministry of Non – Conventional Energy Sources.

Table 1.1 (b): Target achievements of renewable energy in the 8th five year plan

Category	1992/1993	1993/1994	1994/1995	1995/1996	1996/1997 (Target)
SPV (SolarPhotoVoltaic)					
Power units(kWp)	143.66	122	100	89	50
Domestic lights (Number)	3043	6339	500	----	----
SPV lanterns (Number)	----	----	----	----	----
SPV street lights(Number)	----	----	----	----	----
SPV water pumps (Number)	106	1894	1000	738	1000
Solar Thermal					
Solar thermal systems(m^2)	24,595	40,866	35,000	50,000	35,000
Solar cookers (millions)	0.05	0.05	0.03	0.04	0.03
Wind					
Wind power (MW)	12.68	61.09	235	382.11	100
Wind pumps (Number)	93	41	200	29	200
Wind battery chargers(Number)	4	6	15	1	35
Biomass /Biogas					
Biomass stand alone gasifiers (MW)	2	4	5	4.4	6
Biogas (family type units) (Number)	0.19	0.22	0.2	0.18	0.18
Biogas (community type units) (Number)	189	215	236	35.3	250
Biomass combustion (MW)	----	----	4	37	55
Microhydels(MW)	12.02	5.35	25	7.5	30

Source : TEDDY 2000/2001.

1.3 RURAL ENERGY CONSUMPTION TRENDS IN INDIA: A GENERAL OVERVIEW

Almost 70 percent of the population in India lies in rural areas, and meeting their energy requirements in a sustainable manner continues to be a major challenge for the country [Venkata Ramana (1996)]. The majority of the rural population continues to be heavily dependent on traditional biomass resources despite the introduction of commercial fuels like kerosene and LPG (Liquefied Petroleum Gas). The chief cause for this is that such fuels are usually beyond the reach of the average villager due to high costs and low accessibility. Only the affluent rural households can afford to purchase and use such fuels.

In Indian rural areas, the main traditional biomass fuels used are : fuel wood, crop residues and animal dung. Such fuels are used for cooking, which accounts for nearly 90 % of the total energy consumption in the domestic household. The other energy uses of importance are: lighting and space heating. Among commercial fuels, only kerosene is important, being used mainly for lighting. In the Agricultural sector, direct energy inputs are mainly in irrigation using diesel and electric pump sets and diesel consumption for tractors used in tilling, harvesting etc. The other sectors in the rural economy i.e. Industry and Transport have low level of energy consumption, although rural industries like brick kilns are energy intensive and use fuel wood extensively. For domestic needs, the fuel wood used is generally collected by women and children and is seldom purchased. Table 1.2 shows the main sources of fuel wood used for meeting rural energy needs.

The per capita or family consumption of fuel wood varies considerably across different regions and agro climatic zones depending upon the resource endowments and accessibility. The average consumption of fuel wood is estimated to be between 100-300 million tonnes/year [Sinha and Joshi (1996)], while the annual sustainable yield from different land resources is estimated in the range 36-86 million tonnes/year [TERI Report (1995)]. The figures show wide gaps in demand and sustainable supply. It is believed that this gap is satisfied from illicit and unsustainable exploitation of biomass resources. With the growing population and the accompanying expected increase in the fuel wood demand, the rural energy planner is concerned about the large scale deforestation and efforts are on to reduce much of that demand by the use of more efficient cooking devices, and wear possible, by replacements with alternative fuels like biogas.

Table 1.2 : Sources of fuel wood in Indian villages

S. No.	Source	Percentage share of total fuel wood supply (%)
1.	Plantations	18.30
2.	Farmlands	21.05
3.	Homesteads	7.32
4.	Degraded land	12.10
5.	Shrubs	8.97
6.	Forests(Log wood)	8.69
7.	Forests(Twigs/Branches)	19.22
8.	Forests (Waste)	4.35

Source : P. VenkataRamana (1996)

Animal waste in the form of dung cakes is an important fuel in the region which are agriculturally prosperous, and, where fuel wood supply is poor. Estimates of animal dung production and consumption are approximately 200 M tones/year and 100 M tonnes/year respectively [VenkataRamana (1996)]. Thus, the demand is well within the limits of the supply. However, most of the villagers prefer to use animal dung as manure if fuel wood is available, and it is not expected that the use of dung as a fuel is likely to rise considerably in the near future.

Another resource that is used in some rural areas are crop residues. They are the least preferred of biomass fuels, because, being in the loose form, they burn at a fast rate and involve large heat losses and low efficiency. Nonetheless, this resource serves as a backup fuel in the event of scarcity of fuelwood, and due to the increased curtailment of use of fuel wood, this resource is gaining prominence as a substitute. It is estimated that about 100 M tonnes of non- fodder crop residue is produced and consumed as fuel in various rural regions of the country.

Apart from the traditional biomass fuels discussed, rural areas also make use of some commercial forms of energy, notably, kerosene, LPG, diesel and electricity. Electricity is used mostly for lighting needs in electrified villages However, kerosene is also used as a substitute in low income and non-electrified households, and also as a backup for power cuts. LPG is used for cooking and is available to rural households that can afford this relatively expensive resource, and, where consumer supply is extended. Diesel is used for tractors and for rural transportation, while diesel and electricity serve to operate tube wells for agricultural irrigation purposes.

Electricity provision was envisaged as a means of improving the agricultural productivity by providing the needed irrigation facilities. Further, it was felt that the introduction of electricity would improve the life style of the rural population. The *Rural Electrification Cooperation (REC)* was accordingly founded to implement electrification in the villages. By the end of 1993-94, more than 85% of the 580 villages in India were reported to have been electrified and more than 10 millions pumps were energized.

[Central Electricity Authority (CEA) Report (1996)]. However, despite these impressive figures, the actual number of households with electric connections is only about 30 percent.[Gupta(1996)]. Apart from this, the quality of supply has not been satisfactory. Rural electrification, as of present, implies an extension of the conventional grid supply into villages that are located within acceptable distances from grid tapping points. Remote and inaccessible villages are not expected to be energized on account of poor techno-economics feasibility of the grid extension projects. It is estimated that nearly 90,000 villages are still under this category and must rely on non-electric energy routes for irrigation and lighting needs.

The rural energy consumption trends of rural households categories in relation to various fuels and end uses applications is shown in table 1.3. The table shows that cooking and water heating are predominant energy consumption activities in rural areas while lighting and miscellaneous uses are the main energy consuming activities in the urban areas. This suggests that energy planning for rural areas should be different from that for urban areas, which, are essentially on lines of centralized planning.

Table 1.3: Proportion of energy consumed in urban and rural households by end-use (1984-85)

S. No.	End use	Urban share (percentage of total energy) (%)	Rural share (percentage of total energy) (%)	Total (%)
1.	Cooking	28.00	72.00	100.00
2.	Lighting	60.00	40.00	100.00
3.	Water heating	34.00	66.00	100.00
4.	Other Uses	87.00	13.00	100.00

Source: Sinha et al (1997)

Table 1.4 shows the rural and urban energy consumption pattern for different fuels/energy resources. It may be seen from table 1.4 that in the urban areas, electricity, oil, LPG and coal i.e. the commercial forms of energy are the main ones in use. The rural areas on the other hand make extensive use of fuel wood, dung cake crop residues i.e. the traditional fuels and very little of the commercial fuels like electricity, oil, LPG and coal.

Table 1.4 : Resource consumption pattern in Indian urban and rural sectors

S.No.	Resource	Percentage urban share (%)	Percentage rural share (%)	Total (%)
1.	Electricity	76.00	24.00	100.00
2.	Fuel wood	17.00	83.00	100.00
3.	Dung cake	7.00	93.00	100.00
4.	Crop residue	1.00	99.00	100.00
5.	Oil	73.0	27.0	100.00
6.	LPG	97.0	3.0	100.00
7.	Coal	94.0	6.0	100.00

Source: Sinha et al (1997)

Table 1.5 depicts the proportions of various commercial and traditional fuels in the average Indian rural household Thus it may be seen that even within an average rural household, that make use of both commercial as well as traditional energy resources, the traditional energy inputs outweigh the commercial energy ones in the approximate ratio of 1:9.

Table 1.5: Proportions of commercial and traditional fuels in Indian households.

S. No.	Resource	Percentage composition of total energy demand in rural households (%)
	Commercial	
1.	Soft coke	5.10
2.	Kerosene	2.10
3.	Electricity	2.67
	Traditional	
1.	Fire wood	54.13
2.	Vegetable Waste	15.60
3.	Dung Cake	20.40
	Total	100.00

Source: TEDDY 1996-97, TERI, New.Delhi (India)

Tables 1.6-1.7 indicate the extent to which different factors are responsible for the observed choice of different energy resources in the population. Table 1.6 shows cost to be an important reason for not favouring electricity followed by kerosene and soft coke. Surprisingly, fuel wood appears to be more costly than LPG to the rural consumer, presumably on account of the time effort spent in its collection, storage etc. On the basis of unavailability, LPG ranks first followed by fuel wood and soft coke. The statistics pertaining to the availability of electricity are not reported in the table, but the trend points this resource to be the least available on a definite basis.

Table 1.6 : Reasons for the non-use of various energy resource options.

S. No.	Resource	No. of households not using resource %	Reasons			
			Costly %	Not easily available %	Other causes %	Total %
1.	Soft Coke	19.70	34.00	57.90	8.10	100.00
2.	Kerosene	17.30	66.70	33.20	0.10	100.00
3.	Electricity	1.80	79.70	**	20.30	100.00
4.	Fuel wood	14.20	25.30	60.80	13.90	100.00
5.	LPG	29.20	12.60	76.80	10.60	100.00

Source: TEDDY 1996-'97, TERI, New Delhi(India)
*** Applies to only Electrified Villages*

Table 1.7: Energy Resources Preference in Rural Households

S. No.	Energy resource	Main reason for using resource					
		Rise in household income %	Resource is now cheaper %	Resource was not available earlier %	Resource is now easily available %	Other reasons %	Total %
1.	Soft Coke	72.60	15.60	11.80	-	-	100.00
2.	Kerosene	30.90	9.60	-	59.50	-	100.00
3.	Electricity	-	-	-	-	100.00	100.00
4.	Fuel wood	91.80	8.20	-	-	-	100.00
5.	LPG	66.70	-	33.30	-	-	100.00

Source: TEDDY (1996-'97)

Among "Other Causes" (c.f. table 1.6) that could include factors like: convenience in operation, environmental and hygienic considerations and efficiency of fuel-device combination, it may be seen that the energy resources least preferred are electricity, fuel wood and LPG. Kerosene soft coke apparently are not rejected on the basis of these factors by the majority of the rural population. In the overall assessment, the choice of various fuels would be governed by all these three considerations. On the basis of this, LPG is not used by approximately 30% of rural households followed by soft coke (approximately 20%) and kerosene (approximately 17%). Fuel wood and electricity are generally preferred by rural households when made available, although the overall energy consumption may not be large. Table 1.7 highlights the various resources and causes favouring their use in rural households. The findings show that the rise in income is the predominant factor influencing the shift of energy resource preferences among the rural population. Various other factors take a secondary place in different resources in accordance with specific difficulties associated with their procurement and use.

Thus it may be concluded that the rural household energy preferences and consumption pattern are dependent on various issues for which an in depth analysis is necessary. Planners need to carry out detailed studies to ascertain the determinants shaping the energy resource preference and consumption among the rural population.

1.4 LITERATURE REVIEW

An attempt has been made to review the related literature pertaining to the present investigation. Various authors have done research on diverse aspects of rural energy planning. The reviews relevant to the present investigation are collected, grouped under different heads and presented in the subsequent sub-sections.

The diverse issues discussed are as follows:

(i) Potential for Renewable Energy - A Global Perspective

(ii) Energy Consumption Patterns

(iii) Rural Energy Technology

(iv) Renewable Energy Technology: Experiences in Developing /Developed nations

(v) Growth of Renewable Energy Technology: Promotion, Barriers and Policy Measures for Improvement.

(vi) IREP in the Indian Context: Efforts for growth and Promotion of Renewable Energy Technology.

1.4.1 Potential for Renewable Energy - A Global Perspective

The design of an integrated energy system requires a preliminary estimation of the existing potential of various resources being considered for different sub- systems of the overall system. In regard to this aspect, various researchers have attempted to understand the details of the existing potential of different types of renewable energy resources at various locations.

It has been observed that solar energy has always been a popular renewable energy resource. This resource owes its acceptance to the fact that it is available virtually in all areas and regions, and, can therefore be conveniently tapped. However, the extent to which solar energy can be usefully extracted would depend on the geographical and climatic location of the area under consideration. Attempts have been made to measure the insolation level of the available solar radiation in different regions where solar systems could be proposed. In most cases, indirect estimation methods have been used that make use of mathematical/statistical models. [Elagib et al (1998), Al-Jamal (1999), Udo and Aro (1999), Ertekin and Yaldiz (1999), Luhanga and Nijegorodov (1997), Hein (1997), Rahman and Halawani (1997), Al-Ayed et. al. (1998), Stoyanova et. al. (1998), Meladze (1998) and Kemmoku et al (1999)] It has been seen from these reports that the scope for solar energy based technology appears to be promising in the tropical zones that have abundant sunshine.

Another area of interest, in which various researchers are active, is the evaluation and scope for solar photovoltaic electrical energy conversion systems. [Ananthia (1997), Al-Ismaily et al (1998), Stutenbaumer et al (1999)] The main finding observed in these reports is that the solar photovoltaic systems have appreciable techno- economic potential in countries with high annual insolation levels.

Although solar photovoltaic systems are efficient means of generating electricity from solar radiation, certain authors are inclined to believe that solar thermal systems are better suited for electric power generation on a techno-economic basis. [Al- Sakaf(1998), Islam and Huda (1990)]

While solar energy is a suitable resource for meeting lighting energy needs using solar PV systems, it must be understood that a variety of other needs also exist for which solar thermal systems are suitable. Such needs are generally low thermal energy based applications. Performance evaluation of solar heaters was done for applications like space heating, cash crops dehydration etc. [Bansal (1999), Garg and Adhikari (1999)]

Applications of the solar cooker for rural households needs is also economically favourable. Reports that are available highlight the diverse issues involved like: field experiences, design performance, economics and the scope of the solar cooker for rural households. [Sharma (1984), George (1987), Agarwal (1987), Balasubramanian et. al. (1990), Gore et. al. (1990), Nahar and Gupta (1991), Hussain at. al. (1997), Sharan and Chaudhuri, (1998), Singhal (1998) , Oberoi et. al. (1999), Biermann et. al. (1999)]

Another area of solar thermal applications is the purification of brackish water for drinking purposes in arid/semi arid/coastal areas. Different schemes have been proposed that include: solar stills, solar ponds, multi effect solar systems and solar photovoltaic based systems. The studies cover multidimensional aspects like: economics, design, analysis performance, barriers and problems in field implementation of the technology and comparison between different types of solar water purifying systems. [Hamad et. al. (1993), Samad (1993), El-Bassouni and Abdel–Monem(1993), Alida et. al. (1994), Al-Ismaily and Probert(1995), Tsilingiris(1995),Varol and Yazar (1996), Belessiotis and Delyannis (1996) Alajlan and Smiai(1996), Al-Qahtani (1996), Fahmy et. al. (1998), Hassan (1998), Hasnain and Alajlan (1998), Tzen et. al. (1998) , Nishikawa et. al. (1998), Al-Harbi (1998), Sherif and Harker (1999)]

Wind energy is another renewable energy that has been taken up seriously in developing nations for augmenting the existing electrical supply or for providing electrical/mechanical motive power for remote area farm and agricultural applications, in the absence of a centralized power supply. Evidently, then, the potential of wind power that is available in an area being considered for erection of wind mills is a subject attracting interest among energy planners. [El-Shobokshy and El-Zayat (1991), Ranganathan et. al. (1991), Nasir et. al. (1991), Nasir et. al. 1991(a), Persaud et. al. (1999), Pallabazzer and Gabow (1991), Sarkar and Hussain (1991), Adekoyu and Adewale (1992), Khogali et. al. (1991) and Feretu et. al. (1999)]

The inconsistent supply of solar and wind energy resources necessitates the use of *hybrid* systems, in which solar and wind energy systems can be combined for maximizing the availability of any one or both of the resources for electricity generation. In some schemes additional sub- generating systems like diesel generating sets, micro hydels etc.

are also used. Different combinations of solar/wind and/or diesel/micro hydel/gasifier hybrid systems are then possible. Hybrid systems, thus have a favourable scope which has been investigated in several studies which include those by: Takashima et. al. (1994), Nfaoui et. al. (1994), He (1994), Bonanno et. al. (1994), Tomilson et. al. (1998), Panicker (1998) Tayata et. al. (1998), Muselli et. al. (1999), Hongwei et. al. (1999), McGowan and Manwell (1999), and El-Hadidy and Shaahid (1999). The use of suitable battery backup has also been suggested for *hybrid* systems for additional reliability enhancement. Apart from use as a means of generating electricity, wind energy can also be applied for operating mechanical pumps in irrigation. [Clark (1981), Rizk [1989, 1994, 1994 (a)]

Biomass is yet another renewable energy resource that has always been popular with the rural population of developing nations. Biomass is generally used in the direct form as a solid fuel. It may also be used in the processed form as *briquettes* (pulverized form) or as alcohol (liquid form) or, as biogas (anaerobic fermentation) and producer gas. The estimation of the potential of biomass in various countries has been a subject of interest to energy planners since biomass reserves conservation is one of the prime concerns of the government in developing countries. Assessment of fuel wood and other biomass resources with scope for sustainable development were reported by: Razak et al (1991), Abdallah (1991), Laichena (1993), Ravindranath and Hall (1995), Charturvedi (1998), Bhattacharya et al (1999), Rao (1999), Moss and Morgan (1981), Tripathi et al (1998), Kaygusuz and Turker (1998), Kannan(1999), Hussain et. al. (1998), Faaij et. al. (1998), Lin (1998), Gemtos and Siricoglou (1999) and Sudha and Ravindranath (1999).

The suitability of various vegetation and species for biomass energy production is another active area of research. Studies reported in the literature explore suitability of different types of wood species. Some of the work reported in this area is described in various reports [Cherney et. al. (1991), Dyer (1996), Jain and Singh (1999), Sims et. al. (1999), Marosvolgyi et. al. (1999)]. In general it was seen that the eucalyptus and the poplar species had high productivity rates and are ideal choices for energy plantations.

The fuel wood consumption in different regions is yet another area of interest among biomass energy researchers. The existing usage pattern, problems that accompany such usage and the observational experience of different investigators is documented in several studies. It was seen from most reports that fuel wood continues to occupy a major share of the total energy resources used in developing countries. [Turker and Kaygusuz (1995), Lin (1998), Kong (1999), Rosch and Kaltschmitt (1999), Somasekhara (1985), Bowander et. al. (1986), Ranganathan and Subbarao (1987), and Kannan (1999)].

As fuel wood continues to be the largest form of biomass that is being consumed in developing countries, large scale deforestation would be the inevitable consequence in the years to come. Thus, proper forest management and the use of more efficient means of utilization of fuel wood for cooking are being advocated by several scientists. It is in this backdrop that research to reduce energy wastage in combustion is on the increase, and, the use of improved cook stoves is being advocated. The research activity related to improved cook stoves is reviewed in several reports. These reports, in general, investigate the performance of various types of cook stoves promoted in different energy saving programs conducted in various places. It is seen that the introduction of the improved cook stove leads to large savings in fuel and at the same time is ecologically beneficial. [Sadaphal et. al. (1990), Kalra and Singh (1990), Pokharel and Chandrashekar (1995), Rao et. al. (1996)]

Biomass can also be used in biomass gasifiers for electric power generation. The scope and potential of biomass gasifiers for such applications has been examined in a few reports. These reports point out to the immense availability of biomass in developing countries and hence the enormous scope of harnessing this resource for electricity generation using biomass gasifier technology. [Kishore and Thakur (1987), Jain (1989), (2000), Todd (2001), Soma sekhar et. al. (2000)].

Another way of utilizing biomass is in the gaseous form using the principle of anaerobic digestion. This technology goes by the popular name of "Biogas Technology". In developing nations such as India, it has been realized that biogas is a valuable energy resource which encourages sustainable development. The Indian government has therefore launched a large-scale biogas program under the supervision of the *MNES* and *Non Government Organizations (NGO's).* Research in biogas technology, itself is highly diversified. The important areas of research in this renewable energy technology include the following issues:

(i) **Potential and performance assessment of biogas plants of different sizes.**

[Ghaffar(1995), Mohanty (1997), Singh et. al. (1998), Kalia and Kanwar (1998), Kalia and Singh(1998) and Jash and Basu (1999)]. The potential is limited by the ambient temperature available for biogas fermentation, availability of dung fuel and other biomass substitutes and the socio-economic acceptance of the technology among the people served.

(ii) **Economics of biogas generation**

[Prasad et. al. (1974), Makhijana and Poole (1975), Sathianathan (1975) , Tyner (1978), Eusaf (1984), Vyas (1992) and Rubab and Kandpal (1995)] The reports in general, indicate that the economics of biomass technology are favourable, and, that the promotion of this technology deserves the impetus that it is currently enjoying.

(iii) **Operational experience and related problems**

[Sivagnanam et. al. (1984), Vyas et. al. (1990), Dhawan et. al. (1990), Dutta et. al. (1997)] The problems reported deals with technological difficulties in operation and maintenance, barriers in the socio-economic acceptance of the technology and the shortcomings of the financial mechanism that makes the technology unavailable to the beneficiaries.

Besides the renewable energy resources and associated technology discussed above, there are also certain other renewable energy resources and technologies that need a special mention in the Indian context. These are:

(i) Small Hydro Plant technology (including water mills)

(ii) Geothermal technology

(iii) Tidal wave power based technology

(iv) Fuel cell based technology

Small hydro plants and water wheel technology are well suited for hilly areas that have abundant free flowing streams. Small hydro plants generate needed electric power that is use for remote area lighting needs and for motive power. Motive power can also be obtained from water wheels that are located at convenient sites along the streams. The potential of such technology is being explored by field exercises and techno-economic feasibility studies as indicated by various reports on the subject. Some of the reported work includes studies by: Maher et. al. (1998), Kumar (1997), Paish et. al. (1997), Monnaiah (1998), Iyer (1999) and Kumar(1999). Small hydro plants are in general seen to have a large scope for hilly areas and are one of the means of ensuring sustainable growth in the local regions where they can be harnessed.

Geothermal energy and tidal wave power technology are recent technology areas that are being taken up by the *MNES*, Government of India. These technologies are site specific. It is reported that there exists some potential for these in certain hilly and coastal regions of the Indian sub-continent. (TEDDY 2000). In addition, research is also being encouraged in fuel cell technology, alcohol based hybrid fuel mixtures development and battery operated transportation. The potential of renewable energy resources and associated technology for supplying rural energy needs for rural areas thus appears to be quite appreciable.

It may be noted that while the scope for renewable energy technologies discussed here is applicable to most of the developing nations, we have focused largely on India, since our main objective is in highlighting the scope of renewable energy for the Indian rural energy scenario. The favourable scope as observed from various reports, is mainly responsible for the impetus being given by the Indian Government in promoting such sustainable technology for overall rural growth and development.

1.4.2 Energy Consumption Patterns

Studies related to the energy usage patterns are perhaps the first step in framing a rural energy plan for a given area, as it is important to understand the energy consumption habits of the rural population in question. Studies have been carried out at macro levels for different regions of India. The studies mostly involve energy surveys for particular regions. The results of the energy surveys as reported by such bodies are generalized for particular regions and do not provide in depth information for specific sites falling within such regions for which energy planning is being contemplated. To fill this need therefore, micro level surveys are needed.

Various researchers have contributed to a wealth of literature that attempts to highlight the peculiarities of the energy consumption trends existing in different geographical pockets of the Indian sub-continent. Some of these reports include the following: [Revelle (1979), Reddy (1981), Giriappa (1991), Somasekhara (1985), Bowander (1986), Ranganathan and Subbarao (1987), Reddy and Ravindranath (1987), Rao (1990), Reddy (1995), Rijal (1999), Ramachandra and Shastri (1996), Maheshwari et. al. (1981), Sehgal and Mittal (1982), Sharma and Bhatia (1987), Sharan et. al. (1987), Deo et. al. (1990), Dhanapal (1990), Yadav and Sharma (1990), Reddy (1982), Paul (1987), Sinha et. al. (1998)]. The findings of most of these studies indicate that in the rural household, domestic needs occupy the highest energy demand followed by agricultural needs. In the domestic sector, itself, more than 90% of the resources used are of traditional origin (fuel wood, animal dung, agro waste), while the commercial energy resources that are used are limited to electricity, kerosene and diesel for lighting, agricultural and transportation needs.

The scope of such energy consumption studies is not confined to India alone. Several studies have also been carried out on this issue in other developing countries. [Kong (1999), Turker and Kaygusuz (1995), Kaygusuz (1999), Akash and Mohsen (1999), Bala et. al. (1989), Sarkar and Islam (1998), Masera and Navia (1997), Xiaohua and Zhenming (1996) and Wang, et. al. (1999)]. Even in such developing countries, fuel wood demand remains at a high level in preference to other available energy resources.

These few reports though not extensive, may help to highlight the importance associated with energy surveys for energy planning of rural energy needs in developing countries.

1.4.3 Rural Energy Technology

For meeting different energy end uses, appropriate energy conversion schemes and devices are necessary. A large number of renewable/integrated energy *hybrid* schemes make use of a mix of options such as: solar PV/ wind turbines/diesel generating sets etc. This enhances the reliability of the power delivery and helps in conservation of diesel fuel wherever possible. Research is therefore directed to the evaluation of such *hybrid* systems and some of the studies in this direction include the following: [Bhave (1999), Muselli et. al. (1999), Nfaoui et. al. (1994), He (1994),Tomilson et. al. (1998), Panicker et. al. (1998), Al-Ashwal (1998),El-Hadidy and Shaahid (1999), Bonanno et. al. (1999), and Hongwei et. al. (1999),.Takashima et. al. (1994), Al Harbi et. al. (1998), Garg and Adhikari (1999)]. The studies are both experimental and simulated, and in general, indicate that the *hybrid* schemes are more cost effective than those employing a single energy based conversion system.

Another kind of stand alone solar PV system is the solar lantern. This device is a miniature solar PV based arrangement with an internal storage battery capable of providing illumination on the basis of the stored energy in the battery. Thus the device is "charged" during the day from solar energy and "discharged" during the night as illumination energy for rural households. The level of acceptance of the device is evaluated in some reports. [VanDer Plas (1997), Maithel et al (1997)] These reports indicated in general, the low level of popularity of such devices and suggested that efforts were needed to highlight the advantages of the device in improving the traditional life style and standard of living of the rural population. At the same time, the necessity of improving the design and performance of the device was also stressed upon.

Other types of rural energy technology have also been investigated in regard to their economics, performance and acceptability. Some of the several reports available on these technologies include the following:

(i) Solar Cookers [Balasubramanian et. al. (1990), Oberoi et. al. (1990), Hussain et. al. (1997), Sharan and Chaudhari (1998), Gore et. al. (1990)].

(ii) Cookstoves [Sadaphal et. al. (1990), Bhatt (1990), Pokharel and Chandrashekar (1995)].

(iii) Biogas systems [Prasad et. al. (1974), Sathianathan (1975) , Makhijana and Poole (1975), Tyner (1978), Eusaf (1984), Vyas et. al. (1990), Dhawan et. al. (1990), Vyas (1992), Rubab and Kandpal (1995), Mohanty (1997), Singh et. al. (1998), Kalia and Kanwar(1998), Kalia and Singh (1998)].

(iv) Biomass gasifier technology [Kishore and Thakur (1987), Kapur et. al. (1998), Tripathi et. al. (1998), Jain (1989), Todd (2001)].

(v) Miscellaneous rural technology reports are also available.[Sinha (1996), Kalogirou et. al. (1996, 1997, 1999), Rizk (1989, 1994 (a), 1994 (b)), Sherif and Harker (1999)]

These few reports indicate the importance associated with pre-evaluation studies of renewable energy technology based schemes for implementation as projects in developing countries.

1.4.4 Renewable Energy Technology : Experiences in Developing/Developed Nations

Decentralized Energy Planning, the main objective of the IREP, aims at making rural areas self sufficient in relation to their energy needs.

The choice of the technology and the associated energy resources used with them should help in the followings:

(i) Providing an improved standard of living in the village.

(ii) Should be environmentally benign.

(iii) Should be available locally on a renewable basis.

(iv) Should encourage sustainable development.

Renewable Energy technology (RET) have all the above features. The energy resources used are renewable in nature like: solar, wind, biomass energy and that of flowing water in streams, rivulets etc. Much of these resources are available in rural areas and can be profitably used for meeting a portion of the energy needs, the balance being met with commercial and traditional energy inputs (like human/animal power).

Experiences in the implementation of renewable energy technologies for India and other countries are available in the literature. A wide variety of problems and related experiences have been detailed by different investigator teams in relation to renewable energy based schemes in different countries. These schemes involve single energy conversion devices or they may involve an integration of several energy conversion devices/systems. Experiences also include non-technical aspects such as implementation of energy policy, socio acceptance of systems etc. Some of the various available reports include the following: Arafa (1981, 1985), Bhattacharya (1987), Sastry (1987), Saha et. al. (1987), Jaffe et. al. (1987), Gupta (1987), Barnett (1990), Singh (1993), Jorapur and

Rajvanshi (1993), Dendukuri and Mittal (1993), Venkata Ramana (1993), Kumar (1995), VenkataRamana (1996), Kim and Hwang (1997), Naidu (1997), Mathur (1997), Peterson et. al. (1999), De Gouvello and Leterme (1999), Martin (1997),Van Der Plas (1997),Tayati et. al. (1998), Dutta et. al. (1997), Venkataramana (1997), Haucuz and Agredano (1998), TEDDY 1998-99, Patil and Singh (1999), Pal and Srinivas (1999), Prasad et. al. (1999), Waddel and Bryce (1999), Ibrahim et. al. (1999), MNES Annual Report 1999/2000, Somashekhar et. al. (2000), Zille et. al. (2000), Garg (2000), Youm et. al. (2000), MNES Report 2000, Wade (2000, 2001), TEDDY 2000/2001 and Devadas (2001(a)), (2001(b)), (2001(c).

These reports highlight the field experiences in erection, operation and monitoring of energy generating projects, together with identified problems in the promotion of renewable energy based technology.

1.4.5 Growth of Renewable Energy Technology: Promotion, Barriers and Policy Measures for Improvement

Reports are available in the literatures that discuss various barriers faced in implementing renewable technology based schemes. Barriers can be of the following types:

(i) Financial

(ii) Technical/Operational

(iii) Social

(iv) Institutional

(v) Legal

(vi) Promotional/Market related

These varied barriers are highlighted in different reports in the literature. Some of the several reports that are available in the literature include those by: Coelho et. al. (1999), Martinet (1999), Stanislaw (1999), Moses (1999), Bhattacharya and Kumar (1999), Bronicke (1999), Amin (1999), Sivagnanam et. al. (1984), Vyas et. al. (1990), Dhawan et. al. (1990), Dutta et. al. (1997), and Monga (1997).

The above cited few references indicate some of the barriers that different investigators have encountered in relation to the growth of renewable energy technology in developing countries.

1.4.6 Renewable Energy Technology in the Indian Context: Efforts for Growth and Promotion of Renewable Energy Based Applications

The progress of renewable energy technology in the Indian scenario can be gauged by the efforts and achievements of the Indian government in installing various types of renewable energy systems over the different states of the country. Efforts are directed in the following thrust areas in regard to the promotion of renewable energy technology.

(i) Popularization of various renewable energy technology schemes by the initiation of programs like: biogas program, improved *chula* (stove) program, IREP (integrated rural energy program), *Urjagram* (energy village) program, creation of energy parks and research and development in educational, scientific institutions, special centers and universities, awareness/ demonstration camps.

(ii) Involvement of international agencies in collaborative/ joint ventures on renewable energy technology.

(iii) Publicity through electronic media (radio, television, films, audio-visual shows etc.), magazines, journals and brochures and trade fairs.

(iv) Financing of renewable energy projects with attractive policy terms and incentives for private entrepreneurs.

(v) The strategies, experiences, shortcomings and benefits of the efforts on the part of the Indian government are disseminated in the form of critical reports on various related issues. In the literature, several such reports are available that attempt to analyze and offer suggestions for greater penetration of renewable energy technology in rural sections of India. Some of the various reports available include those by: Chopra (1987) , Rao (1988), Prasad (1988), Bakthavatsalam and Reddy (1988), Lawland (1991), Mishra (1991), Lata and Chamola (1992), Sinha (1994), Sinha (1996), Mathur (1997), Singh and Venkataramana (1997),Gupta (1997), VenkataRamana (1997), Singhal (1998), Bakthavatsalam (1999) and MNES reports (1999) & (2000).

Thus, various studies and reports have been highlighted here, to show the diversity of issues associated with decentralized energy planning involving renewable energy technology in rural areas, and, particularly in developing nations. This background would be helpful in appreciating the development of the subsequent energy planning and analysis in relation to the study area.

1.5 PLANNING FOR RURAL ENERGY NEEDS: SOME BASIC CONSIDERATIONS

The planning of an IREP should be such that the total energy requirements of the village cluster are met in a satisfactory manner. Further, sustainable development should be encouraged. The aim of the planner should be on providing overall benefit to the rural population. The experiences in design and implementation of the *IRES* in the Indian context have shown the following shortcomings:

(i) The program does not take into consideration the socio-economic features of the rural population for which it is being designed. This means that the intentions of the planner are at variance with the aspirations of the rural population, and the success of the program is impaired. The program is usually addressed in a fragmented and piecemeal manner with the different policies for different types of renewable energy technologies (e.g. solar PV systems, residue briquettes, biogas plants etc.) which constitute the components of the program.

(ii) Local support and participation is seldom encouraged, leading to post implementation failure.

(iii) The focus is on "achievement" in terms of the number of installations made rather than in terms of actual benefits to the population.

(iv) No attempt is made to prepare the rural population for the use of better and new energy technologies with which they may be unfamiliar.

(v) Economics of recovery on the investment are not taken seriously. The programs are usually run on a charity basis with social interest in mind. This makes the value of renewable energy technology highly questionable in terms of "development".

(vi) The planner generally does not aim at any particular objective in accordance with which the energy plan must be structured.

Hence, it is clear that an effective energy plan for a given area must address these shortcomings in the most appropriate manner within the existing constraints. On the basis of these observations, it becomes clear that the energy plan for a given rural area should stress on the following considerations:

(i) A study of the energy habits of the population should be carried out in detail in relation to their consumption of various available energy resources

(ii) The socio economic features that characterizes the rural area should be properly understood and addressed so that the formulated energy policy may be to the general satisfaction of the population.

(iii) The scope of the renewable energy technology that is proposed for the area should be carefully considered in terms of the available resource supply, the acceptability of the technology to the population and availability of technical manpower, training facilities and repair facilities in the region.

(iv) Training and awareness camps should be regularly conducted to make the rural population aware of the benefits of the proposed technology and also to encourage them to participate in the operation of scheme and make it a success.

(v) A flexible energy plan should be developed that can simulate several aspects of the energy scenario for effective planning policy formulation.

It is proposed in this work, to develop an energy plan and model for a village on the basis of the above considerations.

1.6 STATEMENT OF THE PROBLEM

1.6.1 Background of the Problem and the Choice of the Study Area

As pointed out earlier, the energy habit of various regions are peculiar to themselves on account of the diversity in socio cultural factors and the availability of the resources to different extents in the region. An effective energy plan needs to take this basic consideration into account in the formulation process. India is a developing country with large agro- climatic and cultural diversity. Energy planning for different regions is therefore a voluminous task. In the literature, several researchers have attempted to design and analyze energy plans for different cluster of regions and thus provide in a piecewise manner a picture of the energy scenario in pockets of the Indian sub-continent. As several rural regions have yet to be explored in regard to the existing energy scenario, the scope for extensions of the reported work is encouraging.

Energy modeling was initiated as an exercise in the present work, for which a suitable study area needs to be taken up as a case study. It was proposed to take up energy studies for a village in the district of Pauri Garhwal, in the newly created state of Uttranchal (India). There are very little studies reported for this region, and, the present work was therefore directed to fill a part of this need. *Kanvashram*, a rural hilly village in the district was chosen for the purpose. This village has recently been identified by the *Garhwal Mandal Vikas Nigam*, a planning body, as a promising site for development into a tourist/pilgrimage centre. It is therefore expected that in view of this proposal, the village of *Kanvashram* is likely to experience rapid development in the near future. Hence the village appears to be ideally suited for the purpose of investigations related to energy studies and planning.

1.6.2 The Objectives of the Study

The main objective of the study is to model for decentralised in a rural set up. With reference to the chosen study area, the following are the proposed sub objectives:

(i) To examine the energy consumption patterns of the rural population in the study area.

(ii) To assess the level of inequality in energy resource consumption in different segments of the population.

(iii) To develop an integrated energy planning model for the major energy end use applications in the study area.

(iv) To apply the developed energy planning model for simulated studies that would help in examining the outcome of different energy scenario variations introduced as policy moves in the study area.

(v) To evolve effective policy measures in relation to energy planning for the study area.

1.6.3 The Methodology of the Study

The objectives as outlined in section 1.6.2 can be realized using appropriate methodology of analysis. The data needed for the study is by and large of a primary nature. This data is collected using a random sampling strategy for the study area. Households are classified into two main categories based on the type of family structure i.e. *Joint* and *Nuclear* family households. A third category that involves both these categories (i.e. *All* households) is also included for comparison of the results with respect to either category. Detailed questionnaires/schedules were prepared to elicit information in regard to the following aspects of the rural population:

(i) Energy consumption of the various available energy resources in the study area.

(ii) Details of the household in relation to family size, type of family structure, land size, occupation, education etc.

(iii) Socio- economic issues in relation to energy usage.

(iv) Problems experienced in use of the existing energy resources i.e. availability, pollution, cost, etc.

A suitable sized sample was chosen in relation to each category of households. The data as obtained from the schedules was then processed for developing the appropriate study models and related analysis. The tools used are:

(i) Statistical tools [mean, standard deviation, decile distribution and linear regression]

(ii) Inequality measures [Lorenz curves, Gini inequality index]

(iii) Linear optimization using Linear Programming software.

The analysis of the energy consumption patterns, the problem formulation for the integrated model and the results of the subsequent simulations is discussed and reported in the relevant chapters of the thesis. Finally the results are highlighted with suggestions for appropriate energy policy measures that can be applied to the study area.

The outline of the adopted methodology for the analysis is depicted graphically in the flow chart of Figure 1.1.

1.7 AN OVERVIEW OF THE THESIS

The present thesis is structured in terms of 6 chapters. A brief outline of the constituent chapters is presented as follows:

Chapter 1 provides an introduction to the rural energy planning scenario in the Indian context. The status of the renewable energy technology in meeting rural energy needs has been discussed. The statement of the research problem, the objectives and the methodology to be pursued are also discussed. An in depth coverage of the literature related to renewable energy technology and decentralized energy planning has also been presented. The literature review relates to several different sub issues of renewable energy

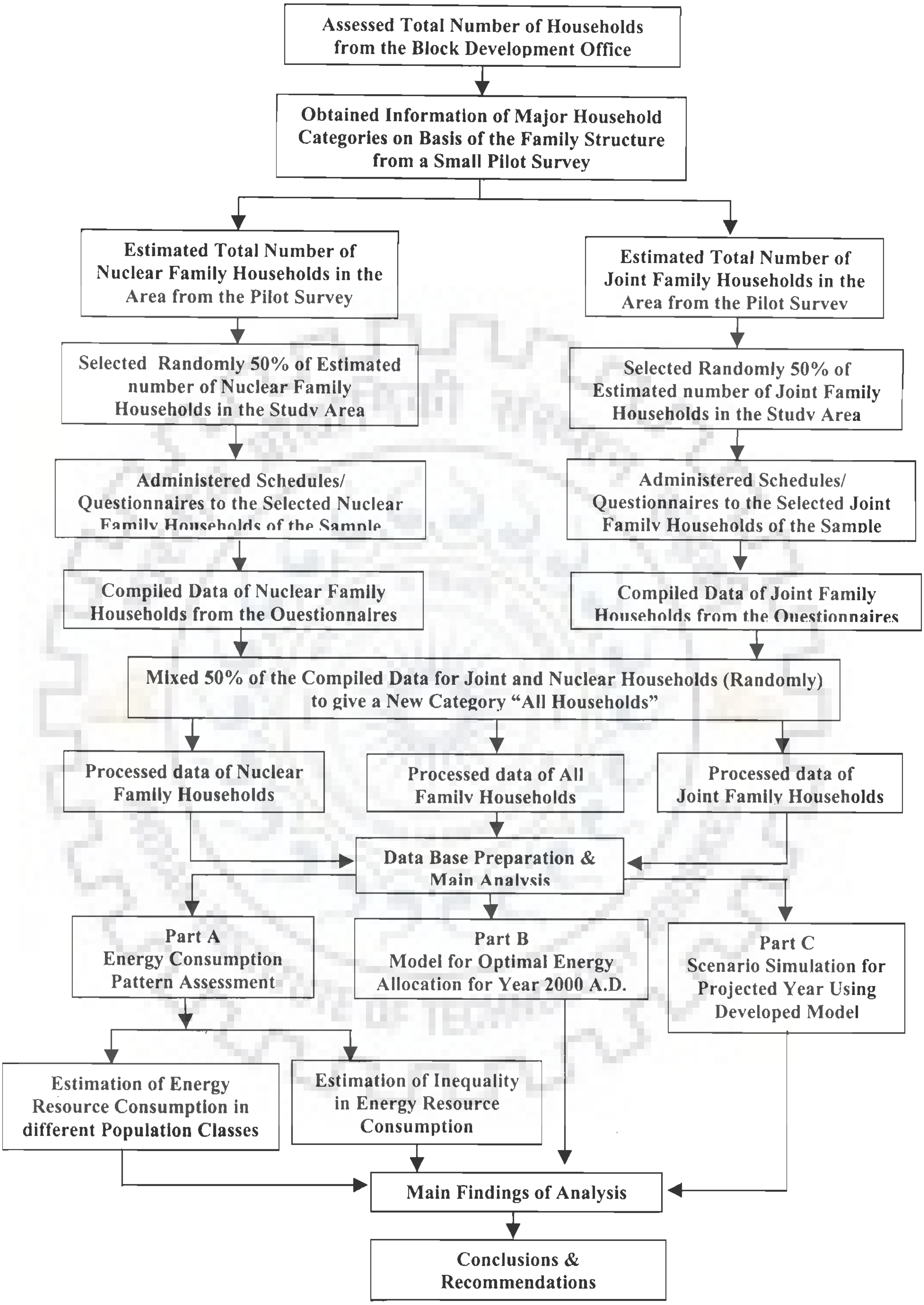

Figure 1.1: Basic methodology adopted for the study

and associated decentralized energy planning for rural areas in India and other developing countries. The major focus, however, is confined to the rural energy scenario in the Indian context. Lastly, a brief outline of the constituent chapters of the thesis is presented.

Chapter 2 presents a profile of the study area in which the physical, demographic, infra-structural, economic, social and agricultural aspects are covered. The energy resource consumption and potential characteristics of the study area are also presented.

Chapter 3 presents the major findings of the energy consumption pattern in Kanvashram., the study area chosen for energy studies and modeling. The analysis is divided into two sub analyses that attempt to study the mean and decile share distributions in different household categories and the levels of inequality in consumption of different resources.

Chapter 4 involves the basic formulation of the optimization model using Linear Programming methodology. An integrated energy-planning model is developed that optimizes the resource allocations for the three major energy needs in the study area i.e. cooking, lighting and space heating. The model has been prepared for the base year 2000 A.D.

Chapter 5 presents the application of the developed model for the examination of the energy scenario in the study area in the projected year 2005 A.D. through computer simulations. Relevant projections in the demand and supply constraints are introduced for this purpose with respect to the data for the base year. The model forecasts the resource allocation in the study area under various simulated conditions related to energy policy moves introduced as scenarios and examines their suitability.

Chapter 6 concludes with the highlighting of the main findings of the study in relation to chapters 3 and 5. Suitable policy measures that can be applied to the study area for effective energy planning are also indicated. Extensions for the present work are also suggested.

CHAPTER–2

THE STUDY AREA PROFILE

2.1 INTRODUCTION

Decentralized energy planning has been initiated as an important exercise by the Indian Government in an attempt to make rural areas self sufficient or near self sufficient in relation to their basis energy needs. The *Integrated Rural Energy Program (IREP)* which was conceived with these objectives in mind has grown from an initial handful of 9 projects to as many as 856 projects in different states of the country. (TEDDY 2000/2001) The massive increase in these projects bears testimony to the importance which the Indian Government attaches to such projects. To implement an *IREP* project, it is necessary to prepare an extensive energy data base in relation to the rural population in the area. The vast expanse of the country has been a limitation in obtaining detailed information of the energy issues for different geographical pockets of the country. Thus, despite an impressive growth of *IREP* projects in several blocks of districts in different states, there are still a large number of rural areas that have yet to be explored in relation to energy planning.

To fulfil a small portion of this vast unexplored scope, it was felt suitable to carry out investigations as regards energy planning in relation to a rural area that has immediate scope for future growth and development. Kanvashram, a rural hilly village located in the district of *Pauri Garhwal* of the newly created state of Uttaranchal (India), was chosen for the present study. The village has been identified by the *Garhwal Mandal Vikas Nigam*, a planning body, as a village offering potential scope for development into a pilgrimage/tourist spot. Energy planning for this village offers a challenge that has been the motivation for the present investigation. It is expected that the study would pave the way for designing similar energy plans in other rural areas in the district that share similar agro-climatic, geographical and socio-economical characteristics.

A brief outline of the profile of the study area is being presented in this chapter for understanding the characteristic features of the study area.

2.2 PHYSICAL FEATURES OF THE STUDY AREA

2.2.1 Background and Location

The village name *Kanvashram* literally means "The hermitage of the sage *Kanva*", who was once said to have lived there. The village is located at the banks of the river *Malin* at the foothills of the *Shivalik* range of hills of Uttaranchal state, and lies in the *Dogadda* block. Its latitude is 29° 47′ 30″ N, while its longitude is 78° 27′ 30″ E. The nearest town is *Kotdwar* situated some 12 kilometers east of the village. It is believed that the original *Kanvashram* village consisted of a few households in the neighborhood of the hermitage, but with time the few handful of households grew and broadened the limits of the village. Today the original small village has matured into a complex village made up of three major sub-villages: *Udairampur*, *Bhimsinghpur* and *Maanpur*. The village constitutes a portion of the *Kalalghati* region of the district.

Kanvashram is located in zone IV as classified by the Indian standard code of practice in relation to seismic vulnerability with a seismic coefficient of 0.05.

The location of the village in *Pauri Garhwal* district is shown in figure 2.1.

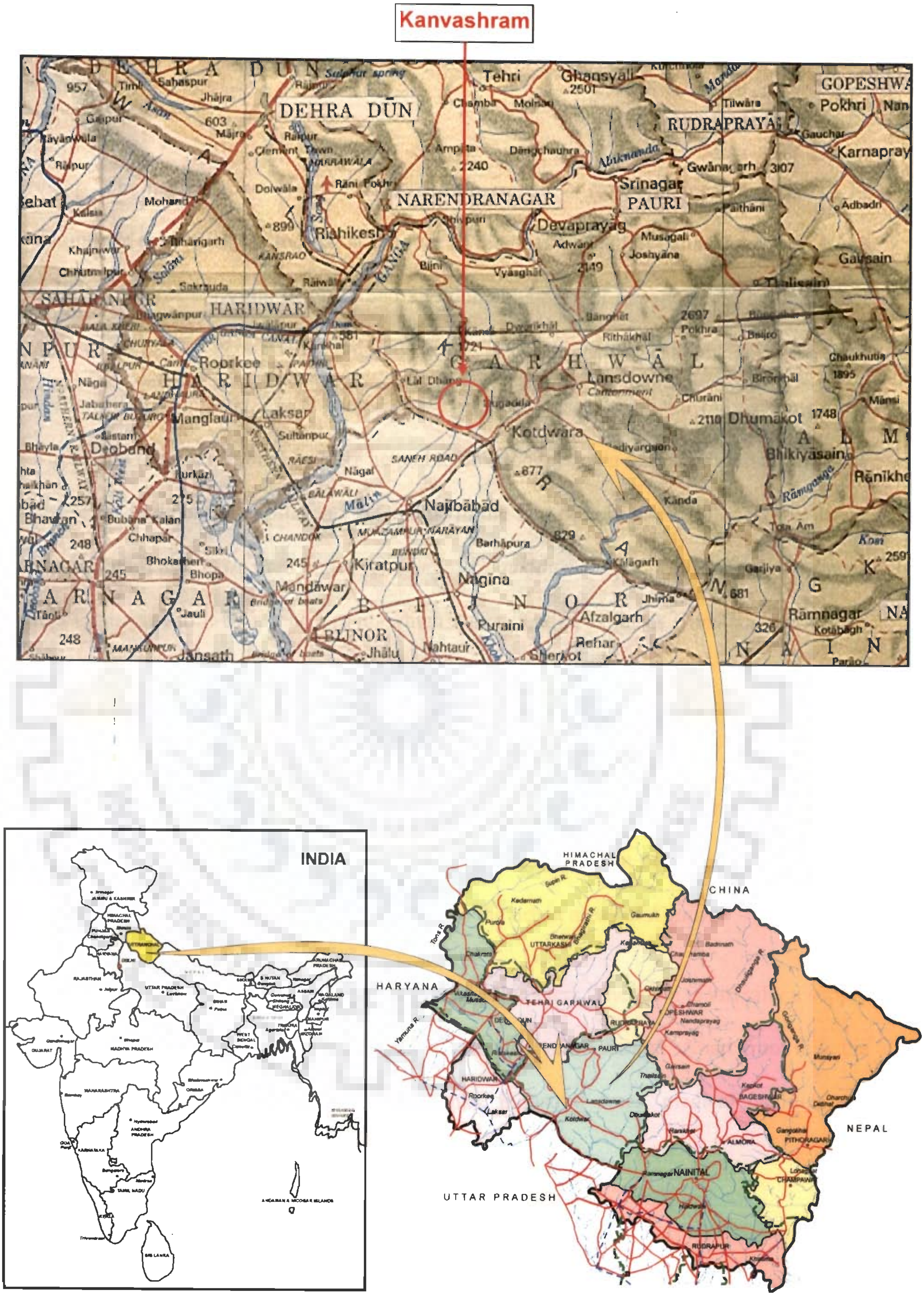

Figure 2.1 : Geographical Location of the Study Area

2.2.2 Neighbouring Areas

(i) Kotdwar

The nearest town to the village of *Kanvashram* is *Kotdwar*, located about 12-13 kilometers east of it. It is located at the foot of the hills on the left bank of the river *Khoh* about 77 kilometers south of *Pauri* and 28 kilometers S-W of *Lansdowne*. The latitude of *Kotdwar* is 29° 46′ N, while its longitude is 78° 32′ E. *Kotdwar* was an insignificant place before 1870 with only 25-30 shops. However, the extension of the railway line from *Najibabad* (District *Bijnor*) in 1897 helped to develop the town into an important business centre for trade between hills and the plains. In the first decade of the 20th century, it was administered as a town area under the *Bengal Chaukidari Act 1856*. In 1909, *Lansdowne* was connected to it by a motor road, which was extended as far as *Gumkhal* in 1939. In 1944, the town was connected to *Pauri* by a motor road. An intermediate level college for the public was set up in 1950 and the town received an electric supply in 1957.

The 1991 census statistics (the latest available statistics at the time of the present profile compilation) indicates a total population of 682,535, out of which, 81,182 belong to the rural sectors of the block and 601, 353 to the urban areas of *Kotdwar*

The total area of *Kotdwar* is 2.59 square kilometers. The town is virtually a supply depot of all sorts of goods to the district of *Garhwal* and *Chamoli.* Apart from this, the town has basic and secondary schools, banks, industrial areas, medical facilities and cinema halls.

(ii) Dogadda

The town of *Dogadda*, of which block the village of *Kanvashram* is part, lies at a latitude of 29° 45′ N, and a longitude of 78° 37′ E, about 14 kilometers S-W of

Lansdowne and 16 kilometers north of *Kotdwar* at the confluence of the *Siligadh* and *Khoh* streams.

The name *Dogadda(Do= two;gad=streams)* has thus been given to this town. It is situated on the road from *Kothdwar* to *Pauri*. The road from *Lansdowne* also joins the *Kotdwar-Pauri* road at *Dogadda*. Until 1891, *Dogadda* did not have any commercial importance. However, in this year, several sites were put up for auction and about 20 shops were established. *Dogadda* owes its growth to the construction of the cart-road to *Lansdowne* in 1909, which enabled shopkeepers to command commercial prices at the same rates as in *Kotdwar*. In 1944, it was declared as a notified area, and, in 1949, a higher secondary school was established there. Electricity was provided to the town in 1957.

The 1991 census reports statistics indicates an existing population of 91,120 in the *Dogadda* development block of which 80,593 are in the rural sector and 10,527 reside in the urban sectors. The area of the town is about 2.6 square kilometers. It has basic amenities of schools, medical services and banks.

Other neighbouring areas include:

(iii) Pauri

This town is located at a latitude of 30° 9′ N, and a longitude of 78° 46′ E. at 1643 meters above sea level. It has an existing population of 31,356 (1991 population census reports) in rural area and a population of 20, 397 in urban pockets of the region.

(iv) *Pokhra* (latitude 29° 55 N, longitude 78° 55′ E.). This region lies about 95 kilometers N-E of *Lansdowne* and has a rural population of 201,016 (based on 1991 population census report).

(v) *Rikhnikhal* (latitude 29° 46′ N, longitude 78° ′ E) about 24 kilometers S-E of Lansdowne with a population of 33, 937 (based on 1991 population census report).

2.2.3 Topography of the Kanvashram village

The village of *Kanvashram* is a part of the district of *Garhwal*, and, as such possesses characteristics of the region in relation to its topography. The area has a mix of slopes and plains with dense forests areas, small and low elevated hillocks and valley bottoms. The vegetation comprises mixed forests of bamboo, *sal, sheesham* and shrubs. The soil is rich in organic matter with clay, silt and fire sand. Sedimentary deposits abound in the region. The river *Malin* emerges from the *Shivalik* foothills and enters the plains at *Kanvashram*.

2.2.4 Flora and Fauna

Kanvashram has a mix of plain area and small hillocks which give it a picturesque setting. The hillocks are covered with thick vegetation of mixed forests while the plains have been leveled for cultivation purposes. The village is located mostly in the plain regions and has a vegetation characteristics typical of those in the plains. Due to mass deforestation, that naturally accompanies settlement, many of the wild animals that once abounded in the region have now become extinct. However, in some rare instances, it is not uncommon to spot herds of elephants or some leopards, bears, jackals, monkeys and tigers, but these are mostly seen in the hilly areas that lie on the outskirts of the village.

Wild birds that are seen in the area include: pheasants, partridges, pigeons and water fowl of various kinds.

Reptiles like snakes (cobra, krait and *Russel's* viper) are present. Crocodiles are rare. A variety of fish may be found in the streams. Game and forests are under protection acts of the State. In the village, common domesticated animals like sheep, goats, mules, cows, buffaloes and pigs are found in plenty.

2.2.5 Climate

A fairly long and moderately severe winter is the chief characteristics of the climate of the district in general. Being situated on the southern slopes of the Himalayas, *Garhwal* district gets a good rainfall from the S-W monsoon current, but tropical heat may be expected from April to May and the first half of June in the valleys and comparatively lower elevated areas. The rainy season in *Kanvashram* lasts from around the third week of June to the end of September. The period from October to the middle of November constitutes the post monsoon season which sets in and lasts till the middle of March. The summer season follows this period and continues till the beginning of the rainy season. In general, the temperature may vary in *Kanvashram*, from a maximum of 45 °C in summer to a minimum of 5°C in winter.

Thunderstorms occur throughout the year, their frequency being the least in November and December, and maximum during May to September. They are sometimes accompanied by hail. Fogs are common during monsoon months. Morning fogs may occur in the valley regions frequently during winter. The period March to May i.e. summer is the driest part of the year with the relative humidity varying between 30-40 %. It may go as high as 70-90% during the monsoon season while it remains between 50-60% during the other seasons (apart from summer). Clouds are dense during the monsoon months and during short spells of the winter months, when the region is affected by climatic disturbances in other parts of the Himalayas. Wind speeds are low (up to 3-6 kilometers/hour) and may not be helpful for any form of power generation. However, during violent storms, the winds can become very turbulent.

2.3 DEMOGRAPHIC FEATURES

Since detailed reports on demographic details of *Kanvashram* are not readily available in government records, it was necessary to compile this information by means of a primary survey in the study area. The data is combined with other data obtained from secondary sources. The following details, therefore make extensive use of the findings of the primary survey conducted for the purpose.

2.3.1 Population Distribution and Development in Kanvashram

Population details of the sub villages comprising *Kanvashram* were obtained from the office of The Block Development Officer (BDO) of the region. The records shows a total population of 1990 persons in 396 households (as on January 2000). The distribution of the households in the three sub villages of the Kanvashram village complex is shown in table 2.1.

Table 2.1: Distribution of households in *Kanvashram* village complex (as on January 2000)

S.No.	Name of the constituent sub village	No. of households in the constituent village
1.	*Udairampur*	229 Households
2.	*Bhimsinghpur*	118 Households
3.	*Maanpur*	49 households
		Total =396 households

Source: Records of the Block Development Office, Dogadda, Pauri Garhwal District

Maanpur is the most developed sub- village having markets, medical and miscellaneous facilities. It serves as the main area of commerce for the whole of *Kanvashram*. *Bhimsinghpur*, the next less developed sub-village, has a few houses scattered unevenly on a plain terrain which are basically large fields near the foothills.

Udairampur is the sub village closest to the *Kanvashram* hermitage. This is a mildly hilly terrain in which the lower caste households constitute the predominant population. Like *Bhimsinghpur*, the houses are unevenly scattered. Thatched and mud walled houses are common in this part of the village , although some brick houses of a few prosperous farmers are also seen. By contrast, the houses in the other two sub villages are more developed as the population in these parts belong to the middle and upper income classes. Many of the households are in a position to afford luxuries like: television sets, telephones and modern domestic electric gadgets. Television and radio are the only means of recreation available in *Kanvashram,* while cinema halls are located in *Kotdwar*, some 12 kilometers away from the village. Thus, *Kanvashram* is a mix of households involving different levels of economic and social diversity.

2.3.2 Population Composition in terms of Various Issues

2.3.2.1 Population based on the principal religious communities

Hindus and Muslims constitute the two major religious communities in the village. Other religious communities like Christians, Jains, Sikhs etc. are in the minority in general in *Garhwal* district, and are virtually non existent in the village. The composition of the religious communities in *Kanvashram* has been computed and shown in table 2.2.

Table 2.2 : Percentage composition of religious communities in *Kanvashram*

S.No.	Religious community	Approximate percentage composition (%)
1.	Hindus	74.60
2.	Muslims	25.40
3.	Others	Negligible
	Total	100.00

Source: Primary survey data

2.3.2.2 Educational level of the general population of Kanvashram

The primary survey data indicates the following composition of the population in terms of average educational levels (expressed as "years of schooling") [table 2.3].

It may be seen from table 2.3 that the population possessing an educational level from 5 to 10 years comprises as much as 50 % of the total population of *Kanvashram*. A sizeable proportion of the population has educational; levels between 10-12 years of schooling, while graduates and post graduates are the least in number.

Table 2.3 : Composition of the population in *Kanvashram* based on the educational level

S. No.	Average educational level (Years of schooling)	Percentage composition (%)
1.	Illiterate	12.50
2.	Up to 5 years	25.00
3.	More than 5 years upto 10 Years	25.00
4.	More than 10 years upto 12 Years	31.25
5.	More than 12 Years (graduation/post graduation)	6.25

Source: Primary survey data

2.3.2.3 Occupations of the population

The main occupation practised in the village is agriculture and allied agricultural activities. However, several households engage in additional economic activities to supplement their earnings from basic agricultural activities. In certain cases, it has been observed that the earnings from the non-agro based activities exceed those obtained from agriculture. Various non agricultural economic activities commonly practised in the village include: carpentry, trade, cottage industrial activity, small scale engineering works, miscellaneous services in Government/private establishments that exist within the village, etc. The relative distribution of these economic activities within the population is shown in table 2.4 (a) and 2.4 (b).

Table 2.4 (a) shows that the percentage of agricultural households is about three times that of the non-agricultural households (considering only pure agricultural and non agricultural households). However, when mixed economic activities are considered, then it is seen that the number of households having limited agro activity in preference to non agro activity account for about 44% of the population. Only about 6% of households indulge in major agro activity with small non agro activity as an off time economic persuit.

Table 2.4 (a) : Composition of *Kanvashram* based on the nature of economic activity

S.No.	Nature of economic activity	Percentage of households (%)
1.	Only Agriculture & Allied Activities	37.50
2	Only Non-Agricultural Activities	12.50
3.	Agricultural Activity (as major activity with Non Agricultural Activity	6.25
4.	Non Agricultural Activity (as major activity with Agricultural Activity	43.75

Source: Primary survey data

Table 2.4 (b) : Composition of *Kanvashram* based on the type of economic activity

S.No.	Type of economic activity	Percentage of households (%)
1.	Agriculture & Allied Activities (Orchards/fruits/vegetable cultivation)	62.50
2.	Carpentry and small engineering works	12.50
3.	Trade and commerce	37.50
4.	Services in Govt./private organizations	6.25

Source: Primary survey data

Table 2.4 (b) shows the basic percentage composition of the different types of occupations practised by the rural population of the village. The percentage may not total to 100% on account of multiple occupations practised by certain households. It is clear from this table that the agricultural and allied activities constitute the most widely practised occupation, accounting for as much as about 63 % of the total economic activity in the village. Trade and commerce come next with about 38%, while other types of economic activity trail behind.

2.3.2.4 Average Per- capita income of the population

The average annual per -capita income of the population ranges from as low as about Rs. 5000 to as high as Rs. 44, 000 and above. A distribution of the number of households falling in different average per-capita income slabs is presented in table 2.5. The greater proportion of the households (approx. 63%) has per capita income in the slab Rs. 5000 to Rs. 15,000, which is some what low in relation to the relative standard of living with respect to the urban areas of the state in Uttaranchal.

2.3.2.5 Family Structure

Two types of family structures exist in the village. These are:

(i) *Joint* family structure

(ii) *Nuclear* family structure

In the *Joint* family structured household, a number of closely knit families function under a common head, who for most purposes in the eldest family member of the combined family households. Such households are frequently characterized by large family sizes, and, are usually well to do economically on account of the availability of pooled income resources / assets of the constituent family units for a common business venture managed as a family activity. The venture could be of an agricultural or non-agricultural nature. However, its is also noticed, the certain closely related households maintain this order to prevent fragmentation of the common land holdings/property that could be economically disadvantageous to all concerned.

Table 2.5 : Percentage of households in different per-capita income slabs

S.No.	Annual per-capita income slab (Rs.)	Percentage of households in the slab (%)
1.	< 5000	12.50
2.	5000- 10,000	31.25
3.	10,000-15,000	31.25
4.	15,000- 20,000	12.50
5.	> Rs 20,000	12.50
		Total = 100.00

Source: Primary survey data

Nuclear family households, on the other hand consist of a single family unit of father, mother and children (unmarried) with occasional dependent relative(s). (e.g.aged parents, uncle, etc.) In such families, the size is generally small, and, the head of the family is usually the father. *Nuclear* families in general have total incomes below those of the *Joint* families. However, exceptions are possible.

Table 2.6 shows the percentage composition of households on the basis of the family structure along with other details of the household.

Table 2.6: Percentage composition of households in *Kanvashram* classified on basis of the type of family structure

S.No.	Type Of Family structure	Percentage of occurrence (%)	Average per capita family income (Rs.)	Average annual income of household (Rs.)
1.	Joint	43.75	10, 423.21	86, 000.00
2.	Nuclear	56.25	17,771.60	61, 778.00

Source: Primary survey data

An interesting observation can be seen in table 2.6. The average annual income of the *Joint* family structured household (Rs. 86,000) *is about 1.4 times greater* than that of the *Nuclear* family structured household (Rs. 61,778). However, the per capita income of the *Nuclear* family structured household is found to be *approximately 1.7 times higher* than that for the *Joint* family structured household. (Rs. 10,423.21). This implies that although in *Joint* family structured households, the overall income in higher, the average standard of living is inferior to that of the *Nuclear* family structured household since the per capita income is much lower. Another observation is that the *Nuclear* households are in excess in the village. This may perhaps reflect changing trends in the village in which the once existent *Joint* structured way of living is now paving the way for independent living desired by modern households.

2.3.2.6 Effective family size

The *Effective Family Size (EFS)* is a term that has been coined to provide an idea of the size of the family in terms of *adult strength* alone. This is given by the formula:

Effective Family Size (EFS)= No. of Adult Members + (No. of Children)/2

A family member is considered an *adult* if his/her age exceeds 15 years. Table 2.7 shows the typical *Effective Family Size (EFS)* for *Joint* and *Nuclear* family households in different income groups.

Table 2.7 : Effective family size statistics for *Kanvashram*

S.No.	Income slab (annual income of the household)	Average effective family size (EFS)	
		***Joint* family household**	***Nuclear* family household**
1.	Up to Rs 50,000	5	3.5
2.	Rs. 50,000-100,000	10	4.5
3.	Above Rs. 100,000	9.3	3.5
4.	All income categories	8.28	3.72

Source: Primary survey data

In both the *Joint* and *Nuclear* family households, the average *EFS* is seen to be greatest in the income group : Rs 50,000-100,000. Further, the *EFS* of the *Joint* family structured household is larger than that of the *Nuclear* household for the corresponding income group.

2.4 INFRA STRUCTURAL FACILITIES IN THE VILLAGE

2.4.1 Educational Facilities

A primary school, junior school (up to class 8) and a high school (upto class 10) operate within the village and cater to the basic educational needs of the children of rural households. Most of the local population are educated on an average up to the 10^{th} class (i.e. high school level) and the percentage of graduates is very small. At *Kishanpuri* a few kilometers from the *Kanvashram* village, is an intermediate level college (pre - graduation level) for further educational needs leading to graduation and beyond, students may have to attend colleges in neighbouring towns/urban areas. Local transport is available in the form of buses that ply to and from the village.

2.4.2 Medical Facilities

Reasonable medical services are available within the village. At present, there are two government hospitals, one of which is a veterinary hospital. In addition three private doctors also run their clinics.

2.4.3 Water Availability

Water for drinking is obtainable from the river *Malin*. This is stored in a reservoir and discharged to the village by stone channels. Pumped water for drinking purposes is also made available in some parts of the village apart from the channel water. There is a public water works department that looks after this operation. A small scope exists for erection of tube wells in the village. It has been experienced that boring of tube wells is made difficult due to the presence of stone beds that are irregularly distributed underground. The availability of water depends upon the supply of water in the river *Malin.* During the summer months, there is a scarcity of water, while in the monsoon period, there is an over supply. Apart from drinking, the water supplied in the stone channels is also used for irrigation and other farm/domestic needs.

2.4.4 Local Transport Facilities

Local transport to and fro from the village to *Kotdwar* town and other neighbouring areas is available at regular intervals in the form of buses and taxis. A state roadways bus stop and a private bus stop are located within the village within accessible distance by the majority of the villagers. Local bus service is available for the greater part of the day. Transportation within the village is mainly by foot or by the use of personal vehicles and bicycles. In general, the short distances within different sections of the village (limited to 1-3 kilometers) make such modes of transport convenient. The nearest railway station is at Kotdwar town located 12 kilometers from the village.

2.4.5 Roads in the Village

Metal tarred or *Pucca* roads exist within the village at most locations. Other less important and less frequented areas, particularly those leading to the forests and hills bordering the village are connected by unmetalled or *Kutchha* roads. At certain important road junctions street lights are also provided.

2.4.6 Local Markets

The local market comprises of some 25 – 30 shops, which surprisingly cater to a vast spectrum of basic needs like: groceries, daily provisions, general articles of daily use, vegetables and fruits, photographic material, electronic goods and repairs, telephone facilities, general hardware material etc. In fact, most of the requirements of the average village household are obtainable in village itself, and, it is only in extreme cases that one is expected to go to *Kotdwar* town for the purchase of some unobtainable commodity.

2.4.7 Government Organizations Operating within the Village

The village has certain essential government offices/institutions that cater to the rural public needs. These include: a post office, dispensary, veterinary hospital, rural banks, water works department and an electricity sub station/office. Rural banks like the *Alaknanda Gramin Bank* and the *Sadhan Sahkari Samiti* trust operate within the village for providing necessary finance to farmers. The public water works department (*Jal Nigam*) has its office in the village and a small colony for the staff employees. In addition, there is a guest house of the *Garhwal Mandal Vikas Nigam* that oversees the management of villages falling within the purview of the district of *Garhwal.*

2.4.8 Local Industries

Some local industries operate within the village and cater to the needs of the local population. These include industries like: workshops/welding works, sheet metal works, furniture making, carpentry, cotton, oil rice and flour mills etc.

2.4.9 Places of Local Interest

The picturesque surroundings of the village and the existence of a few historical sites offer scope for tourism development within the region. The *Garhwal Mandal Vikas Nigam* has evinced a desire to develop *Kanvashram* into a tourist spot in view of the pilgrims that visit the hermitage of the sage *Kanva.* Apart from this, the area is also a scenic picnic spot. Close to the hermitage is located the *Sati Mat*- a place where *Ayurvedic* treatment is offered for cases despaired of by orthodox medicine. *Adhunik Bhim Ashram*, a school for *yogic* sciences, *Vridashram*, sulphur springs at *Sashtra Dhara Mayur Vihar* are some of the other attractions that *Kanvashram* has to offer.

A micro hydel plant of 100 kilowatt total capacity is proposed for installation at Kanvashram by the *Alternate Hydro Energy Centre, Roorkee*, Uttaranchal, under the support of the *Ministry for Non conventional Energy Sources (MNES)*. The unit is located close to the hermitage and makes use of the gushing water flow of the *Malin* river as it emerges from the foothills into the plain.

2.5 AGRICULTURAL ACTIVITIES

2.5.1 Average Size of Land Holdings

The average size of the operational land holdings of the farmers and cultivators varies from as low as 0.2 to as much as 3 acres. In general, most cultivators are *small* farmers by this assessment. Few farmers have land holdings in excess of 5 acres. Table 2.8 shows the percentage of cultivators in the village, the proportion being estimated in terms of the average size of their land holdings.

Table 2.8 : Percentage of cultivators with different sizes of land holdings

S.No.	Average size of land holdings (acres)	Percentage of cultivators (%)
1.	Landless	31.25
2.	< 1.0	18.75
3.	1.0 – 3.0	37.5
4.	> 3.0	12.5
		Total = 100.00

Source: Primary survey data

It is seen from table 2.8 that almost one-third of the population is landless, while of the remaining two- third that possesses land, only about 13% have land holding in excess of three acres. About 38% of the population have land holdings between 1 and 3 acres.

Table 2.9 shows the percentages of cultivators (with own land holdings) under different income earnings slabs.

2.5.2 Irrigation System in Use

The irrigation system within the village mostly uses canal flow. Water in an elevated reservoir is allowed to flow down to the village in stone channels which branch into a network feeding the fields. The water in the channels can also be used for drinking and other purposes. Irrigation by tube wells (electric or diesel operated) is uncommon. Since it is difficult to drill wells in the area on account of the presence of stone beds.

Table 2.9: Percentage of cultivators in different income groups with respect to land holding size

S.No.	Income group (Rs.)	Percentage of cultivators (%)		
		Up to 1 acre	1-3 acres	> 3 acres
1.	50,000	33.33	66.67	---
2.	50,000- 100,000	25.00	75.00	---
3.	100,000	25.00	25.00	50.00

Source: Primary survey data

2.5.3 Crops Cultivated

The total cultivated area of the village is about 119.67 hectares as per the 1997-'98 estimates. The farmers cultivate wheat, rice, pulses, mustard, maize and vegetables in the two major cultivation seasons of the year i.e. *Rabi* and *Kharif*. Table 2.10 gives an overview of the crops cultivated in the village.

It may be seen from table 2.10 that wheat and rice are the two major crops that account for as much as 80-83% of the total cultivation in terms of land use. The cultivation of vegetables is given the least priority and accounts for only 2-3% of the total cultivated area.

Table 2.10 : Crops cultivated in *Kanvashram*

S.No.	Season	Types of crops cultivated	Area under cultivation (Hectares)	Percentage of total cultivated area(%)
1.	*Rabi*	Wheat	99.32	83.00
2.		Mustard	9.57	8.00
3.		Masoor (Pulses)	7.18	6.00
4.		Vegetables	3.59	3.00
		Total	119.66	100.00
1.	*Kharif*	Rice (Paddy)	95.73	80.00
2.		Soya bean	8.37	7.00
3.		Urad (Pulses)	7.17	6.00
4.		Maize	4.78	4.00
5.		*Mandua*	1.19	1.00
6.		Vegetables	2.39	2.00
		Total	119.63	100.00

Source : Bharadwaj (1999)

2.5.4 Agricultural Operational Methods

Various agricultural operational methods that include: tilling/ sowing /harvesting/ thrashing and sometimes transportation are met by the use of mechanized, animal and/or human based operational methods. Tractors are commonly used for tilling, sowing and transportation of crops, while bullocks may be used for only tilling and sowing operations. Manual labour is employed for sowing and harvesting operations.

2.6 ENERGY UTILIZATION IN KANVASHRAM – A BRIEF OUTLINE OF CURRENT PRACTICES

2.6.1 Lighting Energy Needs

The lighting energy needs of the population are met with two types of energy resources i.e. electric power and kerosene. Most households have an electric power supply and illumination needs are met with this energy. Less affluent households use kerosene lamps. However, on account of the erratic supply of electricity, kerosene also serves as a stand by fuel in households that otherwise use electricity for illumination. Table 2.11 shows the percentage of households that use electricity, kerosene or both resources.

Table 2.11 : Percentage of households using different energy resources for illumination needs

S.No.	Type of energy resource used	Percentage of households using resource (%)
1.	Only Electricity	12.50
2.	Only Kerosene	31.25
3.	Both Resources	56.25
		Total =100.00

Source: Primary survey data

2.6.2 Cooking Energy Needs

Three types of energy resources are normally used in the village for meeting cooking needs. These are:

(i) Liquefied Petroleum Gas (LPG)

(ii) Fuel wood

(iii) Biogas

LPG and Fuel wood are commonly used by the majority of the households. Biogas, however is used by the households in the upper income group. Kerosene is greatly restricted to illumination purposes, although, it is possible that a small portion of it may sometimes be used as an emergency fuel for instant needs (e.g. preparing tea, etc.) This is particularly so in household that make use of only fuel wood for meeting their cooking needs. Frequently, most households depend on multiple fuels for meeting all cooking needs. The use of electricity is rare and is generally confined to preparation of tea etc, particularly in the cold season. Table 2.12 shows the percentage consumption of LPG, fuel wood and biogas in households in *Kanvashram*.

Table 2.12: Consumption of cooking fuels in households of *Kanvashram*

S.No.	Type of energy resource(s)	Percentage of households using resource(s) (%)
1.	Only LPG	18.75
2.	Only Fuel wood	37.50
3.	LPG+ Fuel wood	25.00
4.	Only Biogas	0.00
5.	Biogas + Fuel wood	18.75
6.	LPG + Biogas +Fuel wood	0.00
		Total =100.00

Source: Primary survey data

It is seen from table 2.12 that:

(i) Biogas as a sole cooking fuel is not used in households of *Kanvashram* village.

(ii) LPG and biogas are not used together in rural households. This implies that households which have biogas plants do not use LPG as an auxiliary energy resource and vice versa. Instead, fuel wood is used as the supplementary fuel, if at all needed.

2.6.3 Space Heating/Cooling Needs

The average temperature in the region is generally moderate and, as such, a need for fans and desert coolers is seldom required during the greater part of the summer months, except in peak summer when the temperature may rise as high 45 °C. The winter months are, however, relatively cold and space heating is necessary. Fuel wood is commonly used in most rural households for this purpose.

2.6.4 Energy for Motive Power

The main energy applications in the village that require motive power are:

(i) Operation of electric drives mills, small engineering operations and cottage industries.

(ii) Operation of tractors for agricultural operations.

(iii) Operation of buses, taxis and other motor vehicles for local transport to and from the village.

Presently, electricity is available to the village for motive energy based needs, but the supply is erratic and of a poor quality. Diesel fuel for tractors and commuting vehicles is available at selected outlets mostly outside the village.

2.7 CONCLUSIONS

The present chapter attempts to present an overview of *Kanvashram*. A detailed outline of the profile of the study area has been discussed in relation to different aspects that pertain to the geographical, demographic, economic, social and energy based issues characteristic of the region. The outline is expected to provide an idea of the background of the study area for which the energy planning is to be carried out.

CHAPTER–3

ENERGY PLANNING FOR KANVASHRAM

PART A: ASSESSMENT OF ENERGY CONSUMPTION PATTERNS

3.1 INTRODUCTION

India's economic prosperity depends to a large extent on the rural economy. It is thus imperative to take a close look at the energy scenario of the Indian rural system. Quantifying energy resources and assessing the energy consumption patterns in rural areas is an important step in the planning process, since these determine the dynamics of the changes in the energy demand and supply patterns, which is ultimately correlated with the economic growth and development in the area. A knowledge of the existing energy consumption pattern enables the decision maker/rural planner to understand the relevant changes that must be made to the energy habits of the population so as to steer them towards an improved consumption trend in line with the recommendations of a suitable energy planning model. Alternatively, the study of the consumption trends helps the decision maker to effect proportionate distribution of resources that the energy plan may recommend among different categories of the population. Another way in which such exercises may be of value is in to enable demand forecasts to be made for short or medium term planning in terms of existing energy consumption trends.

Energy production in India is very low, whereas the potential demand is considerably higher. In order to meet the requirement for different types of end uses such as cooking, lighting, space heating, agriculture and rural transportation, a mix of energy resources like: fuel wood, kerosene, soft coke, vegetable/agricultural residue, animal dung, biogas, LPG liquefied petroleum gas), charcoal and electricity can be used. The choice of these resources, will, however, be determined by the trade-off in their availability, costs and convenience in their usage.

The quantity and quality of energy consumption varies from region to region, area to area, and depends on factors like resource availability, costs and socio-acceptance of the particular resource. Urban dwellers are accustomed to the use of large amounts of energy, which are by and large made up of commercial energy resources (electricity, LPG, kerosene), whereas the rural masses use smaller amounts of energy and generally meet their energy demand through non-commercial energy resources like fuel wood, agro-residues, charcoal, animal dung and small amounts of rationed kerosene.

Nowadays, many rural areas lie on the outskirts of urban areas and can be included within the city limits. In such types of rural areas, some of the urban energy resources are finding acceptability into the life style of the rural households. Rural households enjoying economic prosperity are more likely to opt for commercial energy resources like LPG and electricity, and may even go for the installation of biogas plants to meet domestic energy needs. However, the majority of rural households are accustomed to living traditional life styles in which energy demands are kept to a minimum, and, are as far as possible satisfied by non –commercial energy resources.

An interesting paradox observed in the energy shortages pertaining to the rural economy is that while the alarm is being sounded on the existing energy shortage, no efforts are being made to promote optimal use of the available energy resources to tackle the problem of energy shortage. If judicious use of the available energy resources can be implemented, then much of the so called "Energy Crisis" can be mitigated.

In the absence of a proper awareness on the appropriate use of energy resources, the rural population resorts to an overuse of resources like: fuel wood, agro residue and dung to meet energy needs, these fuels are potentially damaging from ecological and environmental perspectives. Furthermore, the increase in the usage of such resources initiates an unhealthy trend that reduces the standard of living of the rural masses and as such, is harmful to the socio-economic welfare of the rural sector as a whole. In the face of such undesirable circumstances, the rural energy planner is obliged to prepare an integrated rural energy plan at the micro level which can be used for appropriate allocation of all available energy resources (commercial and non-commercial) in the area so as to satisfy energy needs of the population. Usually such an exercise is done with the prime objective of obtaining the most appropriate energy plan for the least total cost of supplying the energy for various end uses. Sometime additional or alternate objectives can also be included like: minimization of pollution levels, maximization of the system reliability, social welfare, efficiency, etc. An alternative way for energy planning is to assess the existing energy demand pattern and to plan for future needs on the basis of the existing energy consumption trends. However, regardless of which ever approach is adopted, the first step in carrying out the energy planning exercise is to examine the present energy consumption patterns within the rural population of the chosen area. Such an assessment provides a practical working database which can be used as a foundation for constructing or modifying an energy plan suitable for the area in question. The data base gives the rural energy planner an in depth perspective of the peculiarities of the energy consumption trend of the population, which can aid in the formulation of energy policy conducive to sustainable growth.

In this chapter an attempt is made to analyze the energy consumption trends of the rural population of *Kanvashram*. Certain socio-economical factors are identified, which serve as criteria for segregating the population. A detailed energy utilization assessment has been conducted for the village, and, the findings are intended for generalizations in regard to other villages in *Pauri Garhwal* district possessing similar geographical/agro climatic characteristics. The various aspects of the analysis are dealt with in the subsequent sub-sections.

3.2 ENERGY ANALYSIS OF KANVASHRAM : BASIC METHODOLOGY

The reasons for the assessments of energy consumption patterns in the study area are revisited and stated more clearly as under:

(i) The energy consumption patterns in different categories of the rural population will help the rural planner in understanding the extent to which different energy resources are used in the area. This helps in the identification of the prominent types of energy resources preferred by different rural population categories, and this information will be ultimately useful for the formulation of a suitable energy resource allocation plan based on extrapolation of energy consumption trends.

(ii) The energy consumption ratios for different rural population categories in relation to each type of energy resource that are obtainable from the assessment will be later useful in ensuring proportionate allocation of optimal resource recommendations that are suggested by the energy resource allocation plan for the study area. This will help largely in reducing adjustment difficulties with the modified energy consumption so recommended for the population.

Any plan for provision of energy for meeting the needs of a rural population must first attempt to understand the energy scenario involved. A variety of factors are responsible for influencing the energy consumption habits of the population, and a feasible energy plan must take cognizance of this fact.

The Energy scenario in the rural sectors of the district of *Pauri Garhwal* district can therefore, be best understood in terms of the energy consumption habits of the rural population of the constituent villages. *Pauri Garhwal* district has villages at varied elevation. The energy scenario in each of these villages at different altitudes can probably be expected to vary. *Kanvashram*, the village chosen for the present study, is located at a low elevation. The energy habits in this village are therefore likely to be a mix of those prevalent in the hilly as well as plain areas.

The Kanvashram *village complex is made up of three sub-villages viz.* Udairampur, Bhimsinghpur *and* Maanpur. The distribution of the population in these three sub-villages is reproduced in Table 3.1 below:

Table 3.1: Sub-villages of Kanvashram and their household composition

S. No.	Constituent village	No. of households	Percentage of total households(%)
1.	*Udai Ram pur*	229	57.83
2.	*Bhim Singh pur*	118	29.79
3.	*Maanpur*	49	12.38
	Total	**396**	**100.00**

Source: Block Development Office, Dogadda, District Pauri Garhwal (1999)

Energy data pertaining to the analysis was obtained using a primary survey, since, there is very little information available from secondary sources as regards the energy consumption habits of the local population. The household energy consumption patterns were studied with the help of information obtained on specific schedules administered to the rural population. Random sampling techniques were used for eliciting the required information. A 50% coverage was felt adequate for the survey and the number of households taken for the survey from each sub village were in proportion to their respective household populations. The steps that went into the data collection are outlined as there are two types of households in the village i.e. *Joint* and *Nuclear*. In *Joint* households, a number of closely related families operate under a single head, who, for most purposes is the eldest member of the collective household. In the *Nuclear* household, however, a single family functions under a single head, who is generally the father of the family. Size composition is therefore the primary characteristics of the *Joint* family and this may be a cause for the varied energy habits of such households vis-a vis the *Nuclear* family household. It was therefore decided to carry out a purposive survey, in which 50 % of the existing *Joint* and *Nuclear* family households (estimated by a previously carried out pilot survey) were examined in relation to their energy consumption patterns. Specially designed questionnaires, pre-tested against an earlier pilot survey were administered to the two categories of households using random selection. The schedules sought to obtain information on the following type of data:

(a) The socio-economic characteristics of the household, which includes details of the structure of the family, size of the family, literacy level of the head of the household, religion, details of annual income earnings, type of occupation , size of land holdings, etc.

(b) The energy consumption of the household in relation to the various available resources for meeting different end needs. For household of each category, the monthly (or in some cases, daily) energy consumption was recorded in relation to the following energy resources:

(i) Electricity

(ii) Kerosene

(iii) LPG (Liquefied Petroleum Gas)

(iv) Fuel wood

(v) Biogas dung input

(vi) Charcoal

(vii) Animal dung as a fuel

(viii) Agricultural waste as a fuel

Additional information pertaining to details of the livestock/poultry etc. and the availability of dung for use as manure/biogas feedstock, details of the agricultural activities (sowing/tilling/harvesting/irrigating etc.) and details of the cropping pattern and the estimated harvest yields of crops (which can be used for computing the potential of agro-waste for energy generation), was obtained from secondary sources. The schedule/questionnaire used for the survey is given in *Appendix A*.

The collected data was compiled, corrected for minor inconsistencies in respondent replies where necessary, processed and entered as a database for the subsequent analysis. The analysis is carried out as follows:

There are three types of households considered for the analysis of the energy consumption trends as;

(a) *Joint* family households.

(b) *Nuclear* family households.

(c) *All* family households.

The third category is merely a mix of the other two categories and has been introduced for comparison of the overall trends with those of either of the two other household categories.

Two types of analysis are carried out in relation to the energy consumption pattern for the study area as;

(i) Analysis of the mean and percentage share of consumption of the different decile categories of the household categories for different energy resources.

It was seen from the compiled survey data as given in table 3.2 that only four resources were used extensively in the study area. These are: electricity, kerosene, liquefied petroleum gas (LPG) and fuel wood. Accordingly, the analysis has been restricted to only these four energy resources. Households are arranged in ascending orders of their per capita incomes and divided into decile categories. The energy consumption trend of the population is examined in relation to the per capita income decile category of the household.

(ii) Analysis of the levels of inequality in energy resource consumption in relation to each of the four energy resources and the different types of household categories

Lorenz curves based assessment and the use of inequality indices (Gini ratio) are the tools applied for this purpose.

Table 3.2 : Energy resource consumption pattern in households of *Kanvashram*

S. No	Energy resource	Households using energy resource (%)	Primary end use	Secondary end use
1.	Electricity	68.75	Lighting	Space heating/cooling/communication/entertainment
2.	Kerosene	87.50	Lighting	Cooking
3.	LPG	43.75	Cooking	Lighting
4.	Fuel wood	81.25	Cooking	Space /water heating
5.	Animal Dung (Biogas input)	18.75	Cooking	Lighting
6.	Charcoal	6.25	Cooking	Water/space heating
7.	Animal Dung	6.00	Cooking	Organic manure
8.	Agro Waste	3.15	Cooking	Space heating

Source: Primary survey data

The detailed outline of the methodology adopted for the present study has been explained earlier in Fig. 1.1 of Chapter-1.

3.3 ENERGY CONSUMPTION TRENDS IN THE POPULATION IN RELATION TO VARIOUS ENERGY RESOURCES

The data base prepared from the primary survey in the study area was used for assessing the energy consumption trends in the rural population of Kanvashram. Table 3.2 shows the distribution of utilized energy resources in the village. It is clear from the table that the main energy resources favoured by the population are:

(i) Electricity (ii) Kerosene

(iii) LPG (iv) Fuelwood

Animal dung, charcoal, and agro waste are not popular. Biogas plants are few, and mostly found in upper income households that can afford to maintain and operate them.

In view of the observation that Electricity, Kerosene, LPG and Fuel wood constitute the major energy resources used in the area,(the percentage of households using these exceeds 40%) it was thought appropriate to investigate the energy consumption trends in the population in relation to these four resources only. The present analysis, therefore limits itself to consumption patterns involving only these resources.

3.4 ANALYSIS OF THE ENERGY CONSUMPTION TRENDS IN THE STUDY AREA

As discussed earlier, three categories of households are considered for the present analysis, viz., joint, nuclear and all family households.

The third category (i.e. all family households) possesses the characteristics of the previous two categories, and, has been included merely to understand the energy consumption trends in the entire population which is essentially composed of both these categories. The energy resource consumption analysis in relation to these three categories is discussed in the subsequent sub sections. The energy consumption has been analyzed on the basis of the income of the population. The percentage of households and the corresponding decile categories falling within different per capita incomes are indicated in *Appendix B*.

3.5 ENERGY RESOURCE CONSUMPTION: ANALYSIS OF RESOURCE UTILIZATION USING MEAN AND DECILE DISTRIBUTION

3.5.1 Consumption Trends in Use of Electricity

Electricity is a major energy resource that is provided in the village through a grid extension. The resource is affordable by most of the rural households. The main use of the resource is for lighting purposes, but, the more affluent classes use it for additional/secondary applications like operating domestic equipment, television sets etc. The supply in the village is quite erratic necessitating the use of a backup in the form of LPG or kerosene lamps for illumination purposes. There exists some potential for the augmentation of the existing grid supply power with local power generation using micro hydel plants. Generation using biomass gasification is yet another possibility in this direction.

It is expected that the electricity consumption trends in the *Joint* and *Nuclear* family households would differ. To examine this, a statistical evaluation is done for each type of household. The main findings are discussed as follows:

3.5.1.1 Consumption of electricity in *joint* family households

Table 3.3 shows the consumption trends for *Joint* family households and provides an idea of the mean and percentage share of each decile of the *Joint* family households in relation to their consumption of electricity. It is seen from Table 3.3 that the mean annual consumption of the *Joint* family household varies from 879.23 kWh to 1116.85 kWh for the per capita income variation ranging from about Rs. 6,700 to Rs. 19,200. The consumption of electricity is seen to be negatively correlated with the per capita income, and, a higher consumption of electricity is associated with households in the lower range of per capita annual incomes. The observed negative correlation is probably due to the fact that the upper income *Joint* family households usually have biogas plants installed in their premises, and may possibly depend more on this energy resource for illumination needs (the main end use application for electricity) than on electricity alone.

Table 3.3: Mean and percentage share distribution of deciles in regard to consumption of electricity in *Joint* family households

S.No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6655.00	1116.85	10.92
2.	Second	7005.00	1105.25	10.81
3.	Third	7308.00	1095.64	10.71
4.	Fourth	7987.00	1075.59	10.52
5.	Fifth	8902.00	1051.27	10.28
6.	Sixth	9606.00	1034.00	10.11
7.	Seventh	10,336.00	1016.96	9.95
8.	Eighth	14,665.00	938.46	9.18
9.	Ninth	16,665.00	909.69	8.89
10.	Top	19,160.00	879.23	8.60

Source: Primary survey data

Table 3.4 shows the relative deviation in the consumption of electricity among different decile groups with respect to the bottom decile group taken as reference for comparison. The trends indicated in Table 3.4 point to a regular fall in the consumption of electric energy from bottom to the top decile categories. However, the variation is virtually negligible upto the seventh decile (approximately 9%). From the eighth decile it rises steeply to about 21% in the top decile. A look into the cumulative share of consumption indicates that in the *Joint* family households, the first five decile groups account for approximately 53% of the total energy consumption of the category. The cumulative share upto the ninth decile group is 91%. This suggests that the consumption is largely uniform.

Table 3.4: Relative Deviation in electricity consumption of deciles with respect to consumption of the bottom decile for *Joint* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile(%)
1.	Bottom	0
2.	Second	-1.00
3.	Third	-1.90
4.	Fourth	-3.70
5.	Fifth	-5.90
6.	Sixth	-7.41
7.	Seventh	-8.90
8.	Eighth	-15.90
9.	Ninth	-18.54
10.	Top	-21.27

Source: Primary survey data

3.5.1.2 Consumption of electricity in *nuclear* family households

Table 3.5 shows the consumption trends for *Nuclear* family households and provides an estimate of the mean and percentage share of each decile of the *Nuclear* households.

Table 3.5 : Mean and percentage share distribution of deciles in regard to consumption of electricity in nuclear households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	7808.00	0	0
2.	Second	8860.00	0	0
3.	Third	16716.00	0	0
4.	Fourth	17916.00	0	0
5.	Fifth	20995.00	0	0
6.	Sixth	23322.00	0	0
7.	Seventh	33392.00	138.57	17.06
8.	Eighth	38381.00	189.44	23.33
9.	Ninth	43886.00	239.24	29.46
10.	Top	44543.00	244.72	30.13

Source: Primary survey data

It may be seen from Table 3.5 that *Nuclear* households have virtually no electric consumption up to the 6th decile The annual per capita income up to this decile category is Rs. 23322.00, which, incidentally is higher than the corresponding per capita income of the joint family household for the same decile category. The absence of electric power consumption upto the 6th decile category suggests that the average *Nuclear* household is not in a position to afford an electric connection. The per capita income of the *Nuclear* household is generally larger than that of the joint family household due to lesser number of family members, but the total household income is generally lower than that of the *Joint* family household. Thus the overall economic condition of the *Nuclear* family household may be much inferior to that of the *Joint* family household in the same decile category and this would explain why the lower per capita income joint family households of the 6th decile category show a reasonable consumption of electric energy while the higher per capita income *Nuclear* family household of the same decile category are not able to afford electric energy. However, from the 7th decile upwards, to the top decile, a rapid increase in the electricity consumption is observed, but, the overall consumption is still far below that in *Joint* family households of the same decile category consumption. The cumulative percentage share up to the 5th decile is 0%, rising to 69.86% in the 9th decile. The consumption trend is therefore largely skewed in favour of the upper decile categories (beyond the 5th decile).

Table 3.6 shows the deviation in electricity consumption of the different deciles with respect to the 7th decile taken as reference, since measurable electric consumption begins from this decile onwards. The highly unequal consumption of electricity is reflected in the above table, particularly between the 7th and the 8th decile categories.

Table 3.6: Relative deviation in electricity consumption of deciles with respect to consumption of the 7th decile for nuclear family households

S. No.	Decile category	Relative deviation with respect to the 7th decile(%)
1.	Bottom	-
2.	Second	-
3.	Third	-
4.	Fourth	-
5.	Fifth	-
6.	Sixth	-
7.	Seventh	0
8.	Eighth	36.70
9.	Ninth	72.64
10.	Top	76.59

Source: Primary survey data

3.5.1.3 Consumption of electricity in *All* family households

When the entire population is considered without segregation into *Joint* and *Nuclear* family households then an overall picture emerges that provides the mean electrical energy consumption scenario for the study area.

Table 3.7 highlights the electrical energy consumption trends for all households in terms of the mean and percentage share consumption of each decile of the rural households. The mean annual consumption for the entire population appears to fall from the bottom decile (approximately 1070 kWh/annum) to the top decile (approximately 503 kWh/annum). Further, the percentage share of consumption among the different decile categories is varied. It is maximum in the bottom decile (15.51%) and falls regularly to 7.30% in the top decile.

Table 3.7: Mean and percentage share distribution of deciles in regard to consumption of electricity in *All* households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6128.00	1070.28	15.51
2.	Second	9059.00	955.18	13.84
3.	Third	16492.00	771.41	11.18
4.	Fourth	18612.00	733.12	10.63
5.	Fifth	23442.00	663.32	9.61
6.	Sixth	27896.00	611.24	8.86
7.	Seventh	34192.00	548.94	7.96
8.	Eighth	36434.00	529.69	7.68
9.	Ninth	38635.00	511.94	7.42
10.	Top	39702.00	503.88	7.30

Source: Primary survey data

This indicates that as the per capita income of the households increase, the overall mean consumption of electricity as well as well as the percentage consumption falls. The observed trends lie in between those for the *Joint* and the *Nuclear* family households. The cumulative percentage share of the electricity consumption in this category shows that the total share up to the 5th decile stands at 60.78 %. This indicates a slight skew favouring the consumption of electricity in the lower decile groups. Table 3.8 shows the relative deviation in consumption levels with respect to the bottom decile taken as reference.

Table 3.8: Relative deviation in electricity consumption of deciles with respect to consumption of the bottom decile for *All* family households

S. No.	Decile Category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-10.75
3.	Third	-27.92
4.	Fourth	-31.50
5.	Fifth	-38.02
6.	Sixth	-42.89
7.	Seventh	-48.71
8.	Eighth	-50.50
9.	Ninth	-52.16
10.	Top	-52.93

Source: Primary survey data

The annual consumption of the top decile is 52.93% below that of the bottom decile which implies that the top decile consumes even less than one half of the electricity that the bottom decile consumes. The inequality in consumption levels is also apparent from the relative deviation levels of the above table.

The main findings in relation to the consumption of electricity in Kanvashram are summarized as follows:

(i) *Joint* and *All* family categories show similar trends of consumption in which the bottom decile shows the maximum consumption while the top decile shows the least consumption, there being a regular fall in the consumption levels from bottom to the top decile. The relative deviation in consumption levels for the top decile with respect to the lowermost decile is –21.27% for the *Joint* family category and –52.93% for the *all* family category. However, the *Nuclear* family household shows a different picture. Up to the 6th decile group the consumption of electricity is negligible, possibly, because such households may not be able to procure/install or afford this energy resource. From the 7th decile upwards, an increase in the consumption is observed, but, nonetheless, the magnitude of the consumption falls much below that in the other two categories.

(ii) The percentage share of consumption in the deciles is most uniform for the *Joint* family households, lesser for the *All* household category and most irregular for the *Nuclear* family household category. The cumulative consumption up to the 5th decile group for these different categories suggest skewness favouring consumption of electricity in the lower decile groups for the *Joint* and *All* family categories, and upper decile categories for the *Nuclear* family category.

3.5.2 Consumption Trends in Use of Kerosene

3.5.2.1 Consumption of kerosene in *Joint* family households

The consumption trends for kerosene among the *Joint* family households of Kanvashram are given in table 3.9.

Table 3.9: Mean and percentage share distribution of deciles in regard to consumption of kerosene in *Joint* family households

S.No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6655.00	59.89	10.39
2.	Second	7005.00	59.61	10.34
3.	Third	7308.00	59.38	10.30
4.	Fourth	7987.00	58.90	10.22
5.	Fifth	8902.00	58.30	10.12
6.	Sixth	9606.00	57.91	10.04
7.	Seventh	10,336.00	57.50	9.97
8.	Eighth	14,665.00	55.62	9.65
9.	Ninth	16,665.00	54.93	9.53
10.	Top	19,160.00	54.21	9.40

Source: Primary survey data

It may be seen from this table that the mean annual kerosene consumption of the *Joint* family household is virtually constant for all the decile income groups of this category. The variation is marginal ranging from a maximum of 59.89 litres/annum in the bottom decile to a minimum of 54.21 litres/annum for the top decile. On an average, the monthly consumption works out to be approximately 5 litres, which, incidentally, corresponds to the maximum sanctioned quota per household from the government subsidy or ration depot. Thus it would appear that virtually all *Joint* family households purchase the maximum rationed kerosene fuel to meet various domestic needs. As mentioned earlier, kerosene is used mostly as a fuel for lighting purposes in the low income households and as a standby fuel for electric power failures in upper income households. Its use for cooking is probably restricted for certain operations like making tea, etc, when the use of alternative fuels appears to involve time and inconvenience.

A study of the percentage share of consumption among different deciles points to the fact that the variation of consumption in different deciles is very marginal with a slight fall in the annual consumption indicated in the upper deciles. The cumulative share of the 5th decile is 51.38%, showing that the consumption is almost uniform in such households.

This fact is further corroborated by the findings of Table 3.10 in which the relative deviation of consumption of different deciles is given with respect to the bottom decile.

Table 3.10: Relative Deviation in Kerosene Consumption of Deciles with respect to Consumption of the Bottom Decile for *Joint* Family Households

S.No.	Decile Category	Relative deviation with respect to the bottom decile(%)
1.	Bottom	0
2.	Second	-0.46
3.	Third	-0.84
4.	Fourth	-1.64
5.	Fifth	-2.61
6.	Sixth	-3.30
7.	Seventh	-3.98
8.	Eighth	-7.12
9.	Ninth	-8.27
10.	Top	-9.48

Source: Primary survey data

3.5.2.2 Consumption of kerosene in *nuclear* households

The consumption trends for kerosene in *Nuclear* family households is shown in Table 3.11.

Table 3.11: Mean and percentage share distribution of deciles in regard to consumption of kerosene in *Nuclear* households

S. No.	Decile category	Mean Annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	7808.00	181.25	15.98
2.	Second	8860.00	173.08	15.26
3.	Third	16716.00	130.93	11.54
4.	Fourth	17916.00	126.57	11.16
5.	Fifth	20995.00	116.14	10.24
6.	Sixth	23322.00	109.33	9.64
7.	Seventh	33392.00	85.59	7.54
8.	Eighth	38381.00	76.50	6.74
9.	Ninth	43886.00	67.61	5.96
10.	Top	44543.00	66.63	5.88

Source: Primary survey data

This table shows that unlike *Joint* family households, the *Nuclear* household shows a progressive decrease in the consumption of kerosene with rise in the per capita income. The mean annual consumption falls from 181.25 litres in the bottom decile to 66.63 litres for the top decile. Evidently, with an increase in the per capita income, the *Nuclear* family household tends to consume more of alternative energy fuel resources. This probably implies the greater use of electricity for lighting needs, (that is the major end use for kerosene). The percentage share of the total consumption of the deciles shows that a large unequal distribution in the utilization of this resource exists in nuclear households. The bottom decile accounts for 15.98% of the total share of consumption while the top share accounts for only 5.88 % of the total share. The cumulative share up to the 5th decile amounts to 64.21%, and points to a skewed consumption trend favouring the lower deciles. Table 3.12 shows the relative deviation of the various decile in regard to kerosene consumption with respect to the lowermost decile taken as reference. A large deviation is observed in the consumption between the bottom and the top decile (63.24%). Kerosene, thus appears to be one energy resource that is largely preferred by the lower income *Nuclear* households and lesser by the upper income *Nuclear* households.

Table 3.12: Relative deviation in kerosene consumption of deciles with respect to consumption of the bottom decile for *Nuclear* family households

S.No.	Decile Category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-4.51
3.	Third	-27.76
4.	Fourth	-30.17
5.	Fifth	-35.92
6.	Sixth	-39.68
7.	Seventh	-52.78
8.	Eighth	-57.79
9.	Ninth	-62.69
10.	Top	-63.24

Source: Primary survey data

3.5.2.3 Consumption of kerosene in *All* households

Table 3.13 shows the trends in the consumption of kerosene in the entire population (*All* households) of Kanvashram. This category includes both joint as well as nuclear households. It may be seen from table 3.13 that the change in the consumption of kerosene from the bottom to the top decile falls from 69.86 litres /annum to 50.62 litres/annum. The percentage share of the total consumption of these deciles are respectively 12.26% and 8.88%. From the 6th to the top decile, the fall in consumption levels is marginal. The trends as indicated by table 3.13 lie in between those of the *Joint* and *Nuclear* household consumption trends. They are closer to the trends for the *Joint* family household. The cumulative percentage share upto the 5th decile is 63.96 % pointing to a skew in consumption favouring the lower deciles groups.

Table 3.13: Mean and percentage share distribution of deciles in regard to consumption of kerosene in *All* households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6128.00	69.86	12.26
2.	Second	9059.00	65.96	11.58
3.	Third	16492.00	59.71	10.48
4.	Fourth	18612.00	58.41	10.26
5.	Fifth	23442.00	56.05	9.84
6.	Sixth	27896.00	54.28	9.53
7.	Seventh	34192.00	52.16	9.15
8.	Eighth	36434.00	51.50	9.04
9.	Ninth	38635.00	50.90	8.93
10.	Top	39702.00	50.62	8.88

Source: Primary survey data

Table 3.14 shows the relative deviation of the consumption of various deciles with respect to bottom decile as reference. It may be seen from table 3.14 that the percentage fall is almost uniform from the 7th to the top decile. Nonetheless, the top decile is 27.54% below the bottom decile in its consumption showing the large inequality levels in consumption of kerosene between these two extreme decile categories.

Table 3.14: Relative deviation in kerosene consumption of deciles with respect to consumption of the bottom decile for *All* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-5.59
3.	Third	-14.52
4.	Fourth	-16.38
5.	Fifth	-19.77
6.	Sixth	-22.31
7.	Seventh	-25.33
8.	Eighth	-26.27
9.	Ninth	-27.13
10.	Top	-27.54

Source: Primary survey data

The main findings of the consumption pattern for kerosene are summarized as follows:

(i) In *Joint* family households, the mean annual consumption varies from 54 to 60 litres between the top and the bottom decile groups. It is maximum for the bottom decile and least for the top decile. The small variation in the consumption levels points to almost constant. In the *Nuclear* household category, the variations are much higher the fact that in the *Joint* family households the consumption levels at all decile levels are ranging from 66 litres/annum to 181 litres/annum. Similar trends to the *Joint* family household are witnessed for this category. The *All* households category shows trends that lie in between the trends of the other two categories, but the trends lie closer to that for the *Joint* family households, with a minimum and maximum consumption level of 50 litres/annum and 70 litres/annum respectively.

(ii) The relative deviation of the top decile groups in regard to the consumption of kerosene with respect to the bottom decile is highest for the *Nuclear* family household (-63.24%), lesser for the *All* household category (-27.54%) and least for the *Joint* family households (-9.48%).

(iii) The cumulative percentage share distribution indicates that in *Joint* family households, the 5th decile accounts for 51.38% of the total consumption of the household category In the *Nuclear* household, the 5th decile accounts for a cumulative share of 64.21% of the total share, while for the *All* household category, the cumulative percentage share upto the 5th decile was found to be approximately 54%. Thus these results indicate that the consumption is most uniform for the *Joint* family household, lesser for the *All* household category and skewed in favour of the lower decile groups for the *Nuclear* household category

3.5.3 Consumption Trends in Use of LPG

3.5.3.1 Consumption of LPG in joint family households

Table 3.15 shows the consumption of LPG in the *Joint* family household. The findings show that when the per capita income improves, the mean annual consumption of the household falls. A maximum consumption of 85.64 Kg/year is observed in the bottom decile and a minimum of 27.82 Kg/year in the top decile. The average LPG cylinder currently in use in the Indian market is provided at a subsidized rate and holds about 14.2 Kg of compressed/pressurized gas. With this figure, the maximum consumption of the bottom decile is roughly 6 cylinders /year, while the top decile category consumes approximately 2 cylinders/year. The low consumption rate of the top decile is probably accounted for by the fact that *Joint* household families in the upper income bracket in the study area are generally known to maintain their own biogas plants, and, consequently, use LPG only as an emergency standby. The percentage share of the total consumption falls from 13.67% in the bottom decile to 4.44% in the top decile.

Table 3.15: Mean and percentage share distribution of deciles in regard to consumption of LPG in *Joint* family households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6655.00	85.64	13.67
2.	Second	7005.00	82.81	13.22
3.	Third	7308.00	80.47	12.84
4.	Fourth	7987.00	75.59	12.07
5.	Fifth	8902.00	69.68	11.12
6.	Sixth	9606.00	65.48	10.45
7.	Seventh	10,336.00	61.33	9.79
8.	Eighth	14,665.00	42.23	6.74
9.	Ninth	16,665.00	35.24	5.62
10.	Top	19,160.00	27.82	4.44

Source: Primary survey data

Table 3.16 shows the relative deviation of the consumption in different deciles with respect to the bottom decile as a reference. The relative deviation is highest in the top decile with -67.50%. A marked fall is observed from the 7th decile to the 8th decile of approximately 22%.The percentage cumulative share of shows that the total consumption up to the 5th decile is 62.93 % of the total share. The consumption of LPG appears to be skewed in favour of the lower decile categories.

Table 3.16: Relative deviation in LPG consumption of deciles with respect to consumption of the bottom decile for *Joint* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-3.29
3.	Third	-6.03
4.	Fourth	-11.72
5.	Fifth	-18.63
6.	Sixth	-23.53
7.	Seventh	-28.37
8.	Eighth	-50.67
9.	Ninth	-58.84
10.	Top	-67.50

Source: Primary survey data

3.5.3.2 Consumption of LPG in nuclear family households

Table 3.17 shows the consumption pattern for *Nuclear* households in relation to the use of LPG. The findings of Table 3.17 indicates that up to the 7th decile, *Nuclear* family households cannot afford LPG as a cooking fuel. The low consumption level of LPG as indicated inthe 7th decile shows that it is from this decile category that the first noticeable signs of LPG consumption are perceived. In terms of the quantity of gas per cylinder (14.2 Kgs), even the 7th decile group fails to qualify as a group consuming LPG. The 8th to the top decile groups shows some improvement in the consumption of LPG. They account for 20.36%, 37.39% and 39.27% respectively of the total share of LPG consumption of the category. The cumulative share of LPG consumption up to the 5th decile is 0.00%, thereby pointing to the highly skewed consumption of LPG favouring the upper decile groups.

Table 3.17: Mean and percentage share distribution of deciles in regard to consumption of LPG in *Nuclear* households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	7808.00	0.00	0.00
2.	Second	8860.00	0.00	0.00
3.	Third	16716.00	0.00	0.00
4.	Fourth	17916.00	0.00	0.00
5.	Fifth	20995.00	0.00	0.00
6.	Sixth	23322.00	0.00	0.00
7.	Seventh	33392.00	3.046	2.96
8.	Eighth	38381.00	20.90	20.36
9.	Ninth	43886.00	38.38	37.39
10.	Top	44543.00	40.31	39.27

Source: Primary survey data

Table 3.18 shows the relative deviation in consumption levels with respect to the 7th decile group (as a ratio to the consumption of the 7th decile group), since no consumption is observed up to the 6th decile group. The findings of the table indicate that from the 8th decile upwards, a rise from 5.86 times the consumption of the 7th decile group to as much as 12.23 times the consumption of the 7th decile is perceived in the top decile group.

Table 3.18: Relative deviation in LPG consumption of deciles with respect to consumption of the 7th decile for *Nuclear* family households

S.No.	Decile category	Relative deviation with respect to the 7th decile
1.	Bottom	0
2.	Second	0
3.	Third	0
4.	Fourth	0
5.	Fifth	0
6.	Sixth	0
7.	Seventh	0
8.	Eighth	5.86
9.	Ninth	11.60
10.	Top	12.23

Source: Primary survey data

3.5.3.3 Consumption of LPG in all family households

Table 3.19 shows the consumption trends of LPG in the all household category. It is seen that the two inverse trends (i.e. of the *Joint* and the *Nuclear* households) in regard to the consumption of LPG normalize the overall trend in the whole population so that in this category, the consumption of LPG in all categories appears to be almost uniform. In terms of a normal cylinder of 14.2 Kgs of compressed gas, the effective annual consumption of all household category varies from 9.3 to 10.6 cylinders/annum.

Table 3.19: Mean and percentage share distribution of deciles in regard to consumption of LPG in *All* households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6128.00	131.93	9.09
2.	Second	9059.00	135.90	9.36
3.	Third	16492.00	142.23	9.80
4.	Fourth	18612.00	143.55	9.89
5.	Fifth	23442.00	145.96	10.06
6.	Sixth	27896.00	147.75	10.18
7.	Seventh	34192.00	149.90	10.33
8.	Eighth	36434.00	150.56	10.36
9.	Ninth	38635.00	151.18	10.42
10.	Top	39702.00	151.46	10.44

Source: Primary survey data

The percentage share of the deciles is almost uniform with 9.09% at the bottom decile to 10.44% in the top decile. The cumulative share of consumption up to the 5^{th} decile shows a total of 48.23%, which is quite close to 50 % and implies that negligible skew is indicated in the consumption patterns towards lower or upper decile groups.

Table 3.20 shows the relative deviation in the consumption level for this category with respect to the bottom decile taken as reference. A maximum deviation of 14.8% is observed in the top decile with respect to the bottom decile, while the 5^{th} decile shows a relative deviation of 10.62%.

Table 3.20: Relative deviation in LPG consumption of deciles with respect to consumption of the bottom decile for *All* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	3.00
3.	Third	7.80
4.	Fourth	8.80
5.	Fifth	10.62
6.	Sixth	11.98
7.	Seventh	13.61
8.	Eighth	14.11
9.	Ninth	14.58
10.	Top	14.79

Source: Primary survey data

The main findings of the consumption trends of LPG in Kanvashram are thus summarized as follows:

(i) In the *Joint* family households, a regular fall in the mean annual consumption of LPG is observed. The consumption is maximum in the bottom decile and falls progressively to an insignificant magnitude in the top decile group. It is felt that this may be due to the possibility of the *Joint* family households in the upper income bracket in maintaining their own biogas plants so that the need of LPG is dispensed with partially. In *Nuclear* family households, most of the households (upto the 6th decile) are possibly not in a position to afford LPG as a cooking fuel. The consumption of LPG in the upper decile groups is also very low as compared to the consumption level in the corresponding decile groups of the *Joint* family households. In the *All* household category, the two reverse trends apparently normalize yielding a trend that is fairly uniform over various decile groups.

(ii) In the *Joint* family household, the relative deviation with respect to the bottom group is maximum for the top decile group (i.e. the consumption of the top decile is 0.325 times that of the bottom decile). In the *Nuclear* household category, it is largest for the top decile group accounting for 12.123 times the consumption of the 7th decile group, at which a minimum consumption is observed. In the *All* household category, the relative deviation of the top decile with respect to the bottom decile is only 1.148 times.

(iii) The cumulative share of the consumption level in each category points to non uniformity in resource utilization. The 5th decile shows a cumulative share of 62.93% in the *Joint* family household, while the *Nuclear* household shows a cumulative share of 0.00% The *All* household category shows a cumulative share of 48.23%. From these observations, it is concluded that the most level distribution in the various decile groups is observed in the *All* household category followed by the *Joint* and then *Nuclear* household categories. The consumption of LPG is skewed in favour of the lower decile groups in the *Joint* family households, while the reverse is perceived for the *Nuclear* family household category.

3.5.4 Consumption Trends in Use of Fuel wood

3.5.4.1 Consumption of fuel wood in the joint family household

Table 3.21 shows the consumption trends for the *Joint* family households in Kanvashram in relation to fuel wood. The table shows the mean annual consumption level to vary from 506.39 Kg to 793.53 Kg. The trend involved points to a higher consumption in the lower decile groups and a progressive reduction in consumption levels in the higher income decile groups. It is presumed that fuel wood which is largely used for cooking purposes is substituted to a greater extent by alternative resources like biogas or LPG, which is fairly affordable by the upper income groups. The percentage share of the total consumption is also seen to fall from the bottom to the top decile.

Table 3.21: Mean and percentage share distribution of deciles in regard to consumption of fuel wood in *Joint* family households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6655.00	793.53	11.68
2.	Second	7005.00	779.52	11.47
3.	Third	7308.00	767.90	11.30
4.	Fourth	7987.00	743.66	10.95
5.	Fifth	8902.00	714.28	10.51
6.	Sixth	9606.00	693.42	10.20
7.	Seventh	10,336.00	672.82	9.91
8.	Eighth	14,665.00	577.96	8.50
9.	Ninth	16,665.00	543.21	7.99
10.	Top	19,160.00	506.39	7.45

Source: Primary survey data

Table 3.22 shows the relative deviation in consumption of fuelwood of the decile groups with respect to the bottom decile as reference. It is seen that a fall of 36.18% is observed in the top decile group with respect to the bottom decile. The cumulative share of consumption upto the 5^{th} decile amounts to 55.92%, and, implies a fairly level consumption in the different decile groups. Fuel wood thus appears to be used to virtually the same extent by *Joint* family households in the different decile groups. Fuel wood finds application for cooking and space heating. It can be argued that the larger occurrence of biogas plants in the upper income households of the *Joint* family category reflects in a decrease in the consumption of fuel wood for cooking purposes. This theory appears to be supported by the findings of Table 3.21. None the less, the annual consumption of fuelwood in the upper income groups is still appreciable implying the probable use of fuelwood for other end uses like space heating. In the lower decile groups, the use of fuelwood could be more as an adjunct fuel for cooking (in addition to other fuel resources) and lesser for space heating applications.

Table 3.22: Relative Deviation in fuel wood consumption of deciles with respect to consumption of the bottom decile for *Joint* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-1.76
3.	Third	-3.23
4.	Fourth	-6.28
5.	Fifth	-9.98
6.	Sixth	-12.61
7.	Seventh	-15.21
8.	Eighth	-27.16
9.	Ninth	-31.54
10.	Top	-36.18

Source: Primary survey data

3.5.4.2 Consumption of fuel wood in nuclear family households

Table 3.23 shows the consumption pattern for fuel wood in *Nuclear* family households.

Table 3.23: Mean and percentage share distribution of deciles in regard to consumption of fuel wood in *Nuclear* households

S. No.	Decile category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	7808.00	4198.8	16.06
2.	Second	8860.00	4008.0	15.33
3.	Third	16716.00	3023.82	11.56
4.	Fourth	17916.00	2921.88	11.17
5.	Fifth	20995.00	2678.44	10.24
6.	Sixth	23322.00	2519.51	9.63
7.	Seventh	33392.00	1965.09	7.52
8.	Eighth	38381.00	1752.94	6.70
9.	Ninth	43886.00	1545.26	5.91
10.	Top	44543.00	1522.42	5.82

Source: Primary survey data

It is seen that the relative consumption per annum of the *Nuclear* household is many times more than that of the *Joint* family household for the same decile categories. A fall in consumption occurs with the increase in the per capita income in a similar manner as in the *Joint* family household category, but the fall is much more steep. The percentage share of the total consumption is 16.06% for the bottom decile and steadily falls to 5.82% in the top decile. Evidently, in the upper deciles, there is a case of fuel substitution and more sophisticated (and perhaps expensive) fuels are preferred. By the households in these decile groups. The percentage cumulative share of fuelwood consumption upto the 5th decile amounts to 64.39%, showing, that the consumption of fuelwood is skewed in favour of the low decile groups.

Table 3.24 shows the relative deviation in the consumption of fuelwood in the nuclear family households.It is clear that a steep fall of 63.74 % occurs in the top decile and, therefore,. the top decile consumes only 36.26% of the consumption of the bottom decile.

Table 3.24: Relative deviation in fuel wood consumption of deciles with respect to consumption of the bottom decile for *Nuclear* family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	-4.54
3.	Third	-27.98
4.	Fourth	-30.41
5.	Fifth	-36.21
6.	Sixth	-39.99
7.	Seventh	-53.19
8.	Eighth	-58.25
9.	Ninth	-63.19
10.	Top	-63.74

Source: Primary survey data

3.5.4.3 Consumption of fuel wood in all family households

Table 3.25 shows the consumption of fuel wood in the *All* family category.

Table 3.25: Mean and percentage share distribution of deciles in regard to consumption of fuel wood in *All* family households

S. No.	Decile Category	Mean annual per-capita income of household (Rs.)	Mean annual consumption (kWh)	Percentage share of total consumption of the decile (%)
1.	Bottom	6128.00	925.42	9.60
2.	Second	9059.00	936.86	9.72
3.	Third	16492.00	955.11	9.91
4.	Fourth	18612.00	958.91	9.95
5.	Fifth	23442.00	965.84	10.03
6.	Sixth	27896.00	971.02	10.08
7.	Seventh	34192.00	977.20	10.14
8.	Eighth	36434.00	979.12	10.16
9.	Ninth	38635.00	980.88	10.18
10.	Top	39702.00	981.70	10.19

Source: Primary survey data

The trends as indicated by Table 3.25 point to a very marginal but positive increase in the consumption levels of households with the increase in the per capita income. This is in contrast to the general trends observed in joint and nuclear family households in regard to fuel wood consumption. However, it is clear that the percentage share of the total consumption in the different deciles is almost constant, and, hence, in regard to fuel wood consumption, the population of Kanvashram shows an almost uniform consumption pattern for all decile groups. These findings are corroborated by the cumulative percentage share upto the 5th decile which amounts to 49.23%. Table 3.26 shows the relative deviation in consumption of the different deciles with respect to the bottom decile as reference.

Table 3.26: Relative deviation in fuel wood consumption of deciles with respect to consumption of the bottom decile for all family households

S. No.	Decile category	Relative deviation with respect to the bottom decile (%)
1.	Bottom	0
2.	Second	1.23
3.	Third	3.21
4.	Fourth	3.61
5.	Fifth	4.36
6.	Sixth	4.92
7.	Seventh	5.59
8.	Eighth	5.80
9.	Ninth	5.99
10.	Top	6.08

Source: Primary survey data

The variation from the bottom to the top decile is merely +6.08%. i.e. the top decile group consumes 1.0608 times the consumption of the bottom decile group.. Hence it is safe to state that the consumption of fuel wood for the entire population is almost uniform at all levels of income within the population.

The main findings can be summarized as follows:

(i) Both *Joint* and *Nuclear* family households show a progressive fall in the consumption of fuel wood from the bottom to the top decile. However, the magnitude of consumption as well as the steepness of the fall is greater for the *Nuclear* household. In the *All* households category, a marginal rise in the consumption level is perceived from the bottom to the top decile groups, but the change is so marginal, that for practical purposes, the consumption in the decile groups can be said to be almost constant.

(ii) The cumulative percentage share of consumption up to the 5th decile group points to the greatest uniformity in consumption for the all family category followed by the *Joint* and *Nuclear* household categories.

(iii) The magnitude of the relative deviation of the consumption levels with respect to the bottom decile as reference is maximum for *Nuclear* family households (-63.74%), lesser for the *Joint* family households (-36.18%) and least for the *All* household category (+6.08%).

3.6 OVERALL SUMMARY OF ENERGY CONSUMPTION TRENDS

The energy consumption patterns of four commonly use energy resources in Kanvashram have been studied in this section. These resources are;

(i) Electricity (ii) Kerosene

(ii) LPG (iv) Fuel wood

For a better understanding of the energy consumption pattern in households, it was decided to divide the population into two type of households based on the type of prevailing family structure, viz., *Joint* family households and *Nuclear* family households. A third household category called the *All* household category was also included that includes both types of households. This category serves to show the consumption trends in the entire population taken as a homogenous mix of joint and nuclear households, and, also show how the trends would differ in comparison to joint/nuclear household categories.

The findings indicated that there exists a substantial difference in the magnitude as well as the consumption trends in each of these household categories. The skewness of the consumption gauged from the cumulative percentage share of the resource consumption upto the 5^{th} decile, has also been analyzed for the different household categories. The present analysis of consumption trends in the population of Kanvashram would be helpful for understanding the extent of energy resource preferences that exist within different categories of the population and pave the way for framing resource shift strategies that can lead to more effective utilization of the existing resources in relation to energy planning for the study area.

3.7 ENERGY RESOURCE CONSUMPTION: ANALYSIS OF RESOURCE UTILIZATION INEQUALITY USING LORENZ CURVES AND GINI RATIO

Inequality assessment in energy resource utilization is one of the important concerns of rural energy planning. Such studies provide the rural energy planner with a background of the prevailing energy resource consumption levels in different sections of the rural society and point out whether the inequality in the consumption levels of different energy resources is conducive or detrimental to the socio-economic welfare of the rural population as a whole. The extent of inequality in resource consumption can help in framing suitable normalizing policy useful in correcting undesirable trends observed in the utilization. One way of assessing the relative inequality levels in consumption is by using the decile distribution tables presented earlier. However, more elaborate techniques are also available and it would be appropriate to use these as alternative methods of analysis.

Inequality assessment has been widely applied to income distribution in populations in *Economics* theory. However, its application in the realm of energy studies has not been encountered. In view of this observation, it was thought suitable to apply the

Economics concept of inequality in examining the energy resource consumption variance in the rural population.

The present section discusses the findings of energy resource consumption inequality in Kanvashram using two major tools popularly used in *Economics* viz.

(a) Lorenz Curves

(b) Gini ratio(an inequality index)

These tools are briefly explained prior to their application.

3.7.1 Inequality Assessment using the Lorenz Curve (Chaubey, 1981)

In 1905, M.O. Lorenz published in the *Journal of the American Statistical Association* a paper describing the use of a simple distribution free geometric curve to assess the inequality in wealth in a given distribution [**Lorenz (1905)**]. The curve consisted of plotting the cumulated (proportionate/percentage) share of units (receiving/holding/ possessing/ consuming) with the value of the economic variable less than or equal to *'x'* along the horizontal axis and the cumulated (proportionate/percentage) share of the same units in the aggregate value of the economic variable along the vertical axis. If the value of *'x'* and the probability distribution is given by $p(x)$, the cumulative share of the units with $x=0$ *to* x will be given by:

The cumulative share of these units in the aggregate value of the variable is given by:

$$Q = \int x' p(x)\, dx \,/\, \int x\, p(x)\, dx$$

Where, the numerator gives the part of the aggregate value with $x = 0$ *to* x and the denominator gives the aggregate value of the variable.

Since most measurements are associated with grouped data, the cumulated proportions of the units and cumulated proportions of the aggregate value with the units is expressed as:

$$P_i = \Sigma p_i$$

$$Q_i = \Sigma q_i$$

$$\Sigma p_i = 1$$

$$\Sigma qi = 1$$

Where: p_i = proportion of units in the i^{th} class

qi = proportion of the aggregate value with the units in the i^{th} class

P_i = cumulative proportion of the units in the bottom i^{th} class

Q_i = cumulative proportion of the aggregate value with the units in the bottom i^{th} class

n = number of classes in all.

If the (P_1,Q_1)'s or $(100P_1, 100Q_1)$'s are plotted, the following curve is obtained as shown in Fig. 3.1.

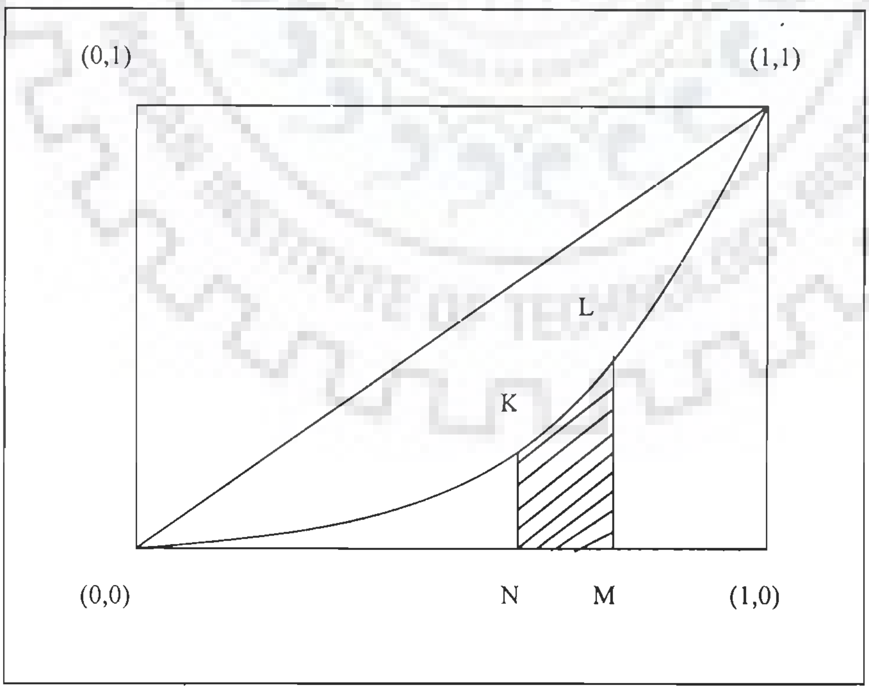

Fig. 3.1: Lorenz Curve

The following points may be noted:

(i) the curve passes through the origin (0,0) and culminates at (1,1) i.e. zero percent of units are with zero percent of the aggregate value of the variable and 100% of units are with 100% of the aggregate value.

(ii) The curve rises monotonically from the bottom left to the top right corner.

(iii) The curve is generally convex to the horizontal axis.

Following are two extreme cases or limits of inequality are indicated in the curve.

(i) Perfect equality (zero inequality) is represented by the diagonal joining (0,0) and (1,1). The diagonal implies that $P_I=Q_I$ and $p_I = q_I$ for all values . The diagonal is therefore known as the *Line of Perfect Equality* or *The Egalitarian Line*

(ii) The other extreme is *Perfect Inequality* in which the "bulge" of the Lorenz curve coincides with the axis below or above the *Egalitarian Line*. This implies that the aggregate of the value is with the last unit alone.

In practical scenarios, inequality exists in between these two extremes .The departure of the trend curve (Lorenz Curve) from the *Egalitarian Line* indicates the extent of inequality involved for the particular cumulative share of units. The greater is the departure, the greater is the level of associated inequality. Lorenz Curves, thus help in comparing inequality in two or more scenarios, the comparison being valid over time, space or sector. The comparison is expressed in convenient graphical terms that present no contradictions provided the various Lorenz curves do not intersect at one or more points. In such cases, however, discretion has to be applied for proper interpretation of the inequality trends involved. Another demerit of the Lorenz curve is that it provides no numerical measurement, so that it is difficult to quantify the extent of associated inequality in two different distributions. Nonetheless, the Lorenz curve is a suitable graphical means of examining the inequality trends in consumption of energy resources in a given population.

The treatment of the Lorenz curve has been mostly confined to the field of *Economics*. However, the concept can also serve to analyze any other situation that entails inequality in distribution. For example Shand (1987) applies Lorenz curves to study the inequality patterns in paddy cultivation. The *Gini* ratio, a derivative of the Lorenz curve has been reportedly used for inequality assessments involving cultivated area, off farm employment, productivity, education, livestock wealth and land holdings. [Anusionwu (1986), Julka and Soni(1988) and Chinnappan(1991)]

The use of the Lorenz curve for analyzing inequality in energy resource consumption is a novel concept which was casually applied by Reddy and Prasad (1980) in depicting the consumption inequality of gross commercial and non commercial energy resources in the Indian context. The concept, however, was not explored beyond this elementary presentation for inequality level assessment. It was felt that the analysis of the inequality levels in consumption in the different categories of the rural population of the study area would provide useful information from the perspective of rural energy planning. Accordingly, the concept has been expanded in application to the present study. To the best of our belief, this concept has not been explored from this angle for detailed analysis involving energy studies.

The results of the analysis of inequality in the consumption of various energy resources are presented in the subsequent sub sections.

3.7.1.1 Inequality in the consumption of electricity

Fig. 3.2 illustrates the family of Lorenz curves for electricity consumption among the various household categories. For convenience, the analysis of trends in inequality is reported for two sections of the curves i.e. upto the 5^{th} decile and beyond the 5^{th} decile. The 5^{th} decile (i.e. the cumulative share of households upto 50%) represents the mid point of the distribution, and, the two sections serve to provide a more comprehensive picture of the relative changes in the inequality levels viewed over the entire distribution.

(a) Trends up to the 5^{th} decile

In the first section (i.e. up to the cumulative percentage share of households equal to 50%) it is seen that the trend closest to the egalitarian line is that due to the joint family household. The relative inequality in the various decile categories of the *Joint* household is thus seen to be almost constant. It is also observed the relative cumulative percentage of total resource lies above the egalitarian line suggesting that for each decile category, the percentage share is greater than the egalitarian share for that decile. The *All* household category shows similar trends, except that the relative deviation from the egalitarian line is much larger denoting wider levels of inequality in electricity consumption. The *Nuclear* household, however, by sharp contrast shows almost 100% inequality and lies below the egalitarian line of consumption, since, up to the 5^{th} decile no consumption is indicated.

(b) Trends beyond the 5^{th} decile

The *Joint* family household continues to maintain the same nature of the inequality trends and bends toward the egalitarian line for the upper decile categories.

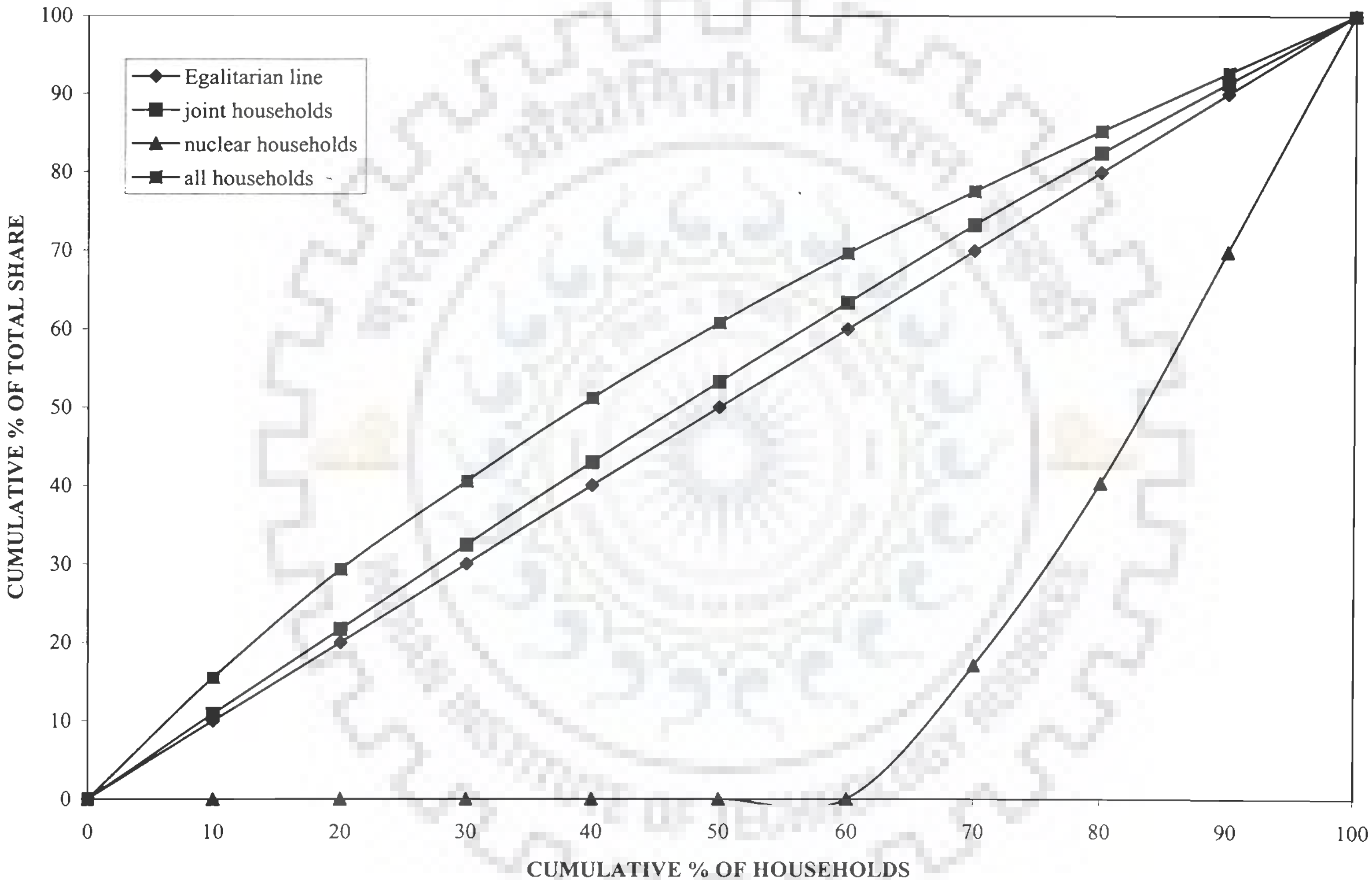

Figure 3.2 : Lorenz curves for inequality in electricity consumption.

The same can be stated for the *All* household category. The *Nuclear* household category shows a steep and regular lowering of the inequality levels beyond the 6th decile.

(c) Overall Trends

The overall trend as indicated by the family of Lorenz curves for electricity consumption points to least inequality in the *Joint* family household, followed by greater inequality levels in the *All* household family category. The maximum inequality was observed in the case of the *Nuclear* family household category. Further, the inequality in the *Joint* and the *All* household category are above the egalitarian line while for the *Nuclear* household, it is seen that the inequality lies below the egalitarian line.

3.7.1.2 Inequality in Kerosene Consumption

Fig. 3.3 shows the family of Lorenz curves for inequality in kerosene consumption in the different household categories. The analysis of the trends is carried out for two sections of the trends i.e. upto and beyond the 5th decile of the household distribution.

(a) Trends up to the 5th decile

The maximum level of inequality is perceived in the *Nuclear* households followed by the *Joint* and then *All* household category. All the inequality levels are seen to exceed the corresponding levels of the egalitarian line. This shows that in all the three categories of households, the average distribution in the consumption levels of kerosene exceeds that of the normal egalitarian line. The inequality is seen to widen up to the 5th decile for the *Nuclear* household category, while it remains fairly constant for the other two categories.

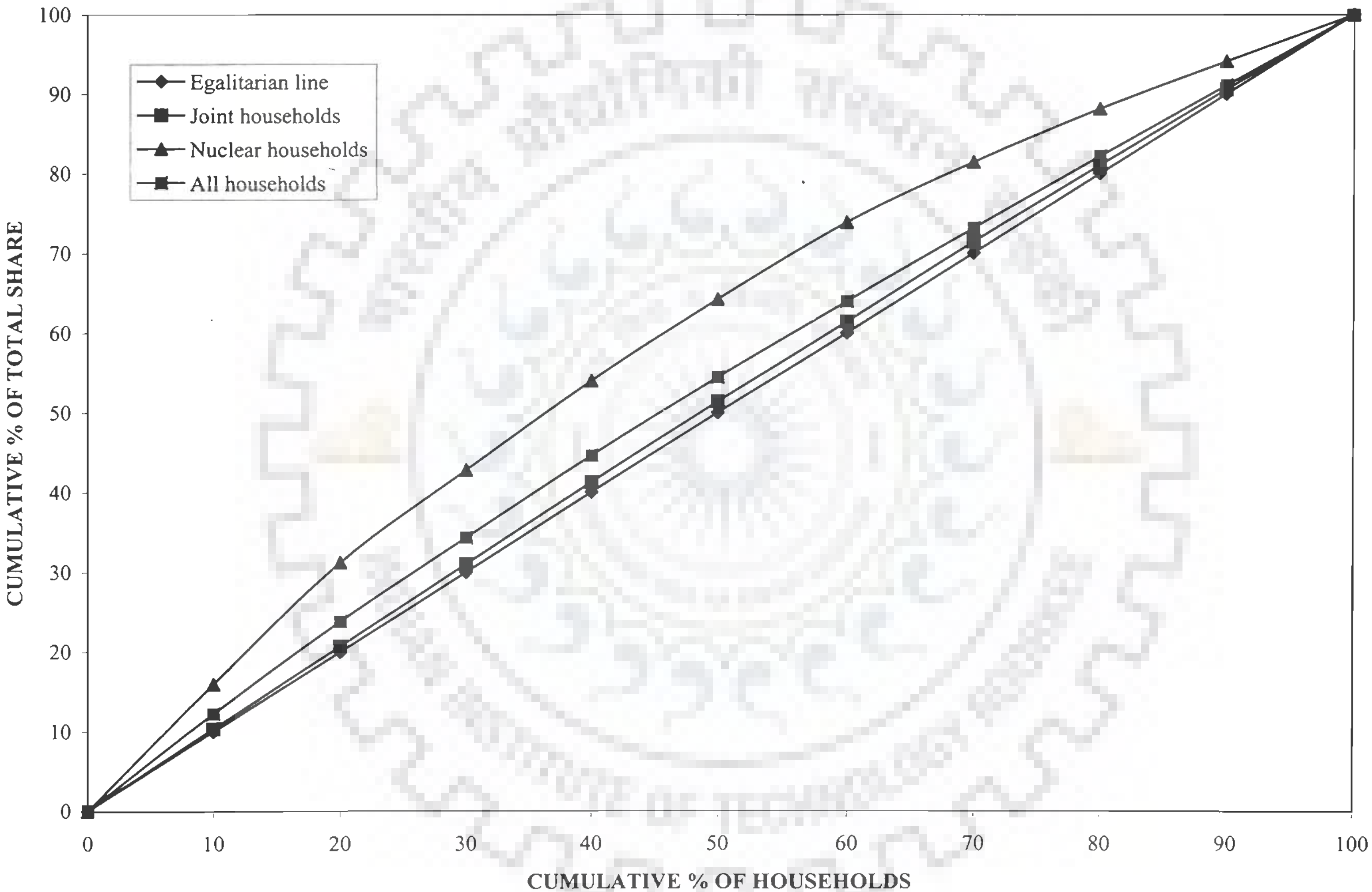

Figure 3.3 : Lorenz curves for inequality in kerosene consumption.

(b) Trends beyond the 5th decile

The same trends are more or less visible in the upper decile groups, except, that the trends for *Nuclear* households show a gradually reducing level of inequality.

(c) Overall Trends

Maximum inequality level is perceived in the *Nuclear* household followed by the *All* households and then the *Joint* household category. All the three categories of households show a distribution in the consumption levels that is above that indicated by the egalitarian line for the respective decile groups.

3.7.1.3 Inequality in LPG consumption

Fig. 3.4 shows the Lorenz curves for the inequality in LPG consumption in the different household categories. The analysis is carried out for the trend up to and beyond the 5th decile.

(a) Trends up to the 5th decile

The inequality trend closest to the egalitarian line is that due to the *All* household category. It shows an almost constant level of inequality with respect to the egalitarian line upto the 5th decile. However, the trend lies below the egalitarian line and points to a consumption distribution that is lower than that recommended by an egalitarian distribution. The *Joint* family household shows trends that are above egalitarian consumption these trends widen in disparity up to the 5th decile. The sharpest levels of inequality are perceived in the nuclear household category with 100% inequality level upto the 5th decile. This is due to zero consumption of LPG upto this decile level.

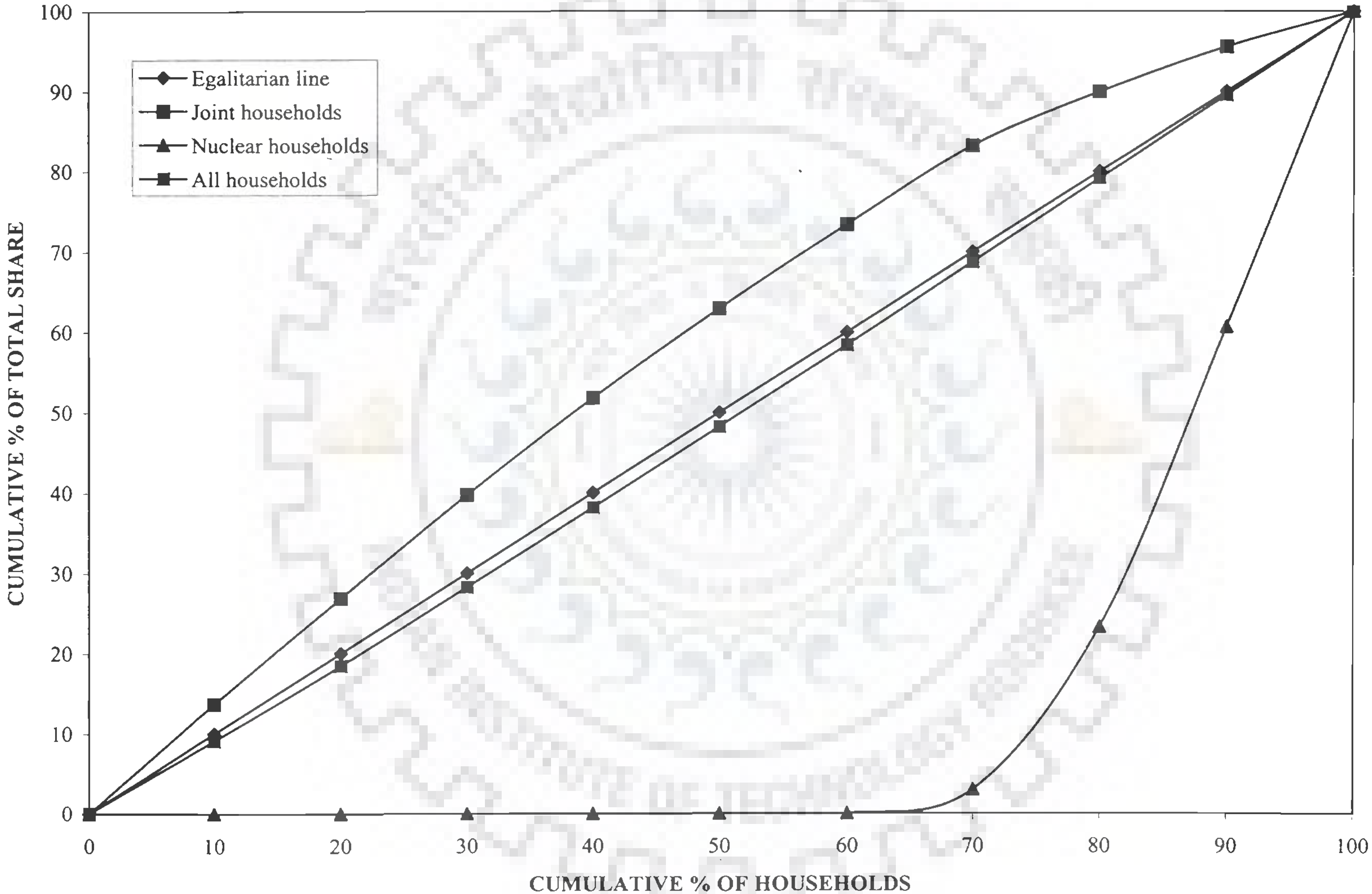

Figure 3.4 : Lorenz curves for inequality in LPG consumption.

(b) Trends beyond the 5th decile

The trends for the *Joint* family household taper towards the egalitarian line showing lower inequality levels in the consumption of LPG at the higher decile levels. This is probably expected in view of the fact that in the high income decile groups, most of the *Joint* family households operate their own biogas plants with consequent lesser dependence on LPG. This means that the consumption trends are more even, and, that the inequality level has decreased. The *All* households category also shows convergence with the egalitarian line at the uppermost decile group. The *Nuclear* household shows a steep lowering of the inequality level beyond the 6th decile. The trend is moves exponentially from the 7th to the top decile.

(c) Overall Trend

It is apparent from the family of Lorenz curves that the maximum inequality in the consumption of LPG is indicated by the Lorenz curve of the *Nuclear* households followed by that of the *Joint* and then the *All* household category. The Joint household shows inequality above the egalitarian consumption while the other two categories show inequality below the egalitarian consumption.

3.7.1.4 Inequality in fuel wood consumption

Figure 3.5 shows the family of Lorenz curves for the Inequality trends in the various household categories of Kanvashram as regards the consumption of fuel wood. The trends are analysed for the inequality variation upto and beyond the 5th decile categories.

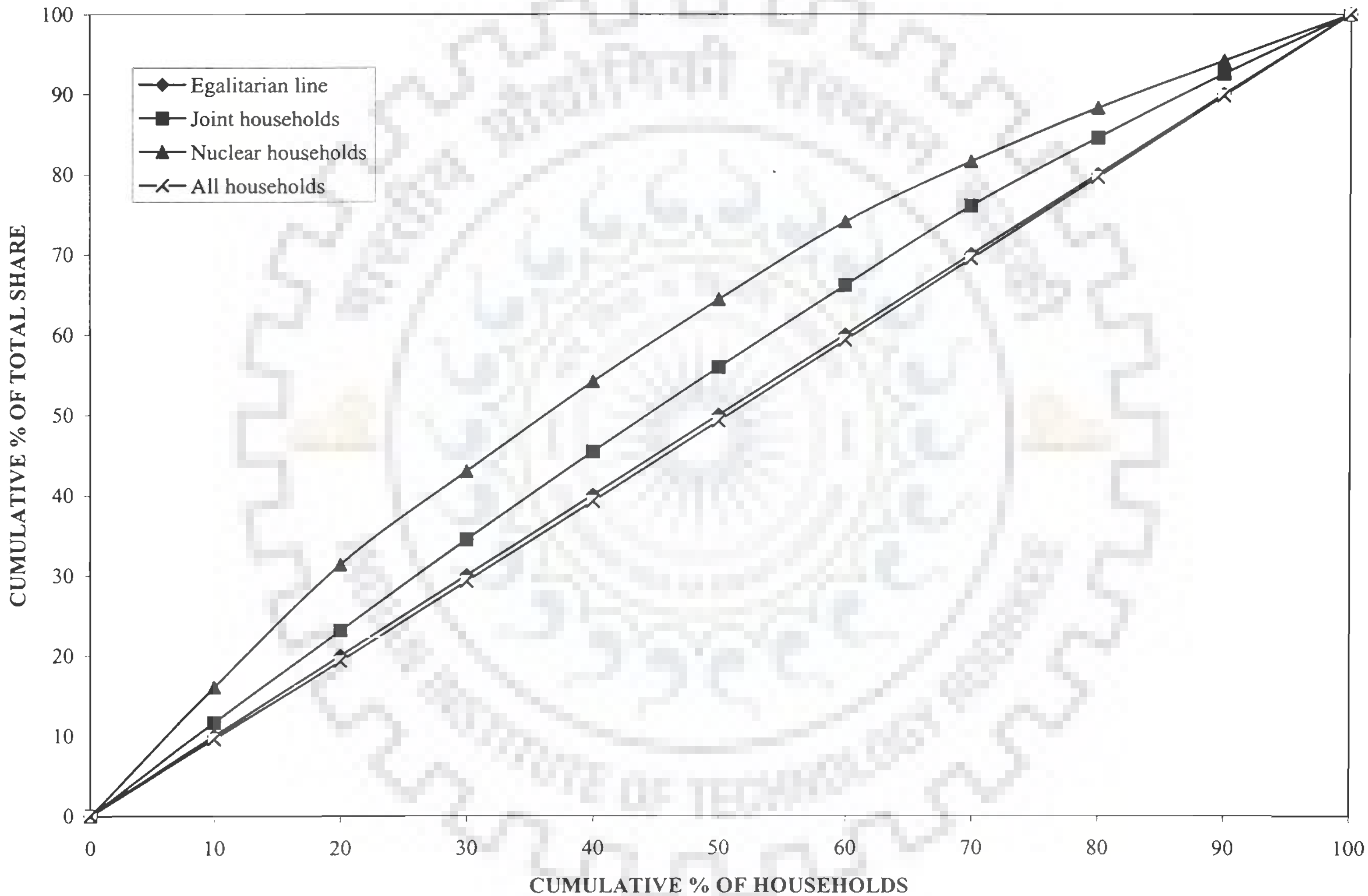

Figure 3.5 : Lorenz curves for inequality in fuel wood consumption.

(a) Up to the 5th decile

With the exception of the *All* household category, the remaining two categories show a progressive rise in the inequality levels of consumption on the positive side (i.e. the inequality is above the egalitarian level). This category shows an almost uniform level of inequality upto the 5th decile. The maximum level of inequality is indicated in *Nuclear* households, lesser for the *Joint* household and least for the *All* household category. Fuel wood usage appears to be most unequal in the Nuclear households, particularly in the lower income groups. The corresponding inequality in the Joint family households at the same decile levels is relatively lower. In the *All* household category, the inequality level in consumption is below that of the egalitarian line and suggests that when considered as a whole, the inequality in consumption of the population falls well below the egalitarian level.

(b) Trends beyond the 5th decile

Similar but gradually tapering extensions of the trends are observed in all the three category of households. For the *Nuclear* household, from the 8th to the top decile group, the tapering is more rapid than that for the other two household categories. At the 9th decile group, the relative inequality amongst the three categories becomes negligible.

(c) Overall Trend

The Lorenz curve area enclosed with respect to the egalitarian line suggests that the maximum inequality is associated with the *Nuclear* family household, followed by lesser inequality within the *Joint* family household and is the least for the *All* household category.

3.8 INEQUALITY ASSESSMENT USING INEQUALITY INDICES

The chief limitations of the Lorenz Curve is that it fails to indicate relative overall inequality levels when intersecting curves are involved. Moreover, it is difficult to quantify the extent of associated inequality merely from graphical estimation. Hence, some numerical estimation of the level of inequality becomes necessary that provides a means of properly identifying trends with greater inequality levels in a given family of Lorenz curves. The work of Corrado Gini (1955) suggested the use of inequality indices that could be useful in providing solutions to these difficulties. The ratio suggested was the *Gini Concentration Ratio*, or, more simply the *Gini Ratio*. This ratio was represented as the ratio of the area enclosed between the Lorenz curve and the egalitarian line to the total area of the right angled triangle under the egalitarian line. Generally, the two areas lie on the same side of the egalitarian line (usually below the egalitarian line), although, in certain instances, they may lie on opposite sides of the egalitarian line.

The Gini ratio is given as:

$$G = 1/2\mu \iint |x - y| \, f(x) f(y) \, dx \, dy$$ [Livada (1991)]

Where: x = mean value of each interval as also is y

μ = population mean

$f(x)$, $f(y)$ = density functions

Alternatively, it may be expressed by the relation:

$$G = \Sigma_i \Sigma_j \, | y_i - y_j | / {}_{2N} 2 {}_{\mu}$$ [Sen(1973), Barooah (1991)]

The latter formulation has been used for the present analysis. There are also several other inequality indices in use such as: the *Coefficient of Variation*, *Standard Deviation of Logarithms, Theil's Entropy index* etc [Sen(1973), Barooah (1991)].

However, the *Gini ratio* appears to be more suitable than these others due to the fact that it can vary only between 0 to 1; 0 implying perfect equality and 1 implying perfect inequality. It is this 0-1 range that makes this ratio appealing in preference to others which are usually expressed in the range zero to infinity.

Figures 3.6-3.9 show the variations of the inequality in energy resource consumption in terms of the *Gini ratios*. These inequality characteristics for the study area show that there are swings in inequality levels for consumption of any energy resource with respect to the different decile levels. However, when viewed critically, it becomes clear that these swing variations are very small (usually varying from near 0 to about 0.2). Thus, in actuality, it can be said that the inequality in resource consumption in the various decile groups of each type of household is generally marginal. The conclusion drawn is that while the population consumption inequality is large on a relative basis with respect to the different deciles, the actual overall inequality within a particular household category is low.

Figures 3.10-3.13 show the relative variations in the *Gini ratios* in the consumption of different energy resources of different deciles with respect to the least decile. As before, it is seen that the relative variation is large but the actual magnitude of variation in terms of the *Gini ratio* is very marginal.

3.9 SUMMARY OF RESULTS

The study was carried out on the following two aspects of consumption for *Joint, Nuclear* and *All* households categories.

(i) Mean energy resource consumption and percentile share of the total energy resource consumption for the various deciles of the various households that were arranged in order of increasing annual per-capita incomes.

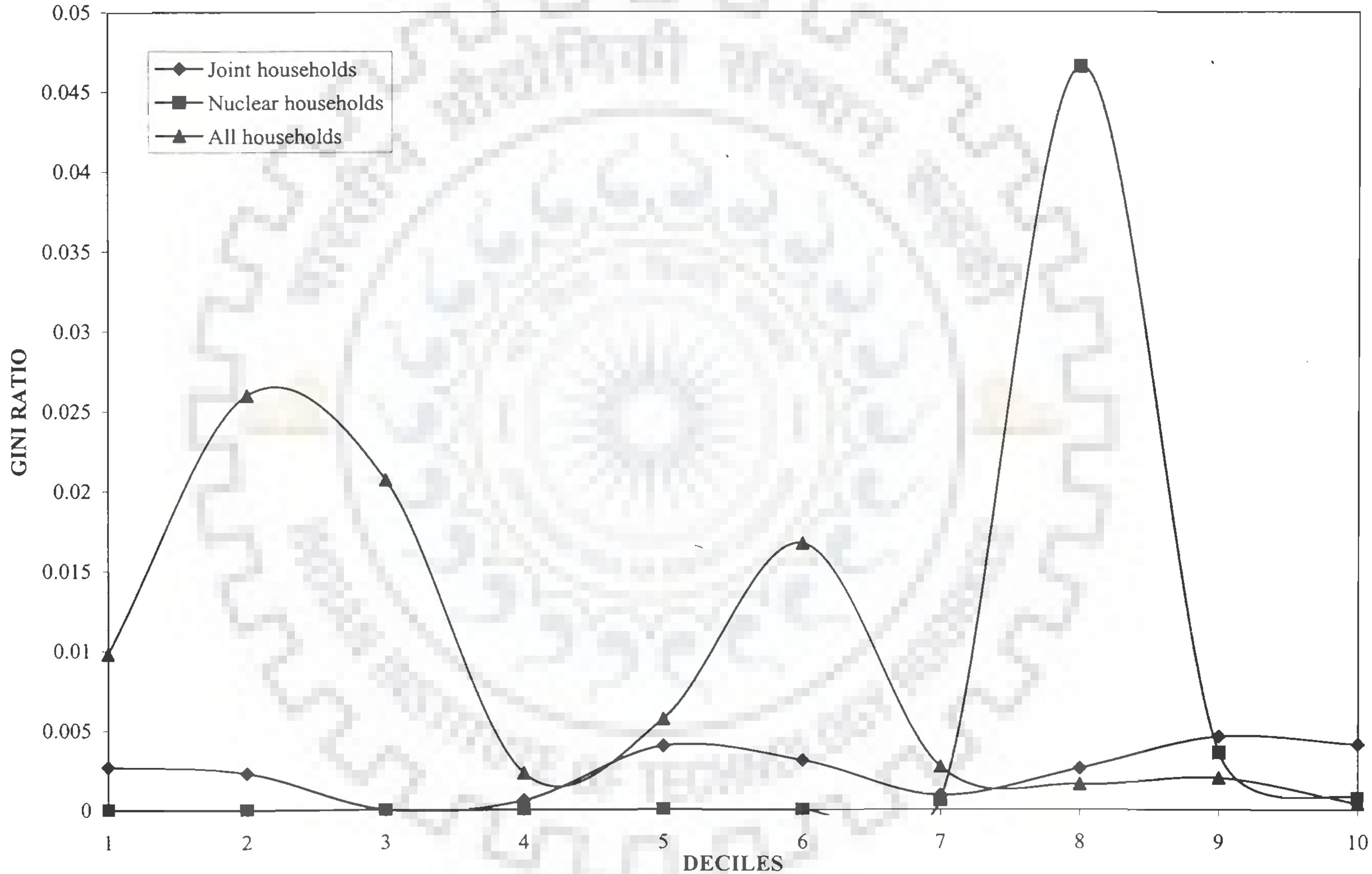

Figure 3.6 : Inequality in electricity consumption in households in terms of Gini Ratios.

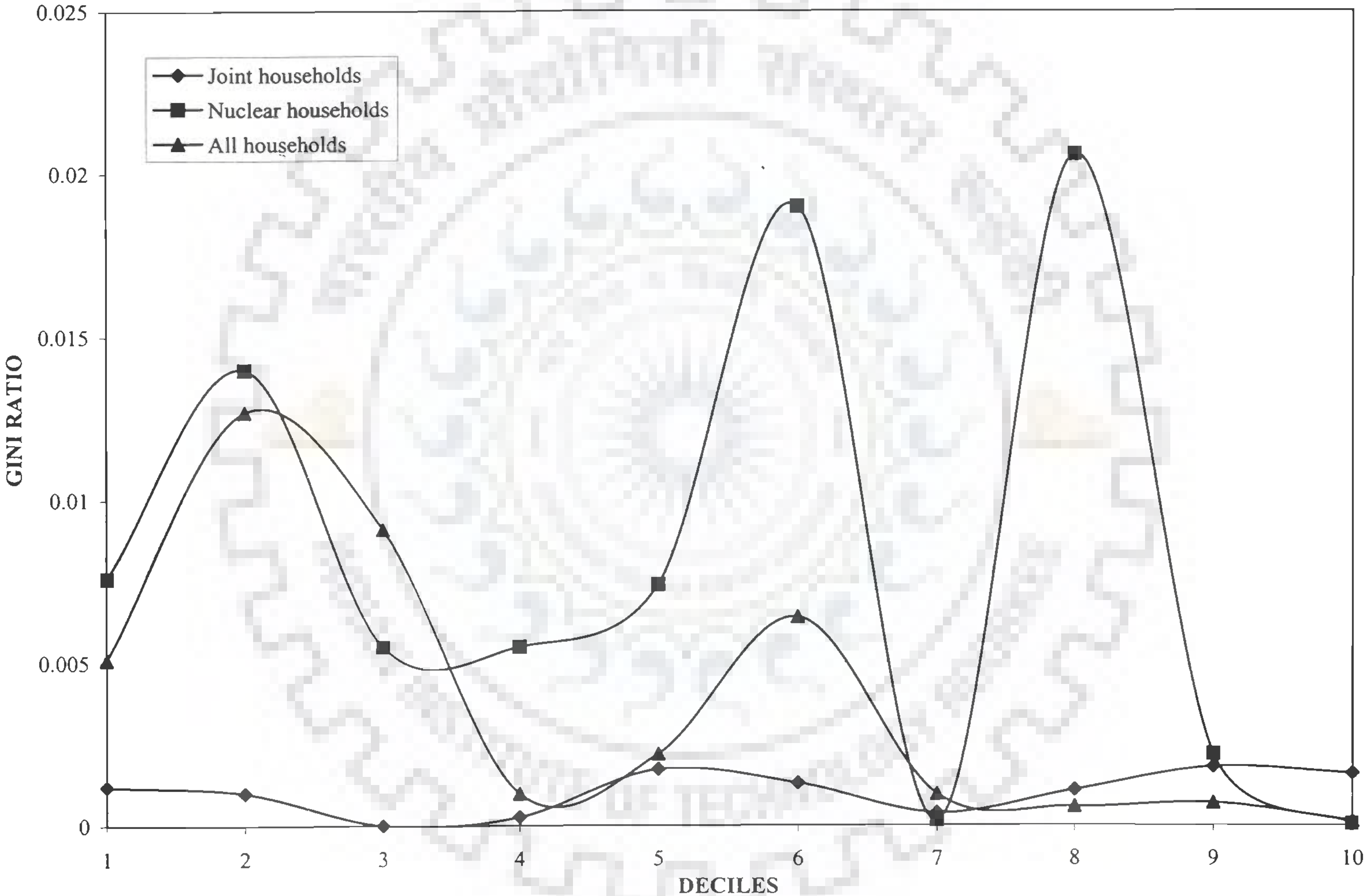

Figure 3.7 : Inequality in kerosene consumption in households in terms of Gini Ratios

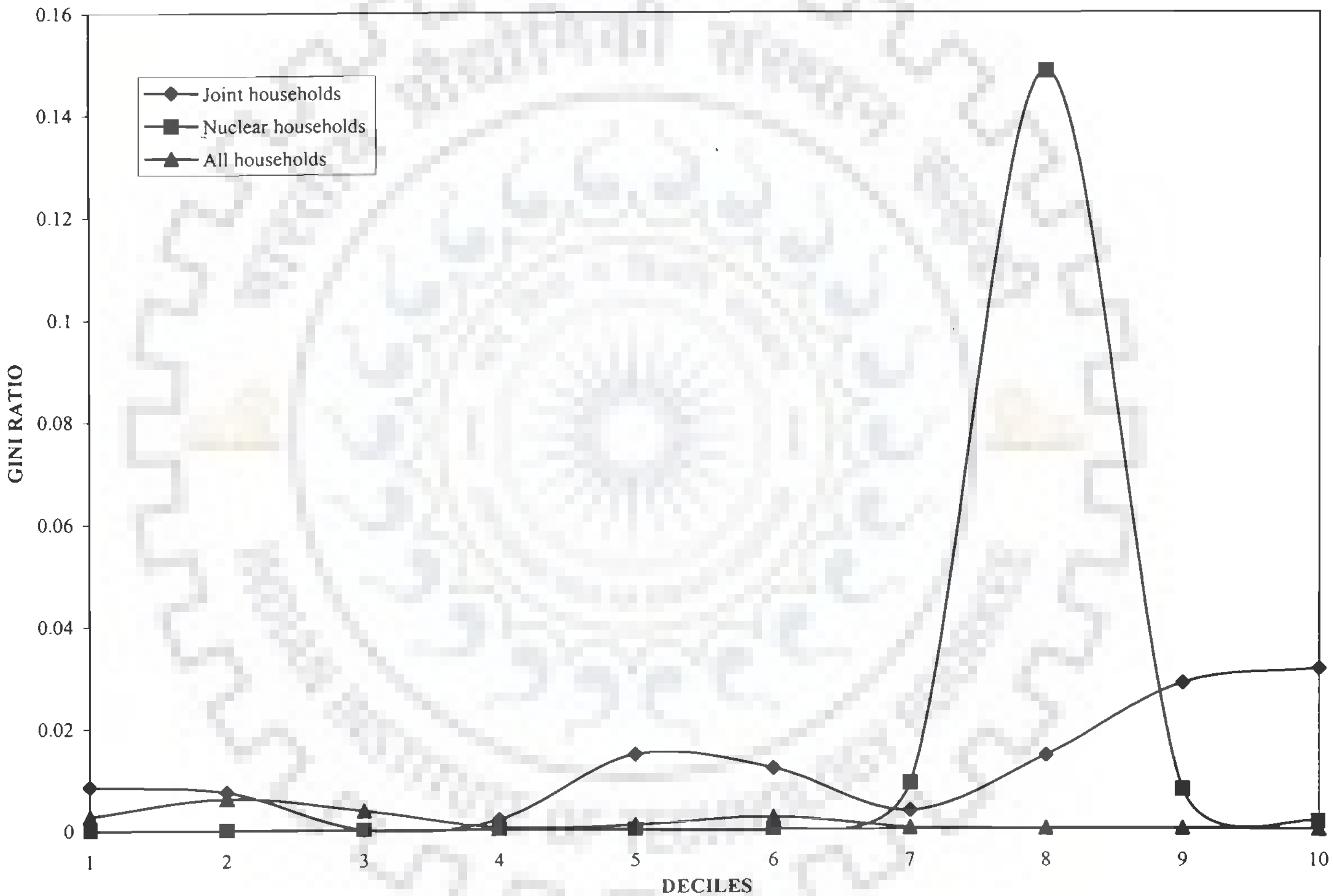

Figure 3.8 : Inequality in LPG consumption in households in terms of Gini Ratios

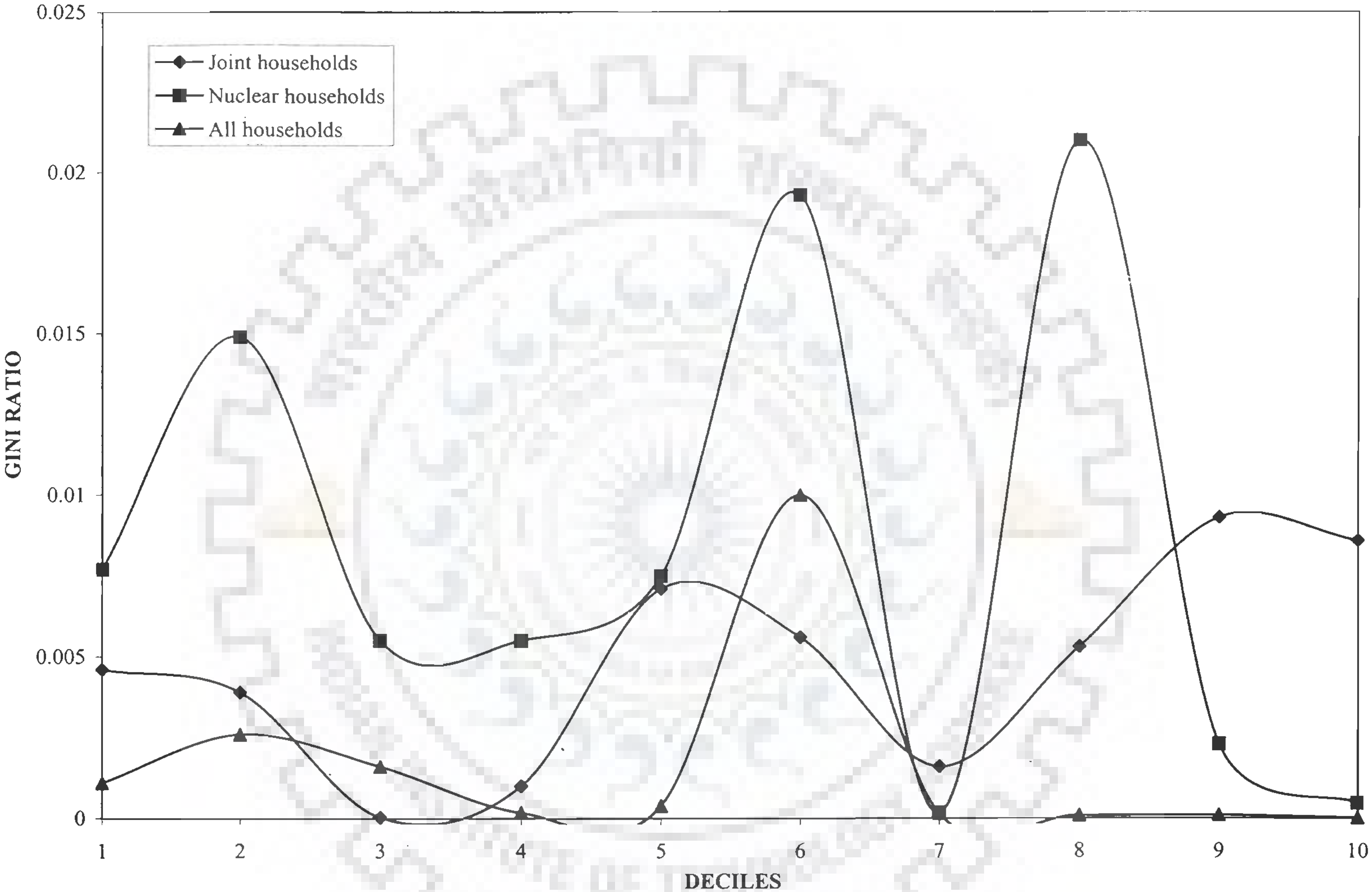

Figure 3.9 : Inequality in fuel wood consumption in households in terms of Gini Ratios

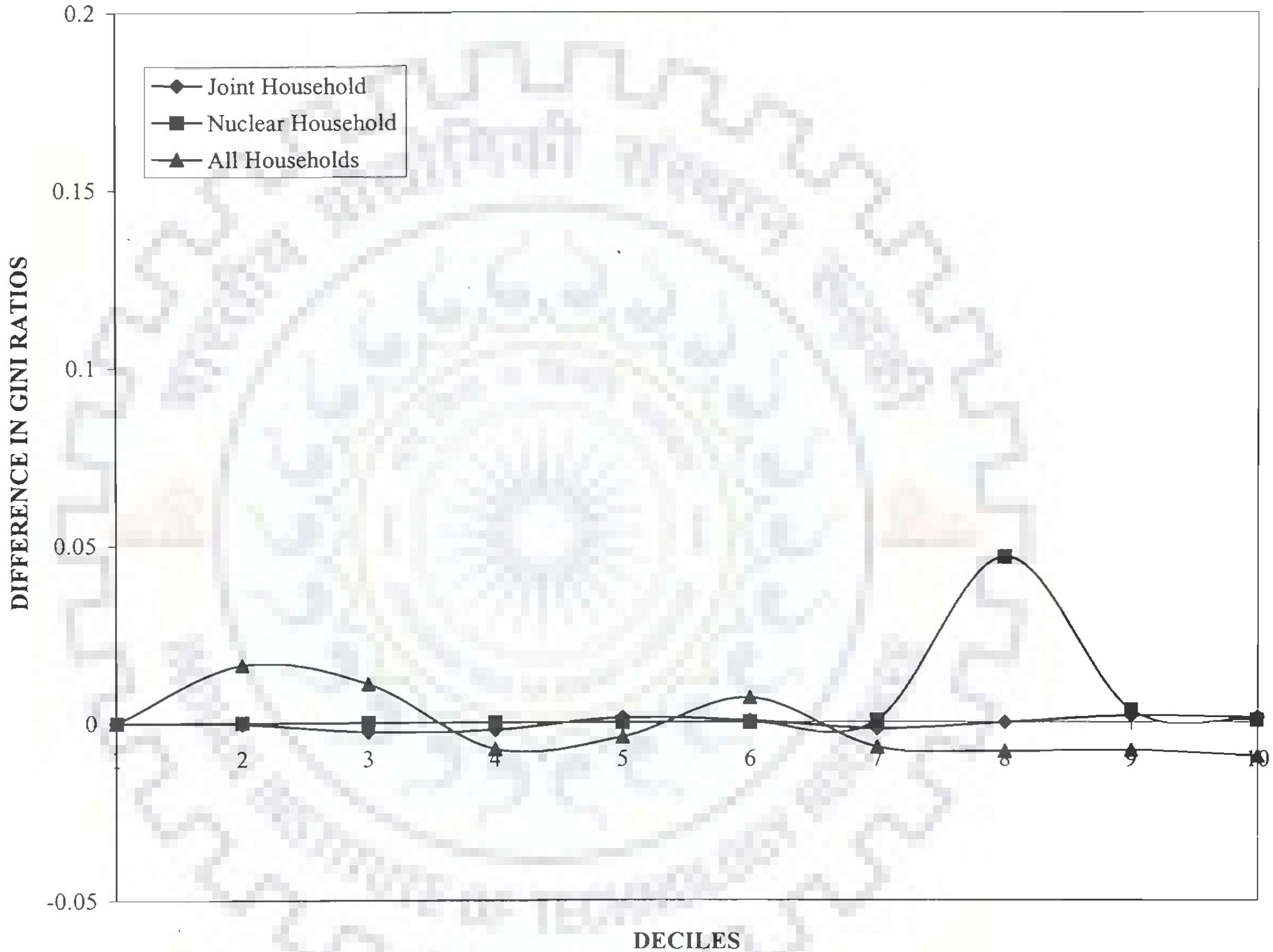

Fig.3.10 : Electricity consumption :Difference in Gini Ratios of deciles with respect to least measurable decile

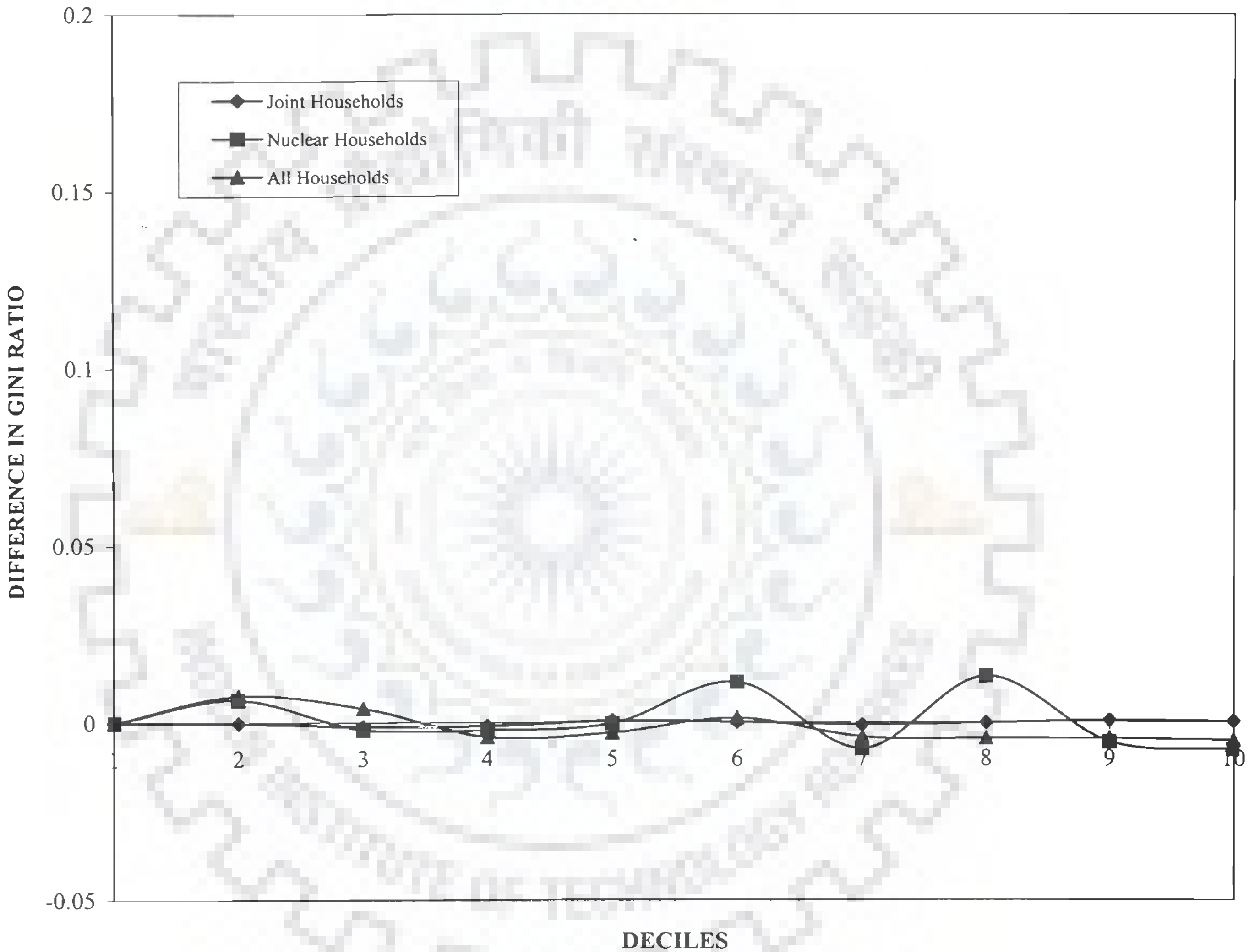

Fig.3.11 : Kerosene consumption :Difference in Gini Ratios of deciles with respect to least measurable decile

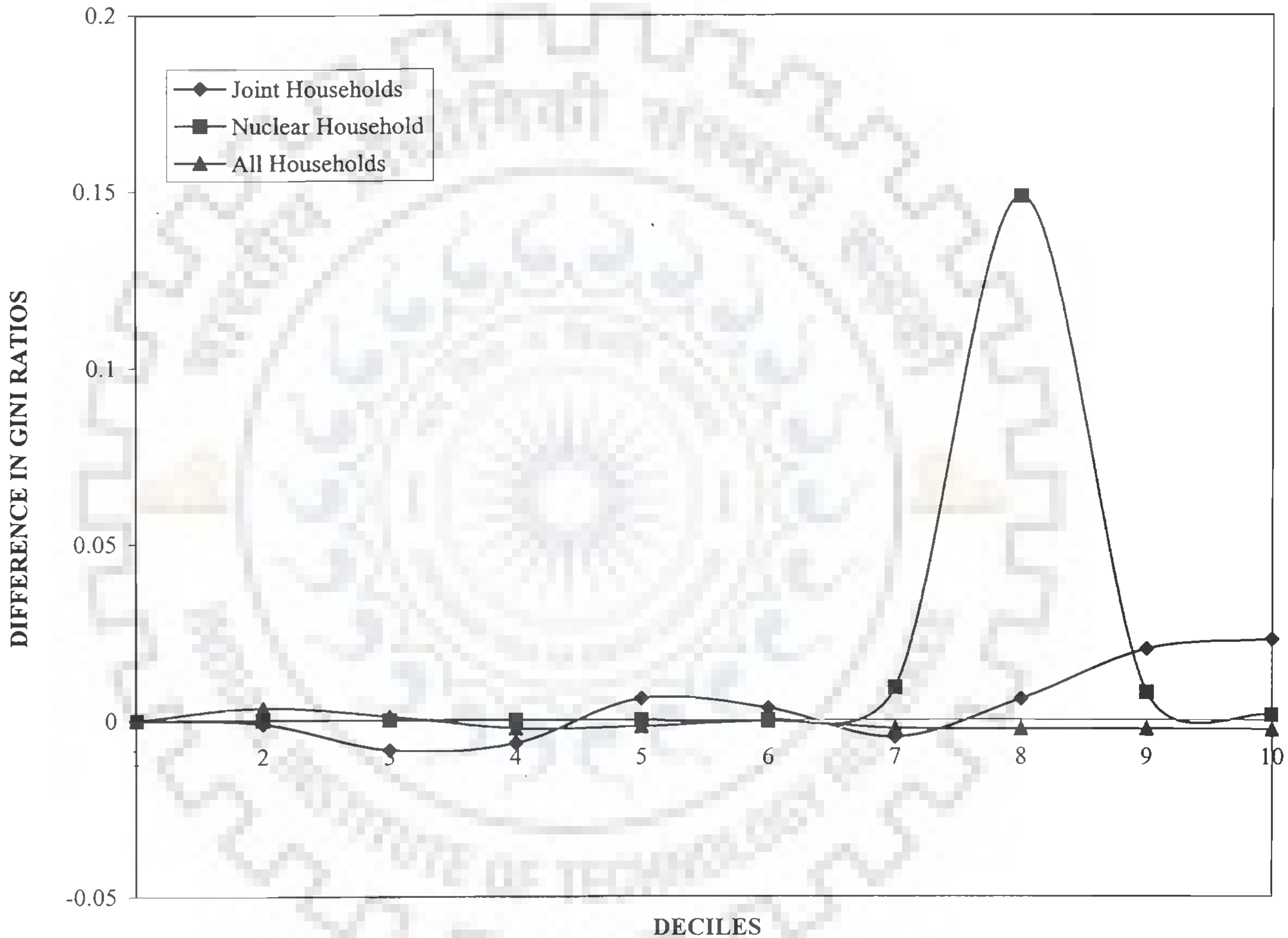

Fig.3.12 : LPG consumption :Difference in Gini Ratios of deciles with respect to least measurable decile

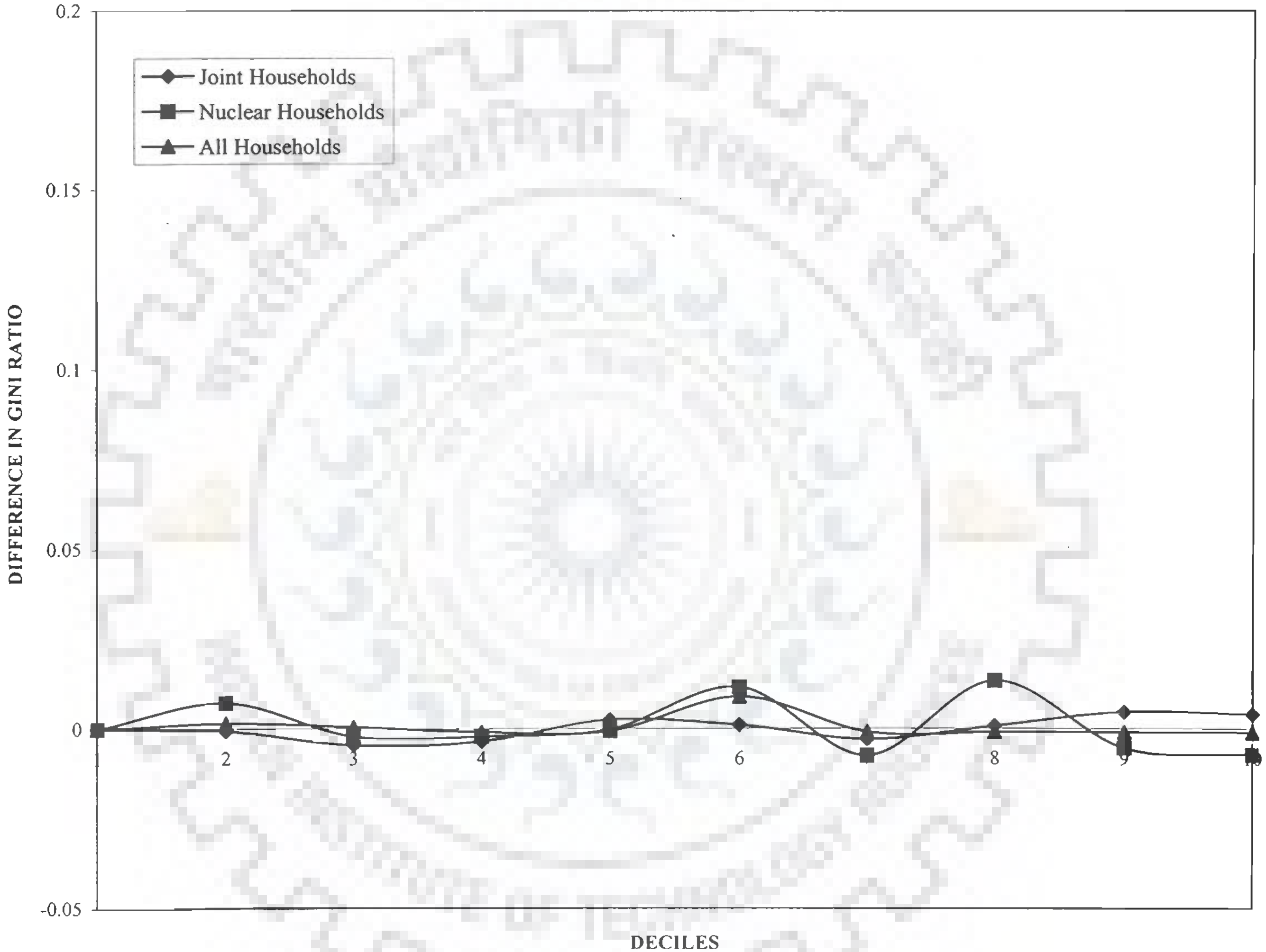

Fig.3.13 : Fuel wood consumption :Difference in Gini Ratios of deciles with respect to least measurable decile

(ii) Inequality in energy resource consumption for the different household categories using Lorenz curves and the *Gini* inequality index.

The study revealed that there are significant differences in the energy consumption habits of the three household categories. These results would therefore serve to highlight the importance of preliminary energy surveys and to the necessity of analyzing the energy consumption trends in the proposed area for rural development so as to provide feedback for more effective and beneficial rural energy planning policies.

CHAPTER–4

ENERGY PLANNING FOR KANVASHRAM

PART B : DESIGN OF A LINEAR PROGRAMMING ENERGY PLANNING MODEL

4.1 INTRODUCTION

Part A of the analysis under Chapter-3 showed that there exist differences in the energy consumption patterns of energy resources for different categories of the same rural population and, that the rural energy planner must make provision for this variance in consumption trends when allotting energy resource reserves for future needs. This is one way of planning for future energy needs i.e. analyzing the existing energy demand trends and extrapolating the energy demand for the future. However, the wastefulness of this type of planning exercise is felt sharply among developing nations that are constrained in terms of expenditure for fuel imports. Optimization based energy resource planning methods offer a better option for analysis. The energy consumption patterns as evaluated by the earlier part of the analysis can also be useful in proportionate distribution of the optimal energy resource allocations within the different categories of the rural population, as advocated by the optimization model used for energy planning. Accordingly, this part of the thesis deals with the design of an optimization based energy resource allocation model. The usefulness of optimization as an analysis tool for energy resource planning is discussed in the sequel.

4.2 OPTIONS FOR MODELLING OF RURAL ENERGY SYSTEMS

In the literature, several options are proposed for modeling of rural energy systems, and a wide range of mathematical tools or methodologies are available for designing suitable mathematical models for the same. In relation to the present study, the following are some of the possible methodologies, which can be used:

(i) Data based expert systems modeling

(ii) Regression based statistical estimation modeling

(iii) Causal –interactions based modeling

(iv) Modeling with uncertainty using fuzzy environment

(v) Optimization based modeling

Each of the above methods have their own merits and limitations, which are discussed subsequently. The choice of the particular methodology that needs to be applied for a specific type of energy related study will depend on the relative priority given to the following requirements:

(i) Versatility

(ii) Degree of complexity involved in model development

(iii) Solution time needed

(iv) Time needed to collect relevant data for model development

With high speed computers, the requirement for solution time is now not of much significance. Hence, the choice of the methodology to be adopted will depend on the relative importance attached by the planner to the other three requirements The main methods used are discussed briefly as follows:

(a) Data based Expert System Modeling

The most accurate modeling can be accomplished using an intensive data base prepared for the study area. Thus data base modeling would be the best choice. However, several difficulties arise while designing this kind of a model. These are:

(i) A large volume of data needs to be collected in order to prepare an accurate data base. This is laborious, time consuming as well as expensive.

(ii) Further, if time series data is involved, data collection would involve a long period of time, and, immediate planning needs cannot be satisfied in the absence of sufficient volume of data for satisfactory decision making. The collected data, if cross-sectional, cannot be used for predicting energy demand trends likely to arise in the future. At the most, the model can help in satisfactory decision making within the time frame / period during which the data is collected.

For prediction of the energy demand trends for the future, a time series data collection may be required, which, as pointed out, earlier may involve a long period in collection.

(b) Regression based Statistical Estimation Modeling

Regression based modeling makes use of historical data in discerning a trend that exists between exogenous variables and the endogenous variable. This type of modeling is well suited for estimating the demand of various resources that are to be planned for, assuming consistent trends. When time series data is used, the trends as applicable for the future can be used for demand computation. However, like expert system based models, when cross-sectional data is used, the trends are not valid for long term planning. At the most, the validity of the forecast can extend for a few years beyond the period at which the cross sectional data is collected. Regression methods help in understanding the natural course of energy trends within the population. They, however, do little to modify the existing trends in a manner that can lead to some positive gains to the economy. Further, the time and effort needed to collect time series data (and sometimes cross sectional data) make such methods unsuitable for immediate planning needs.

(c) **Causal Interactions based Modeling**

Modeling that involves causal inter linkages between sub systems of the overall system present the following difficulties:

(i) It is not easy to model certain inter linkages which are qualitative rather than quantitative in nature.

(ii) Since the system involves inter linkages, a change in the input/output of any given sub- system would result in a series of changes within all the other subsystems, leading to a difficulty in ascertaining the equilibrium state at which the final outputs would stabilize. It may even be possible, that convergence leading to the equilibrium state may not be obtained, particularly, in view of the stochastic nature of rural energy inputs, and the relative inaccuracy with which they are often collected.

(d) **Modeling with Uncertainty using Fuzzy Environments**

When quantification of variable presents difficulty, the use of linguistic variables is needed and the modeling is done in the *Fuzzy Environment*. The concept of Fuzzy Set Theory has been explored in certain reports, but in the absence of any standard interpretation of the results, the validity of the results becomes a matter of controversy, which needs to be avoided.

(e) **Optimization Based Modeling**

Modeling involving optimization methods, are perhaps the best compromise solutions for rural energy planning. These models have the following features:

(i) Require minimal data for preparing suitable energy policy for immediate planning needs.

(ii) Provide the rural energy planner with an economical goal, which steers the planning towards some definite objective.

However, the shortcomings of this type of modeling are that the solutions suggested with a view to realizing a given planning objective (usually cost minimization) may not always be welcomed by the rural population for whom the energy plan is being prepared. Further, to ensure that the objectives are being met, the policy needs to be implemented with the auxiliary support of other organizations/ NGO's. This can upset the economic viability of the budget for the energy plan proposal. Nevertheless, optimization continues to be a popular methodology for rural energy planning, and, as such, has been favoured for the present analysis. Even the Indian Government has in its wisdom used optimization as a tool for preparing energy models for the rural sector.

The most popular form of optimization is Linear Programming (LP). Other variations of Linear Programming such as: Mixed Integer Programming (MIP) and Goal Programming (GP) are also used.

Mixed Integer Programming is helpful when the solution to the optimization problem is desired in integral whole values. As such, there appears to be no reason why this variation of Linear Programming should be in any way superior to the conventional LP formulation. In the literature, researchers using MIP for rural energy planning have not clearly spelt out the reasons for their preference of this form of LP modeling.

Goal Programming is conceived with the intention of obtaining a "compromise" solution for a problem that involves several conflicting objectives. Here, the constraints can have some 'leeway" and are not "rigid" as in LP formulation. The main focus of GP, however, is on the simultaneous realization of different (conflicting) objectives. In the literature, studies using GP formulation for energy planning have listed several objectives. Nonetheless, a careful examination of these objectives reveals that most of them are mere shades of variation of the main objective, and, as such, are uncalled for. The "conflict" in objectives as observed in these studies does not appear to be a serious issue justifying the use of GP in preference to LP for rural energy planning.

Thus, MIP and GP formulations for rural energy planning optimization, do not offer any greater advantages in comparison to the LP formulation.

In summary, then, a cursory review of these methodologies suggests that it would be most appropriate to:

(i) Choose the optimization methodology for modeling of the energy needs.

(ii) Make use of the Linear Programming Methodology for modeling.

The present analysis, has, therefore made use of Linear Programming, for energy planning and modeling in the study area (Kanvashram village) as this appears to be the most appropriate optimization algorithm for modeling rural energy needs.

4.3 LINEAR PROGRAMMING AS AN EFFECTIVE TOOL FOR ENERGY PLANNING: AN OVERVIEW

Linear Programming (LP) had its beginning in the input-Output Analysis developed by the well known economist W.W. Leonteif. Hitchcock and Koopman's "*Transportation Type Problem*" studied during the 1940's and Stigler's *"Diet Problem"* developed in 1945 were the first type of problems to be solved using Linear Programming. The *Simplex* method which is now extensively used for LP solution was developed by George D. Dantzig in 1947. [Shenoy (1989)]

A Linear Programming problem differs from the general variety in that a mathematical model or description of the problem can be stated using relationships that are "Straight –Lined" or *Linear*. The term "Programming" is used to imply a certain set of mathematical techniques to arrive at the best solution.

Mathematically, such relationships are of the form:

$$a_1x_1+a_2x_2+a_3x_3+\dots\dots a_jx_j+\dots\dots a_nx_n= b_1$$

Where a_j's and b_1 are known coefficients and x_j's are unknown variables. The complete mathematical statement of a Linear Programming problem includes a set of simultaneous linear equations which represents the condition of the problem and a linear function that expresses the objective of the problem. The "condition" of the problem includes: the decision variables and their constraint values. The basic constituents and structure of the Linear Programming Problem is shown in Figure 4.1

The general linear programming model is to find a vector $x_1,x_2,\dots\dots x_n$ which optimizes (i.e. maximizes or minimizes) the objective function:

$$Z= c_1x_1+ c_2x_2+ c_3x_3+\dots\dots c_nx_n$$

Subject to:

$$a_{11}x_1+a_{12}x_2+a_{13}x_3+\dots\dots a_{1n}x_n\leq b_1$$

$$a_{21}+a_{22}x_2+a_{23}x_3+\dots\dots a_{2n}x_n\leq b_2$$

$$\dots\dots\dots\dots\dots\dots$$

$$a_{m1}x_1+a_{m2}x_2+a_{m3}x_3+\dots\dots a_{mn}x_n\leq b_m$$

and $x_j \geq 0$ for $j=1,2\dots\dots n$, a_{ij} , b_1 and c_j are given constraints and $m<n$

The linear programming problem may be represented in one or more of the following different forms, depending on the type of notation preferred:

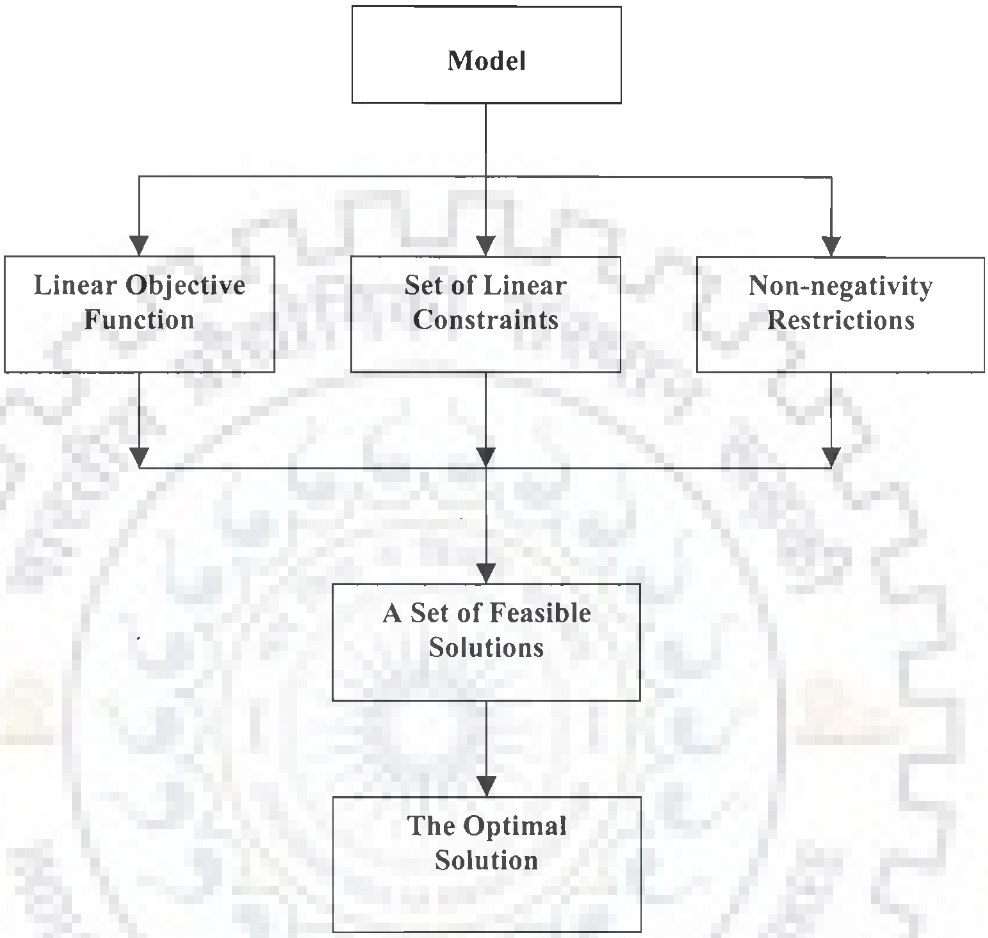

Figure 4.1 The Basic Structure of a Linear Programming Problem

(i) Maximize/Minimize $\sum_{j=1}^{n} Cjxj$

subject to:

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i, i = 1,2.........m$$

$$x_j \geq 0, j = 1,2....n$$

(ii) Maximize/Minimize: CX

subject to: $x_{i1}P_1 + x_2 P_2 + ...x_nP_n \leq P_0$

and $X \geq 0$

Where P_j (for $j=1,2,.....n$) is the j^{th} column of the matrix A and $P_0 = b$

(i) In some formulations, a new unrestricted variable e.g. x_0 is defined which is equal to the objective function value. The problem is stated as :

Maximize/Minimize x_0

subject to :

$$x_0 - \sum_{j=1}^{n} C_j x_j = 0$$

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i, i = 1,2....n$$

$$x_j \geq 0, j=1,2,......n$$

The solution of the LP problem consists in finding an initial solution of the associated set of linear equations. There are various criteria that must be tested to examine the problem for feasible solutions. From the infinite number of solutions that may arise in a given set of equations (feasible region), the problem narrows down to finding the solution that optimizes the objective function.

When two variables are involved, a graphical solution is possible. However, with three or more variables, the increased number of intersecting planes of the *n*-dimension space makes graphical solutions impractical. In such cases, it is the usual practice to apply the *Simplex* algorithm that has been developed by G.B. Dantzig. The *Simplex* Algorithm is explained as follows:

The first step is to convert the system of *m* linear inequalities into *m* linear equations using *slack variables*. Thus the set of inequalities given as:

$$a_{11}x_1+a_{12}x_2+a_{13}x_3+\ldots\ldots\ldots\ldots a_{1n}x_n\leq b_1$$

$$a_{21}+a_{22}x_2+a_{23}x_3+\ldots\ldots\ldots\ldots a_{2n}x_n\leq b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4.1)$$

$$a_{m1}x_1+a_{m2}x_2+a_{m3}x_3+\ldots\ldots\ldots\ldots a_{mn}x_n\leq b_m$$

is converted into equations with the help of *slack variables* $x_{n+1},x_{n+2},\ldots\ldots x_{n+m}$ and the new set of equations are:

$$a_{11}x_1+a_{12}x_2+a_{13}x_3+\ldots\ldots\ldots\ldots a_{1n}x_n+x_{n+1} = b_1$$

$$a_{21}+a_{22}x_2+a_{23}x_3+\ldots\ldots\ldots\ldots a_{2n}x_n+x_{n+2} = b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4.2)$$

$$a_{m1}x_1+a_{m2}x_2+a_{m3}x_3+\ldots\ldots\ldots\ldots a_{mn}x_n+x_{n+3} = b_m$$

The LP problem may now be restated as :

Find among all sets of points $(x1,x2,\ldots\ldots x\,(n+m))$ that satisfy Eq. 4.2 with x_j non -negative, that point $(x1',x2'\ldots\ldots x(n+m)')$ which optimizes the objective function:

$$Z= c_1x_1+ c_2x_2+ c_3x_3+\ldots\ldots\ldots\ldots c_nx_{n+m} \qquad \text{------} \ (4.3)$$

The *slack variables* are merely devices that aid in the arrival of the optimal solution and may or may not have actual physical significance in relation to specific optimization problems.

The key theorem that underlines the *Simplex* algorithm is that the set ($x1, x2, \ldots\ldots\ldots x(n+m)$) that optimizes Eq. 4.3 subject to Eq. 4.2 must necessarily possess n elements which are non-zero. The solution becomes simple when the coordinates that are zero at the optimum solution are known. These, when substituted in Eq. 4.2 will yield as set of m equations in m unknowns that can be solved algebraically to yield the optimal solution. However, in the absence of this knowledge, a step-by-step algorithm is required to arrive at the solution. The steps that go into the solution are explained as follows:

Step 1: Choose n of the $n+m$ co-ordinates , assign them zero values and solve that rest of the equations for the remaining m co-ordinates. Discard solutions in which any of the co-ordinate have negative values. Retry with a new set of n co-ordinates for the zero variables. If none of the co-ordinates is zero for a particular solution, then an *initial feasible solution* has been obtained, which is the starting point of the iterative process that follows.

Step 2: A *Simplex* tableau is prepared in which the C_j column contains the coefficients of the respective variables in the objective function. Elements in the Z_j row are the contributions "lost" per unit of the variables. Optimality of all $C_j - Z_j \leq 0$ values is tested. If the solution is optimal, the problem is solved; if not, further manipulations are needed.

Step 3: The column with the highest positive value i.e. the largest $(C_j - Z_j)$ value is selected, and, the b_j coefficients are divided by the corresponding positive coefficients of x_j i.e. the entering variable.

Step 4: The smallest quotient is selected as the departing variable (intersectional element is pivotal).

Step 5: The elements of the matrix and $C_j - Z_j$ are recalculated, optimality of $C_j - Z_j \leq 0$ is tested and the solution is said to have been obtained when these conditions are satisfied. The iterative process is continued until the solution emerges.

The steps that are involved in the *Simplex* algorithm are additionally presented in the flow chart of figure 4.2.

4.4 CHOICE OF END USE APPLICATIONS FOR MODELING

The following are the basic energy needs of a typical rural Indian village:

(i) Cooking energy needs

(ii) Lighting energy needs

(iii) Space heating/cooling and water boiling energy needs

(iv) Rural transportation

(v) Agricultural/ Irrigation energy needs

(vi) Energy for operating local industries

In the study area (*Kanvashram* village), the following energy needs were not found to be extremely necessary from the energy planning perspective. These are:

(i) Agricultural/irrigation energy needs

(ii) Rural transportation

(iii) Energy for local industries

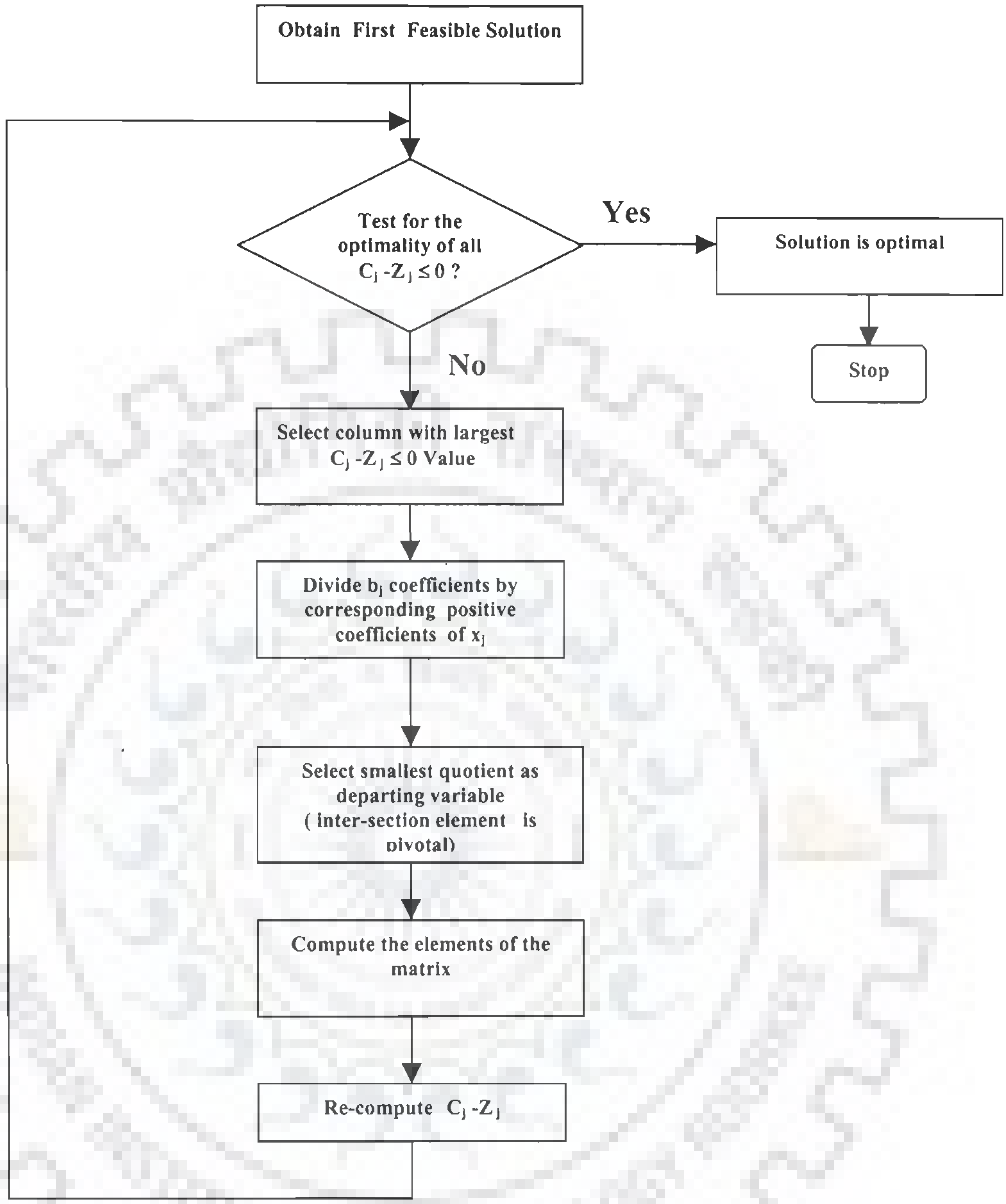

Figure 4.2: Flow Chart of the Simplex Algorithm (Shenoy 1989)

Agricultural energy for tilling (using tractors) and transportation require diesel fuel that is obtained from inputs external to the village. Thus, since internal village inputs are not involved, we have excluded these energy needs in planning for the energy resource allocation in the village. Similarly, irrigation energy needs are not required since canal flow irrigation is applicable for cultivation in the entire village. Energy needs for local industries are presently negligible in comparison to other more important energy needs, and, have hence, also been ignored in the energy modeling for the village. This has be done assuming that in the near future, the greater emphasis for economic development, would continue to concentrate on tourism rather than on industrialization.

Thus the Energy planning model for *Kanvashram* has been designed for the following energy needs:

- Cooking energy (including water boiling)energy needs
- Lighting energy needs
- Space heating/cooling energy needs

4.5 RESOURCES FOR ENERGY PLANNING IN KANVASHRAM

A workable energy plan for a given rural area must consider all those energy resources that are either in current use, or else available but not yet tried. The energy plan intends to obtain an appropriate mix of all possible resources so as to satisfy the major energy needs of the rural population. This is done with respect to the satisfaction of some specific objective, which, is generally the cost of supplying energy. Energy resources that are in use or which are locally available (despite not being tried) can be classified into three categories viz.

(a) Traditional Energy Resources

(b) Modern Energy Resources

(c) Renewable/Non-conventional Energy Resources

The classification of various energy resources available in *Kanvashram* is given in table 4.1. A detailed description of the existing use, availability and potential of each of these energy resources is provided in the subsequent sub sections.

Table 4.1: Classification of energy resources available in *Kanvashram*

S.No.	End –Use Application	Traditional Energy Resources	Modern Energy Resources	Renewable/Non-conventional Energy Resources
1.	Cooking	Fuel wood Agro Waste Animal Dung	Electricity(Grid) LPG Kerosene	Electricity(small hydro) Electricity (biomass gasifier) Biogas
2.	Lighting	Kerosene	Electricity (Grid) LPG	Solar Thermal Energy (solar cooker/solar water heater)
3.	Space -Heating	Fuel wood Agro Waste	Electricity (Grid)	Electricity (small hydro) Electricity (biomass gasifier) Solar PV Energy System Biogas Electricity (small hydro) Electricity (biomass gasifier)

Source: Primary survey data

4.5.1 Solar Energy

The extra-terrestrial radiation and the day length for each month in *Kanvashram* have been reported in other studies. [Bharadwaj (1999)] These are reproduced in table 4.2. Presently solar energy technology is not being used in the village. However, the abundant annual availability of solar energy suggests a possibility of profitably harnessing this energy resource for certain end uses (like lighting, cooking and water heating needs). Solar energy can be applied for meeting energy needs under two routes viz.

(a) Solar Electric (Photovoltaic)Route

(b) Solar Thermal Route

Table 4.2: Daily global solar radiation for different months in *Kanvashram*

S.No.	Month	Total Daily global Solar Radiation (kWh/m^2)
1.	January	4.15
2.	February	5.19
3.	March	6.34
4.	April	7.13
5.	May	7.51
6.	June	6.76
7.	July	5.66
8.	August	5.45
9.	September	6.07
10.	October	5.50
11.	November	4.6
12.	December	4.02

Source: Bharadwaj(1999)

Sufficient scope exists for both types of routes in the village domestic and street lighting needs can be met using solar photovoltaic systems while the cooking /water heating applications can be partially met with solar cookers and solar water heating systems. The use of solar cookers is suitable for preparing meals that require slow heating.

The use of such systems need to be advocated in the village to reduce the drudgery of the task of fuel wood cutting/collection that is generally practised in most households, particular those in the lower income groups.

Solar water heating systems are also useful for small cottage industries and dispensaries where warm water may be required for certain operations. The relatively high potential of solar energy in the village offers scope for the promotion of solar energy systems for meeting a portion of the total energy needs of the population.

4.5.2 Wind Energy

Wind energy is a viable and economical energy alternative that has immense scope in area having high wind densities. Wind energy can be used fôr any one or more of the following purposes:

(i) Electric power generation for rural areas.

(ii) Battery charging for solar/diesel/wind energy using battery back ups.

(iii) Motive power for water lift pump operation/ grinding of grain etc.

The wind potential in *Kanvashram* is not of sufficient magnitude to justify its use for meeting any energy need. Bharadwaj (1999) reports that the maximum wind velocity is 6.0 Kmph which is not usable for any energy based application. Accordingly, wind energy is not considered as one of the energy resources for meeting energy needs in *Kanvashram*.

4.5.3 Biomass Energy

Rural energy scenarios in India are characterized by a large dependence on biomass fuels, which are predominantly gathered as against purchased. The penetration of commercial fuels like Liquefied Petroleum Gas (LPG) and kerosene is relatively poor, particularly in remote villages. The *National Council for Applied Economic Research, India* (NCAER) reports that over 90% of the energy needs of the rural domestic sector in India is met by bio fuels like:

(i) Fuel wood (56%)

(ii) Crop residues/Agro wastes (16%)

(iii) Animal dung (21%)

Thus biomass fuels account for about 93% of the total energy resources used in the Indian village for cooking. Biomass fuels in Indian rural areas include:

(i) Agricultural waste like: rice husk, rice straw, bagasse, coconut shells, jute, coffee husk, etc.

(ii) Forest/ industry waste like: saw dust, twigs, barks.

(iii) Animal wastes like: cattle dung, human excreta, slaughter house waste.

(iv) Industrial wastes like: effluents from sugar industries, distilleries.

(v) Natural vegetation weeds like: aquatic weeds, wild plants, shrubs etc.

In Kanvashram, the study area, the biomass resources are limited to the following:

(i) Agricultural residues of crops

(ii) Cattle dung

Two types of renewable energy technologies can be used in relation to these resources, viz. Biogas technology and Biomass gasifier technology.

Agro waste used as a fuel for direct combustion is not popular on account of its low calorific value and high smoke pollution content. It may however, be more efficiently used as a briquette material for biomass gasification based power generation. Presently, there is no scope for this technology in the study area. None the less, the increasing popularity of biomass gasifiers in the Indian context, and the abundance of agro waste as an energy resource in the study area, would make the implementation of such technology profitable in terms of energy generation. The study area boundaries do not permit an increase in the cultivable area, and, there appears little scope of the increase in the supply of agro waste in the coming years.

The Biogas technology requires cattle dung input for biogas generation, while the Biomass gasifier technology needs agricultural/wood residues. Since forest conservation is the need of the hour, it would be preferable to use agro residues as input fuel for power generation Biogas technology is most effective from the utilization perspectives of the dung input. The slurry that remains after biogas generation is as effective an organic manure as the raw animal dung itself. Thus dual benefits are obtainable when this technology is adopted instead of a single benefits as a consequence of direct combustion of animal dung, or, the direct use as an organic fertilizer in crop cultivation. Moreover, biogas is a clean fuel that has negligible environmental pollution effects (unlike that due to the direct combustion of animal dung cakes), and as such, offers better health benefits to the rural population.

The potential for biogas and biomass gasification in *Kanvashram* in terms of input feedstock is reviewed in tables 4.3 and 4.4 respectively.

Table 4.3: Cattle dung availability and estimated energy potential

S. No.	Type of cattle	Total collected dung (tonnes/day)	Total gas yield/day (m^3/day)	Total estimated energy/day (kWh/day)
1.	Cows	4.35	156.49	227.49
2.	Buffaloes	1.34	48.38	70.34
3.	Calves	1.05	37.93	55.13
	Total	**6.74**	**242.80**	**352.96**

Source: Bharadwaj(1999)

Table 4.4: Potential for biomass gasifier based power generation in *Kanvashram*

S.No.	Crop	Annual yield (tonnes)	Available residue for energy generation (tonnes)	Equivalent energy generated (kWh)
1.	Wheat	913.74	63.20	63200
2.	Mustard	60.29	1.09	1090
3.	Pulses(*Masur*)	41.14	3.84	3840
4.	Vegetables	0.861	0.16	160
5.	Rice	844.33	45.59	45590
6.	Soyabean	77.84	4.11	4110
7.	Pulses(*Urd*)	17.21	1.68	1680
8.	Maize	35.18	1.67	1670
9.	*Mandua*	11.92	0.62	620
				Total=121,960 kWh

Source: Bharadwaj(1999)

The two tables indicate that a total annual potential of 128,830.4 kWh exists in relation to biogas energy based power generation and 121960 kWh for biomass energy based power generation. This implies that a sufficiently large percentage of the energy needs of *Kanvashram* village can be met using biomass and biogas technology.

Biogas can be used for cooking, lighting and generating electrical power. However, if other options are available for electric power generation then biogas should be used solely for meeting cooking and to some extent lighting needs of the rural households.

Biogas technology in *Kanvashram* is adopted by some of the households in the upper income group. Family sized units are popular. Community based biogas plants, however, have definitely better overall economics, but the success of such schemes is probably doubtful on account of caste distinctions in the village that frown upon people of different communities sharing common cooking kitchens or similar facilities.

The use of biogas energy should therefore be promoted on a household basis with assistance particularly being given to households having sufficient cattle to provide the needed dung input as feedstock.

4.5.4 Energy from Small Hydro Schemes

Small Hydro Plants (SHP) are attractive options for tapping useful electrical energy in areas having free water flow in the form of canal, streams or rivulets.

The *Central Electricity Authority of India* (*CEA*) has classified SHP's into three categories based on the capacity of the scheme. These are:

(i) Micro hydro plants ($\leq$ 100 kW capacity)

(ii) Mini hydro plants (101 kW to 2000 kW capacity)

(iii) Small hydro plants (2001 kW to 15,000 kW capacity)

These plants may have water heads ranging from as low as 1.5 meters to as high as 400 meters, and, the corresponding power generation can range from 5-5000 KW. Standard water turbine suitable for the head at the site are used in conjunction with induction/synchronous generators. The choice of the generator depends on the relative economics involved. Electronic load governors are employed with simple monitoring and control equipment. The hydro potential at *Kanvashram* was estimated by a detailed study carried out by the Alternate Hydro Energy Centre (AHEC), at the Indian Institute of Technology, (IIT) Roorkee at *Roorkee*, in the state of *Uttaranchal*. The detailed project report prepared for the purpose indicates two suitable sites, each with an estimated potential of 50 KW. Details of these sites are given in Table 4.5. Like biomass gasifier technology, Small Hydro Plants (SHP) technology has not been exploited in the study area. However, the efforts of the *Alternate Hydro Energy Centre (AHEC)* at IIT, Roorkee, *Roorkee* have shown that a potential of 100 kW of electrical power exists at strategic locations due to the flow of the Malin river as it emerges from the Shivalik foothills. The *AHEC* has also made attempts to set up micro hydel power stations that can provide a potential supply of 100 kW to the local population. The projects are presently under implementation and are likely to be commissioned in the near future.

Table 4.5: Site details of micro hydel schemes proposed for *Kanvashram*

S.No.	Feature	Site 1	Site 2
1.	Net Head	7.83 m	12.8 m
2.	Discharge	$0.97 m^3/sec$	$0.51 m^3/sec$
3.	Capacity	50 kW	50kW

Source: Detailed Project Report for Kanvashram Micro Hydel Electric Project, AHEC, IIT Roorkee, Roorkee (1997)

Assuming that the projects would soon be operative, the study area would receive an additional input of electrical energy to the tune of 100 kW. Thus a total small hydro potential of 100 kW would be available at *Kanvashram*, which can be used for meeting a portion of the total electrical energy needs of the village.

4.5.5 Other Existing Energy Resources in Kanvashram

The other energy resources used by the rural population of Kanvashram include:

(i) Grid electricity

(ii) Fuel wood

(iii) Kerosene

(iv) Diesel

Grid electricity is available for lighting loads and for some small industries requiring motive power (using electric drives). The supply in *Kanvashram* is not available on a regular basis. Rather, the supply is erratic and unreliable.

Fuel wood is used in larger quantities by the lower income households for cooking needs and space heating needs. It is also used by the upper income households as a fuel for routine heating processes and for space heating in the cold months. The resource is purchased as well as collected in the village, the choice depending upon the economic status of the concerned household.

Kerosene is available on a rationed basis within the village. This fuel is used for lighting needs in unelectrified households. It is also used as a back up/standby fuel in electrified households, since the electric supply in the region is erratic involving frequent power cuts.

Diesel fuel is needed by the farmers for tractors used in farm operations. Diesel is also used to some extent for local transportation by buses/taxis that ply from the village to nearby *Kotdwar* Town. As these end uses are not considered in the model, diesel has not been taken up as an energy fuel variable in the present model formulation.

The direct use of animal dung and agro-waste as a fuel is not generally observed in the village. These resources are probably used by a very small percentage of the population, particularly those in the lower most economic strata.

4.5.6 New Energy Resources

Solar energy utilization is of recent origin and has of late been given impetus by the *MNES* in an attempt to reduce the dependence on commercial fuels for electric power generation, and at the same time provide a clean, freely available option of electrical power generation. In the study area, solar energy has as yet not been tried. However, as the solar energy potential in the study area is appreciable, it appears to be practical to harness solar energy profitably for local power generation and meeting a part of the electrical needs, especially for lighting applications in the homes. Solar energy in its thermal form can also be used for meeting low grade heat applications.

In the present analysis, the upper bounds of the supply constraint for solar energy has been estimated by assuming that each household of the study area allocates a space of 2 m^2 for installation of solar devices of various types (solar PV/solar water heaters/ solar cookers). The cumulative area of installation when multiplied by the minimum solar insolation in the year would provide the safe supply upper limit that can be used for designing the energy plan (despite the fact that the estimate would be pessimistic).

4.6 RESOURCE-DEVICE PAIRS FOR MODELING ENERGY RESOURCE ALLOCATION

A variety of resource-device combinations can be used for meeting different energy needs of the population. The three major energy needs identified for *Kanvashram* were: cooking, lighting and space heating energy needs. A flexible energy plan must provide for future energy growth. It is expected that in the near future, *Kanvashram* will develop with adequate infrastructure. Communicational links/ entertainment and education-information technology, which is virtually non existent at present, will then assume greater importance. However, a fourth energy end use is not to be introduced in the proposed energy model, as the additional increase in electrical energy requirement can well be accommodated as an apparent rise in the domestic lighting load demand.

Accordingly, based on the observed energy resource consumption patterns and potential for new energy resources/devices, lists have been prepared that gives a comprehensive choice of all the various options available in relation to the major energy needs in *Kanvashram.*

Tables 4.6-4.8 show the different resource-device options available in relation to the three major energy needs in *Kanvashram*. The energy planning model can use these different energy conversion options to optimize energy supply costs in regard to the different energy resource options available in the village for different end uses. An integrated model incorporating the requirements of all end uses can thus be designed.

Table: 4.6: Resource – device combinations for cooking/water heating needs

S. No.	Resource-device combination
1.	Fuel wood(collected)+ Traditional stove
2.	Fuel wood(collected)+Improved stove
3.	Fuel wood(market)+Traditional stove
4.	Fuel wood (market)+Improved stove
5.	Agro residue+ Traditional stove
6.	Agro residue + Improved stove
7.	Animal dung + Traditional stove
8.	Animal dung+ Improved stove
9.	Kerosene(rationed) +Wick stove
10.	Kerosene(rationed)+Pressure stove
11.	Kerosene(open market)+Wick stove
12.	Kerosene (open market)+ Pressure stove
13.	LPG +Cylinder –stove(combined)
14.	LPG + Cylinder & separate stove
15.	Electricity (grid)+ Heater(1000W)
16.	Electricity (SHP) + Heater (1000W)
17.	Electricity (Biomass gasifier)+ Heater(1000W)
18.	Solar energy + Solar cooker(box type)
19.	Solar energy +Solar cooker (concentrator type)
20.	Biogas (3 m^3 plant)+ biogas stove
21.	Biogas (4 m^3 plant)+ biogas stove
22.	Biogas (8 m^3 plant)+ biogas stove
23.	Solar energy + Solar water heater

Table: 4.7: Resource – device combinations for lighting needs

S. No.	Resource-device combination
1.	Kerosene(rationed) +*Diya* lamp
2.	Kerosene(rationed)+*Noorie* lamp
3.	Kerosene(rationed)+*Petromax* lamp
4.	Kerosene(rationed)+Lantern lamp
5.	Kerosene(open market)+*Diya* lamp
6.	Kerosene(open market)+*Noorie* lamp
7.	Kerosene(open market)+*Petromax* lamp
8.	Kerosene(open market)+Lantern lamp
9.	LPG + LPG lantern
10.	Electricity (grid)+ Bulb lamp(40W)
11.	Electricity (SHP) + Bulb lamp(40W)
12.	Electricity (Biomass gasifier)+ Bulb lamp(40W)
13.	Electricity (grid)+ Bulb lamp(60W)
14.	Electricity (SHP) + Bulb lamp(60W)
15.	Electricity (Biomass gasifier)+ Bulb lamp(60W)
16.	Electricity (grid)+ Bulb lamp(100W)
17.	Electricity (SHP) + Bulb lamp(100W)
18.	Electricity (Biomass gasifier)+ Bulb lamp(100W)
19.	Electricity (grid)+ Florescent lamp(40W)
20.	Electricity (SHP) +Florescent lamp(40W)
21.	Electricity (Biomass gasifier)+ Florescent lamp(40W)
22.	Biogas (3 m^3 plant)+ Biogas mantle lamp

S. No.	Resource-device combination
23.	Biogas (4 m^3 plant)+ Biogas mantle lamp
24.	Biogas (8 m^3 plant)+ Biogas mantle lamp
25.	Solar energy + Solar PV system + Elect bulb(40W)
26.	Solar energy + Solar PV system + Elect bulb(60W)
27.	Solar energy + Solar PV system + Elect bulb(100W)
28.	Solar energy + Solar PV system + Florescent lamp(40W)
29.	Solar energy + Solar lantern (9W)
30.	Solar energy + Solar lantern (11W)
31.	Solar energy + Solar lantern (23W)

Table: 4.8: Resource – device combinations for space heating needs

S. No.	Resource-device combination
1.	Fuel wood + Traditional hearth/stove
2.	Fuel wood + Improved hearth/stove
3.	Agro waste + Traditional hearth/stove
4.	Agro waste + Improved hearth/stove
5.	Animal dung + Traditional hearth/stove
6.	Animal dung + Improved hearth/stove
7.	Electricity (grid)+ Heater(1000W)
8.	Electricity (SHP) + Heater (1000W)
9.	Electricity (Biomass gasifier)+ Heater(1000W)
10.	Electricity (grid)+ Heater(1500W)
11.	Electricity (SHP) + Heater (1500W)
12.	Electricity (Biomass gasifier)+ Heater(1500W)

4.7 THE DEMAND CONSTRAINTS

The computation of the total energy demand for all the energy resources has been done on the basis of the primary survey data. At present, the existing energy demand has been obtained in terms of the consumption of four types of energy resources, that are widely in use in the village. These are:

(i) Electricity

(ii) Kerosene

(iii) LPG

(iv) Fuel wood

The total kWh of energy due to the consumption of these resources would serve as the minimum demand constraint for the proposed optimization models.

Table 4.9 shows the total annual demand for each of the resources as computed from the primary survey data.

Table 4.9: Annual energy demand for *Kanvashram* in relation to energy resources and end uses

S. No.	End use	Electricity demand (kWh)	Kerosene demand (kWh)	LPG demand (kWh)	Fuel wood demand (kWh)	Total annual demand for end use (kWh)
1.	Cooking	27,682.39	24,954.54	292,271.62	1293,437.40	1638,346.00
2.	Lighting	138,411.96	25,2318.13	59,862.86	0.00	450,592.95
3.	Space Heating	13,841.20	0.00	0.00	258,299.00	272140.20
	Total	**179,935.55**	**277,272.67**	**352,134.48**	**1551,736.40**	**2361,079.15**

Source: Primary Survey Data

The total annual demand of 2361.079 MWh can be assumed to satisfy the major end uses i.e. cooking, lighting and space heating. It was pointed out earlier that the other energy end uses in *Kanvashram* are insignificant in relation to these three and may be ignored. Details pertaining to the actual percentage consumption of each of the resources for the different end uses were procured indirectly in the survey in terms of the time of usage of energy devices(hours) and the specific fuel consumption rate of the device used. (see questionnaire/schedule in *Appendix A*)

4.8 THE SUPPLY CONSTRAINTS

The supply constraints have been computed for the study area on the basis of the following considerations:

(i) Actual annual quantity of resource available in the area.

(ii) The collection efficiency.

(iii) The total number of hour of use of resource-device.

(iv) The per capita consumption pattern of the population for each resource application.

(v) The minimum energy consumption needed for the use of a particular resource device system.

(vi) Approximations in estimation of data when it is uncertain.

The existence of upper bounds in the supply constraints is evident. However, in certain cases lower bounds also need to be enforced, particularly in the case of use of certain resource-device systems where, a minimum level of consumption is necessary for breakeven in recovery costs of the total investment. Appropriate values of lower bounds have been chosen as a working basis for the computations.

Table 4.10 shows the upper and lower bounds (annual) for different resource-device combinations (used in relation to various end uses) that have been computed for the present optimization exercise in relation to the major energy end uses of cooking, lighting and space heating. The respective energy device efficiencies for the energy conversion process have been considered in determining the supply constraint bounds. The different units of the concerned energy resources (i.e Kg/Litre/etc.) have all been expressed in terms of kWh for the sake of uniformity in representation of the energy constraint limits. The conversion has been done using relevant conversion formulae.[Kishore (1988)].

4.9 THE OBJECTIVE FUNCTION

The objective function chosen for the present optimization models is the minimization of the total cost of operation of the system for meeting the required energy needs. The actual cost of operating the system on an annual basis depends on the optimal resource allocation in relation to the current per unit prices of different energy resources as given in *Appendix C*.

4.10 THE FINAL MODEL

Based on the final selection of the variables, an integrated model has been constructed for major end uses i.e. cooking, lighting and space heating.

The model can be formulated as:

Minimize : $$C_T = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}X_{ij}$$

Subject to: $$\sum_{i=1}^{n} X_{ij} = D_j$$

Table 4.10 : Lower and upper bounds of constraints for optimization models

S. No.	Energy resource	End use	Lower bound (kWh/annum)	Upper bound (kWh/annum)
1.	Electricity	Cooking	10,449.58	41,438.35
2.	Electricity	Lighting	51,797.84	207,191.40
3.	Electricity	Space Heating	8,879.65	35,518.59
4.	Kerosene	Cooking	5,570.53	24,510.34
5.	Kerosene	Lighting	61,894.80	247,826.80
6.	Kerosene	Space Heating	-----	-----
7.	LPG	Cooking	209,457.90	837,831.40
8.	LPG	Lighting	41,891.57	167,566.30
9.	LPG	Space Heating	-----	-----
10.	Animal Dung(Biogas feed)	Cooking	6374,407.00	1159,764.00
11.	Animal Dung(Biogas feed)	Lighting	128,862.70	515,450.00
12.	Animal Dung(Biogas feed)	Space Heating	-----	-----
13.	Agro Waste	Cooking	0.00	18,964.58
14	Agrowaste	Lighting	-----	-----
15.	Agrowaste	Space Heating	0.00	5,427.22
16.	Fuel wood	Cooking	87,125.15	999,268.1
17.	Fuel wood	Lighting	----	-----
18.	Fuel wood	Space Heating	24,932.90	285,964.10
19.	Solar Energy	Cooking	0.00	466,448.40
20.	Solar Energy	Lighting	494.10	1,976.40
21.	Solar Energy	Space Heating	----	----

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij}/\eta_{ij} \le S_{ij}$$

$$X_{ij} \ge 0$$

Where: C_T = Total cost of providing energy for all end uses

$C_{ij)}$=Cost/unit of the i^{th} resource option for j^{th} end use[Rs/kWh]

X_{ij}=Optimal amount of i^{th} resource option for j^{th} end use[kWh]

D_j = Total energy for j^{th} end use[kWh]

S_{ij} = Availability of i^{th} resource option for j^{th} end use[kWh]

η_{ij} =conversion efficiency for i^{th} resource option for j^{th} end use

The total annual cost of the required energy is obtained by the use of current prices of the different fuels and the optimal allocation of the energy supply to be provided by the different energy resource-device alternatives for all models.

An integrated model of the energy flows for the three major end uses i.e. cooking, lighting and space heating is shown in figure 4.3.

4.11 OPTIMAL ENERGY RESOURCE ALLOCATION USING DEVELOPED OPTIMIZATION MODEL

The developed Linear Programming Model was applied to obtain the optimal energy resource allocation for the various energy options for the base year 2000 A.D. The model gave the optimal allocations as shown in table 4.11. It is seen from the optimal allocations that in regard to cooking, the maximum emphasis is laid on animal dung (as biogas feed input) (49.12%) followed by LPG (8.87%),solar energy (6.22%),fuel wood

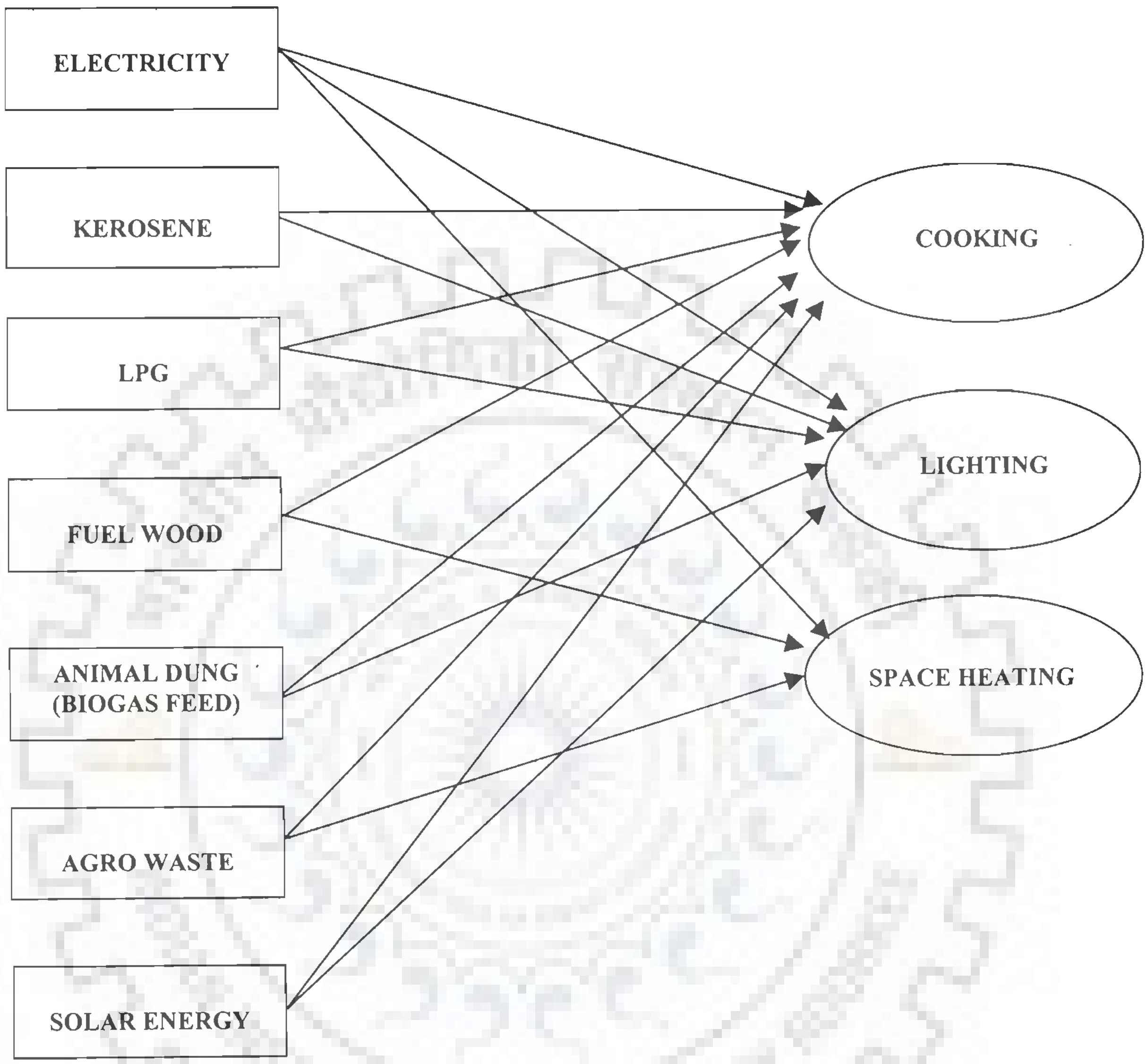

Figure 4.3 : Integrated Model of Energy Flows for Major End Uses in *Kanvashram.*

(3.69%), agro waste (0.80%), electricity (0.44%) and kerosene (0.24%). In regard to lighting energy needs the order of emphasis is: animal dung (as biogas feed input) [12.41%], kerosene (2.62%), electricity (2.19%), LPG (1.77%) and solar energy (0.084%). Agro waste and fuel wood cannot be used for lighting purposes and are hence not considered. Similarly, in regard to space heating energy needs, the order of allocations is: fuel wood (10.92%), electricity (0.38%) and (agro waste (0.23%). The remaining energy resources are not used and therefore not considered.

A comparison of the costs involved for the existing energy allocation and the optimized recommendations on the basis of tables: 4.9, 4.10 and *Appendix C* shows that the cost involved for the present consumption trend based allocation is Rs.1966,180.00, whereas for the optimal energy plan it is Rs. 917,249.60. This implies that the optimal energy planning strategy works out to be 2.144 times more economical. The effectiveness of applying optimization as a planning tool is clearly demonstrated by these observations.

It is seen that the energy planning involves greater allocation to cheaper resources, which may not always be desirable for improving the life style of the rural population. Hence, although there are considerable economical savings in the optimization based energy plan, the decision maker must apply his own discretion in the final assessment to resolve satisfactorily the conflict between energy cost savings and use of better (but more expensive) energy resources.

The application of the developed energy Linear Programming based model for scenario simulations in the projected year 2005 A.D. is the subject of the next chapter.

Table 4.11: Optimal allocation of energy resources for 2000 A.D. (Base Year)

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,449.58
		Lighting	51,797.84
		Space Heating	8,879.65
2.	Kerosene	Cooking	5,570.53
		Lighting	61,894.80
		Space Heating	----
3.	LPG	Cooking	209,457.85
		Lighting	41,891.57
		Space Heating	----
4.	Fuel wood	Cooking	87,125.15
		Lighting	-----
		Space Heating	257,833.34
5.	Animal Dung (Biogas Input)	Cooking	1159,764.00
		Lighting	293,032.34
		Space Heating	----
6.	Agro waste	Cooking	18,964.58
		Lighting	----
		Space Heating	5,427.22
7.	Solar Energy	Cooking	147,014.31
		Lighting	1,976.40
		Space Heating	-----
Total Annual Demand (kWh)			2361,079.15
Optimal Cost of Supplying Energy (Rs.)			Rs.917,249.60

CHAPTER-5

ENERGY PLANNING FOR KANVASHRAM

PART C: PLANNING FOR RURAL ENERGY SYSTEMS USING SCENARIOS

5.1 INTRODUCTION

In decentralized energy planning, long term planning can lead to delays in program implementation due to various administrative formalities. Hence, to bring about immediate relief to the rural population in terms of economic development, short term planning is necessary. In view of this, it is proposed to plan for a short period of 5 years, for the growing energy needs of the rural population of *Kanvashram*, the study area. The present planning is therefore considered for a period of 5 years from 2000A.D, the base year of data collection. The planning exercise has been carried out for the projected year 2005 A.D. The planning also makes use of various scenarios that attempt to investigate the impact of different contingencies in distribution of the energy resource supply normally available to the rural population. The findings of this analysis are then interpreted in relation to the energy planning.

5.2 MODEL INPUTS FOR THE PROJECTED YEAR 2005 A.D.

The newly created state of *Uttaranchal* (India) is experiencing nascent growth, which on account of its hilly geographical layout is expected to proceed at a slow rate. Tourism is one of the main industries in the state. The exploitation of the natural water resources for electrical power generation is yet another means of improving the resource earnings of the state. Due to these major activities, the state hopes to encourage development and growth in various pockets which possess one or both of these assets. The village of *Kanvashram* has potential for growth as a tourist as well as a pilgrimage spot, as has been mentioned earlier. It is anticipated that due to the interest shown by the *Garhwal Mandal Vikas Nigam*, a planning body of the district of *Pauri Garhwal*, in developing the area, the population is likely to experience an influx, leading to an increase in the energy demand. The energy supply inputs for the base year 2000 A.D would accordingly have to be corrected for 2005 A.D. This has been taken care of by enhancing the per capita energy supply requirements in accordance with the population growth trends for the area, as indicated in the available census reports.

5.3 POPULATION GROWTH BY 2005 A.D. IN KANVASHRAM

The population for the year 2005 A.D. was estimated directly from the growth rate of the rural population for the district of *Pauri Garhwal* as provided in the census reports. A bi-variate regression model was constructed to estimate the population growth in the study area after proportionate sizing with respect to the population of the rural segment of *Pauri Garhwal*. For this purpose, the year 1970 has been taken as the zeroeth year and, the model is expressed as:

$$Ln[Population]\ ith = Ln\ [A] + [T_{ith} - T_{1970}]*B$$

Here: A, B are constants (A=466960.5 and B= 0.01014) and $[T_{ith} - T_{1970}]$ denotes the number of years involved with 1970 as the base year.

The population in the study area is then given on a proportionate basis as:

$$[Population]\ ith\ (study\ area) = [Population]ith*0.003144$$

where, the fraction (=0.003144) denotes the ratio of the population of the study area to that for the rural segment of the whole district for the year 2000 A.D and has been assumed to remain constant for future population growth assessment using the regression relationship.

5.4 GROWTH IN THE ENERGY RESOURCE SUPPLY LIMITS

The major energy resources that have been considered for meeting the energy demand in the study area are the following:

(i) Electricity

(ii) Kerosene

(iii) LPG (Liquefied Petroleum Gas)

(iv) Fuel wood

(v) Animal Dung

(vi) Agro waste

(vii) Solar energy

The corrected increase in the demand and supply limits of some of these resources (due to government provided relief) needs to be evaluated for formulating an appropriate energy resource allocation plan for 2005 A.D. The estimation of the increases, where, applicable, is explained in the accompanying sub sections.

5.4.1 Increase in the Demand and Supply of Electricity as an Energy Resource

The electricity demand for the study area is obtained from the primary survey data. The demand for 2005 A.D. can be extrapolated in terms of the estimated population growth in the study area. Since electricity, when provided, in any area must cater to subsequent expansions in that area, it is felt safe in assuming that the supply growth would keep pace with the population growth. Hence, we have assumed that the supply of electrical energy would match that of the demand for 2005 A.D.

5.4.2 Increase in the Demand and Supply of Kerosene as an Energy Resource

Kerosene is an important energy fuel in most households in *Kanvashram*. It is used a means of providing lighting energy in lower income households, while the upper income households use it as a stand by fuel for catering to periods of power cuts. Assuming that the trends would continue, the increase in demand of kerosene, like electricity would also be a function of the increase in population growth. The supply of kerosene to the area is approximated as : the number of households multiplied by the ration quota per household. A certain amount of additional kerosene reserves are included for contingencies of sorts. For the present analysis a 20% additional reserve has been assumed.

5.4.3 Increase in the Demand and Supply of LPG as an Energy Resource

LPG is a modern fuel that has been shown to have a favourable acceptance among the rural population Although it is more expensive than the traditionally used fuel wood or kerosene, it is often convenient in cooking due to its high thermal efficiency, relative cleanliness, ease in operation, absence of smoke and pollution, and instant operation. It is thus preferred to traditional fuels in many households. It is further seen that the use of LPG helps in improving the standard of living in rural areas and should be encouraged by the government. The projected demand for LPG for 2005 A.D. is computed as follows:

(i) The primary survey data shows the percentage of households using LPG as a fuel resource for the base year 2000 A.D.

(ii) This data is used for computing the total LPG consumption/annum (in terms of average consumption of the households using LPG in the sample)

(iii) This data is multiplied by a factor depending on the expected growth in LPG consumption by 2005 A.D. In the present case a 10% increase is assumed so that a factor of 1.1 is required.

(iv) The projected demand for 2005 A.D. obtained from step 3 is further multiplied by 1.2 to cater to contingencies in demand (assuming 20% reserves)

5.4.4 Increase in the Demand and Supply of Fuel wood as an Energy Resource

Fuel wood is a cheap and easily available energy resource in rural areas. It is preferred by the economically weaker sections of rural society, although it is also used by households of the upper income group for routine domestic use and space heating applications in the colder months as a cheaper fuel alternative. It has been observed in general in developing countries, that fuelwood usage places a large stress on the ecological reserves of natural vegetation, and, this in turn has harmful long term repercussions on soil fertility and the environment. Thus while the demand for fuel wood continues to grow in accordance with the population expansion, the supply of fuel wood should not be allowed to keep in pace with the growing demand. The demand projections for the year 2005 A.D. can be assessed in terms of the rate of population growth in the study area, while the supply should be kept somewhat lower than the demand. Although no figures are available as such to decide just how much this decrement should be, we feel that the curtailment of fuel wood supply should not exceed 20 % of the projected demand, on account of the heavy dependence of the rural population on this cheap fuel resource.

5.4.5 Increase in the Demand and Supply of Animal dung as an Energy Resource

Animal dung is not a popular energy fuel in the study area, when used as fuel for direct combustion. It is mostly employed by the rural households as a natural fertilizer for improving the quality of the soil. Nonetheless, a small proportion of the population, particularly in the upper income groups make use of animal dung as an input feedstock for biogas plants. In the near future, it is anticipated that with the growth of the population, the percentage of users of biogas would also increase. The primary survey carried out in the study area indicated that only 3-5% of the rural households use animal dung as a fuel for direct combustion while 19% use it as an input feed for biogas plants.

The projected demand for animal dung as an energy fuel for the year 2005 A.D. is estimated in terms of the corresponding increase in the concerned segments of the rural population by 2005 A.D. The supply, however, is dictated by the animal dung production by 2005 A.D. In the absence of available data on this issue, an indirect estimation is used. It is reasonable to assume, that in the short span of 5-years (2000A.D-2005 A.D), the ratio of the animals to the human population is constant. Accordingly, the increase in the population would result in a proportionate increase in the number of animals, and, new dung production can be computed in terms of the average dung production/animal/day.

5.4.6 Increase in the Demand and Supply of Agro waste as an Energy Resource

The survey data shows that the population in the study area does not use agro waste to any great extent for meeting certain energy needs. However, it is to be noted that agro waste can be used effectively for generating electricity (as fuel for biomass gasifier-generator system) when supplied as briquettes. Thus, although there is presently not much demand for this energy resource, it is felt that with the implementation of the energy plan using biomass gasifiers, the scope for utilization of this resource would improve. The increase in the supply of agro waste is doubtful, as the village boundaries are unlikely to expand to accommodate for greater farming area in the next five years, for which period the energy plan is being formulated. The revised energy supply inputs for the 2005 A.D. model are therefore the same. Another use of agro waste as a fuel for direct combustion is possible for space heating applications with the fuel being processed to minimize on smoke pollution. The total demand for both needs (as a fuel for electricity generation and for direct combustion) are accordingly modified to cater to the population growth for the year 2005 A.D., and the energy resource is included as an appropriate variable in the model for different end uses.

5.4.7 Increase in the Demand and Supply of Solar Energy as a Resource

Solar energy is available in plenty in the study area and has good scope as a prospective energy resource for meeting needs of lighting (as solar PV systems) and low grade thermal heating applications (solar water heaters/ solar cookers/ solar dryers and air heaters) Presently, there is not much use of solar energy as an energy resource in the study area, but, the situation might change in the face of technological advancement that is so dynamic in recent times. This change is thus anticipated for the near future, and the supply limits for the capture of available solar energy have been accordingly computed assuming that the households make provision for a certain minimum space requirement in their homes to install solar energy devices of sorts.

5.5 RESULTS OF THE MODEL FOR PROJECTED YEAR 2005 A.D.

On the basis of the enhancements in the demand and supply constraints, the optimization model for the projected year was simulated. For simplifying the analysis, it is assumed that the changes in the cost of energy resources during this period are marginal, and can be treated as constant. Hence, no change in the costs as specified for 2000 A.D., have been assumed for the analysis. The model yielded the following results as shown in table 5.1.

A comparison of this optimal allocation with that for the year 2000 A.D. is shown in table 5.2. It is clear from table 5.2 that the revised energy allocation for the projected year discourages the use of agro waste as a cooking fuel. Also, the use of biogas has been curtailed for cooking purposes but encouraged for lighting applications. Electricity for cooking, agro waste for space heating and solar energy for lighting purposes do not show any recommended increases. All other energy resources show an increased recommended allocation for the basic energy needs of cooking, lighting and space heating. The energy allocation plan for the projected year 2005 A.D shows that the increase in the annual demand of 123393 kWh involves an additional cost of Rs. 13,181.90, which is a very nominal amount. An interesting observation is that the projected model encourages greater use of electricity for illumination and LPG and solar energy (thermal route) for cooking. The emphasis on use of better energy resources is a positive move which must be given due consideration in the energy plan formulation for rural area.

Table 5.1: Optimal allocation of energy resources for 2005 A.D.

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9343.70
2.	Kerosene	Cooking	5861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.90
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	308,449.80
		Space Heating	-
6.	Agro waste	Cooking	0.00
		Lighting	-
		Space Heating	5427.2
7.	Solar Energy	Cooking	418,728.30
		Lighting	1976.40
		Space Heating	-
Total Annual Demand (kWh)			2484472
Cost of Supplying Energy(Rs.)			Rs. 930,396.00

Table 5.2: Comparative optimal allocation of energy resources for 2000 A.D. & 2005 A.D

S. No.	Energy resource	End use	Allocation for 2000 A.D (kWh)	Allocation for 2005 A.D (kWh)	Resource shift with respect to 2000A.D.(kWh)
1.	Electricity	Cooking	10,995.70	10,995.70	0
		Lighting	51,797.80	54,504.90	+2707.10
		Space Heating	8879.65	9343.70	+464.05
2.	Kerosene	Cooking	5570.50	5861.70	+291.20
		Lighting	61,894.80	65,129.50	+3234.70
		Space Heating	-	-	-
3.	LPG	Cooking	209,457.90	220,404.40	+10946.50
		Lighting	41,891.60	44,080.90	+2189.30
		Space Heating	-	-	-
4.	Fuel wood	Cooking	87,125.20	91,678.40	+4553.20
		Lighting	-	-	-
		Space Heating	257,833.30	271,591.60	+13758.3
5.	Animal Dung (Biogas Input)	Cooking	1159,764.00	976,299.50	-183464.50
		Lighting	293,032.30	308,449.80	+15417.50
		Space Heating	-	-	-
6.	Agro waste	Cooking	18,964.60	0.00	-18964.60
		Lighting	-	-	-
		Space Heating	5427.2	5427.2	0
7.	Solar Energy	Cooking	147,014.30	418,728.30	+27171.40
		Lighting	1976.40	1976.40	0
		Space Heating	-	-	-
Total Annual Demand(kWh)			2361079	2484472	+123393
Cost of Supplying Energy (Rs.)			Rs.917,215.10	Rs.930,396.00	+Rs.13181.90

5.6 ALLOCATION OF ENERGY RESOURCES FOR EACH YEAR

The energy plan that has been proposed in table 5.1 shows the optimal energy resource allocation for the projected year 2005 A.D. The allocation targets for the interim years may be obtained by carrying out separate optimization exercises. However, this would require a re-estimation of the demand and supply constraints for each year involved . Hence, in order to avoid this additional computation, an alternative strategy is proposed. The energy resource allocation for each year from 2000 A. D to 2005 A.D. can be obtained by multiplying the optimal energy resource allocation values with the ratio of the projected population of the year in question to that for the year 2005 A.D. This would, no doubt, yield sub optimal solutions, but in view of the ease introduced in planning together with the fact that optimal recommendations of any optimization model can never be fully implemented in actual practice, it is felt that the error introduced will be small enough to justify the use of the approach so proposed. Accordingly, the approach has been applied and the recommended allocations for the interim year are computed and shown in table 5.3.

Table 5.3: Recommended allocations of energy resources in interim years for period 2000A.D- 2005 A.D

S. No	Energy resource	Resource allocation recommendations for period 2000A.D-2005 A.D (kWh)					
		2000A.D.	2001A.D.	2002A.D.	2003A.D.	2004 A.D.	2005A.D.
1.	Electricity	71,673.15	71,850.53	72,598.97	73,347.41	74,095.86	74,844.30
2.	Kerosene	67,465.30	68,151.55	68,861.46	69,571.38	70,281.29	70,991.20
3.	LPG	251,349.50	253,905.90	256,550.70	259,195.60	261,840.40	264485.30
4.	Fuel wood	344,958.50	348,739.20	352,371.90	356,004.60	359,637.30	363,270.00
5.	Animal Dung	1452,796.30	1233,359.3	1246,206.8	1259,054.30	1271,901.80	1284,749.30
6.	Agro Waste	24,391.80	5,210.11	5,264.38	5,318.65	5,372.93.00	5,427.20
7.	Solar Energy	148,990.70	403,876.51	408,083.56	412,290.60	416,497.65	420,704.70

5.7 APPLICATION OF THE MODEL FOR SCENARIO ANALYSIS FOR THE PROJECTED YEAR 2005 A.D.

One of the tasks of the rural energy planner/decision maker is to investigate the robustness of the prepared energy resource plan for the rural area in question. Simulation of energy resource shifts due to different contingencies, government policies or changes in socio-economic characteristics provide valuable feedback that can help in designing a more effective energy plan for the rural area. Policy moves simulations are introduced as "scenarios", in which the supply/demand constraints are altered in accordance with anticipated future contingencies. The shifts in energy resource, cost and associated social benefits of the policy move are the main features of interest.

The model developed for the projected year 2005 A.D. can be applied for energy planning using scenario analysis. In the present study, hypothetical scenarios are proposed as policy moves that can be contemplated for the study area. The scenario assessment reflects on the suitability of the policy move on which the particular scenario is modelled. A number of moves can be contemplated for energy planning in the study area. These policy moves are examined for their impact on the optimal energy allocation as advocated by the nature of the scenario in question. A realistic energy plan would entail the examination of an infinite number of scenarios, which is evidently an exhausting task. It would thus be practical to limit the study to a few prominent scenarios which, can provide a fairly accurate coverage of the effects of important policy moves for the study area. With this in mind, the present part of the analysis restricts itself to the examination of 10 such scenarios, that are described as under:

(i) Scenario 1: Curtailment of fuel wood by 10%

(ii) Scenario 2: Curtailment of kerosene supply by 10%

(iii) Scenario 3: Increase in the supply of LPG by 10%

(iv) Increase in the supply of biogas by 10%

(v) Increase of 10% in the supply of agro waste for biomass gasifier based electricity generation.

(vi) Encouraging the use of electricity for lighting purposes by assuming a 10% increase in the supply for this purpose only.

(vii) Encouraging growth of energy plantations to increase the fuel wood supply by 10%.

(viii) Encourage the use of solar energy based technology by 10%

(ix) Composite scenario discouraging the simultaneous use of fuel wood and kerosene, each by 10% of the supply at base conditions.

(x) Composite scenario encouraging the simultaneous use of LPG/ dung (as biogas input)/electricity/ agro waste/ solar energy, each by 10%.

In order to assess the impact, a variation of 10 % was chosen for each resource change in the scenarios. This figure was used primarily because it represents a reasonable degree of variation that can be controlled in a practical scenario.

5.8 EVALUATION OF THE SCENARIOS IN TERMS OF THE POLICY EFFECTIVENESS RATIO (PER)

The impact of each scenario can be assessed in terms of a ratio- the *Policy Effectiveness Ratio (PER)*, which is essentially, a modified cost-benefit ratio.

The *Policy Effectiveness Ratio (PER)* is defined as:

Policy Effectiveness Ratio(PER)= Cost Ratio/Social Benefit Ratio

Where: *Cost Ratio* = Cost of supplying energy demand under the scenario/Cost of supplying energy demand under base case

Social Benefit Ratio =Weighted consumption of energy resources under scenario/ Weighted consumption of resources under the base case

Thus the ratio attempts to compare the cost and social advantages associated with a policy move. A PER lesser than 1 signifies a favourable policy move, while that above 1 suggests an unfavourable policy move. Values close to 1 imply break–even situations that need to be investigated further. However, allowing for some leeway in *PER* values, (which need not be rigid in practical planning exercises), it was felt that tolerances upto +3% may be accommodated, and, that the acceptance levels of *PER* may accordingly be redefined.

The procedure of computing the PER is explained using a system of weights for energy resources in accordance with the "energy ladder" concept [Appendix E]. The analysis of the scenarios proposed for the present study are discussed in the subsequent sub-sections.

5.9 SCENARIO 1: CURTAILMENT OF FUEL WOOD BY 10%

Use of fuel wood has always been discouraged on environmental and ecological grounds. The effect on the ecology of the area reflects as a series of repercussions that reduce soil fertility, change the climate and affect flora and fauna habitats. Environmental damage manifests itself as an increase in air pollution levels (smoke etc). On the social front, encouraging the use of fuel wood promotes a primitive standard of living that is not commendable for a growing economy. Thus, one of the energy policies to be introduced should aim at checking the growing dependence on fuel wood as an energy resource. Fuel wood is mostly preferred by low income households, although some upper income households also make use of this resource for routine domestic operations in preference to more expensive fuels. As the rural poor exist in large numbers in most developing nations, the excessive use of fuel wood places ecological pressure on the natural forests and is not desirable in the nation's long term interest. Nonetheless, the resource cannot be done away with entirely. Thus, policy measures should be structured to discourage excessive use of fuel wood. It has been felt that a 10% decrease in the allocated resources for the projected year would represent a practical figure for policy implementation Accordingly, this has been introduced in the present scenario, and the results are highlighted in Tables 5.4 and 5.5.

The results show that with scenario 1, the minimum cost of supplying the energy demand in the study area works out to be Rs. 941,112.90 as against the base cost of Rs. 930,396.00. This indicates that despite the curtailment of fuel wood by 10%, the overall cost of supplying the energy demand rises on account of shifts of the energy deficit to other energy resources (electricity for space heating and agro waste, solar energy for cooking purposes). The overall cost thus increases by Rs 10,716.90 and as such, the scenario does not attract implementation on economical grounds. However, the impact of the scenario must be evaluated on the totality of both economic as well as social benefits (that accrue by the use of improved fuels enhancing the rural life style and welfare). With this in mind, the two ratios (Cost Ratio and Social Benefit Ratio) are considered together to yield the PER as given in Table 5.6.

The corresponding rise in the social benefits as a result of the contemplated policy move helps in offsetting the economic disadvantage so that on the whole, the policy appears to be favourable for implementation.

Table 5.4: Optimal allocation of energy resources for 2005 A.D. under scenario 1

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	23,567.58
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.90
		Space Heating	-
4.	Fuel wood	Cooking	78,412.60
		Lighting	-
		Space Heating	257,367.70
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	308,449.80
		Space Heating	-
6.	Agro waste	Cooking	18,964.50
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	413,029.50
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.941,112.90

Table 5.5: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 1

S.No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	+14,223.90
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	-13,265.80
		Lighting	-
		Space Heating	-14,223.90
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	0.00
		Space Heating	-
6.	Agro waste	Cooking	+18,964.57
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-5,698.8
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.+10,716.90

Table 5.6 : The policy effectiveness ratio for scenario 1

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 1	Fuel wood supply reduced by 10%	1.0115	1.0008	1.0106	Favourable

5.10 SCENARIO 2: CURTAILMENT OF KEROSENE SUPPLY BY 10%

Kerosene is usually used as a back up fuel for lighting needs as well as a primary energy resource for illumination among the rural poor. This energy fuel is scarce and needs to be supplied on a rationed basis in view of the sizeable Indian rural population which depend on it to a large extent for their lighting needs. Since the fuel resources have to be imported, a curtailment of this fuel would be attractive from the national economic perspective. Additional, the fuel involves undesirable smoke pollution .The partial non - availability of the resource which is introduced as a scenario for achieving multiple benefits would tend to create shifts in other energy resources, and this would then result in changes in economics and social benefits.

Table 5.7 and 5.8 show the relative changes in energy resource allocations. It is seen from Table 5.7 that there is a fall in the minimum cost for supplying the given energy demand from Rs 930,696.00 to Rs 926,560.20. Further, Table 5.8 indicates the impact of the scenario i.e. the reduction of kerosene supply by 10% is manifested as changes in allocation of other energy resources, notably in dung for lighting and agro waste and solar energy for cooking purposes.

Table 5.7: Optimal allocation of energy resources for 2005 A.D. under scenario 2

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,275.50
		Lighting	58,616.60
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.90
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	314,962.70
		Space Heating	-
6.	Agro waste	Cooking	18,964.50
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	400,349.90
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.92,650.20

Table 5.8: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 2

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	-586.20
		Lighting	-6,512.90
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	+6,512.90
		Space Heating	-
6.	Agro waste	Cooking	+18,964.57
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-18,378.40
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs-3,835.80

The cost ratio and the social benefit ratios for the scenario show that in the overall analysis, the PER turns out to be favourable to the implementation of the policy. This is given in Table 5.9.

Table 5.9 : The policy effectiveness ratio for scenario 2

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario2	Kerosene supply reduced by 10%	0.9958	0.9972	0.9986	Favourable

5.11 SCENARIO 3: INCREASE IN THE SUPPLY OF LPG BY 10%

LPG is a convenient energy fuel suitable for cooking applications and, to a limited extent for lighting purposes. At present, the low economic status of much of the rural population in the study area restricts its wide spread use, particularly when cheaper alternatives like fuel wood are available. However, there is no doubt that the economic welfare of the population is on the rise due to positive efforts of the government. This implies that in the near future, more and more of the rural population will be in a position to afford LPG for domestic use. It was therefore felt worthwhile to examine the scenario in which the LPG supply is enhanced by 10%.

Table 5.10 and 5.11 show the relative changes in resource allocations, while table 5.12 indicates the suitability of the contemplated policy move introduced in this scenario. It is reasonable to hypothesize that the provision of an increased supply of LPG would probably increase the cost of supplying the energy demand to the study area, and, this hypothesis is shown to hold true by the findings of Table 5.10. However, contrary to expectations, the social benefits introduced by the recommended shifts to use of an improved energy resource (LPG) have not shown a payback to the desired extent. This results in a large PER, making the policy move unfavourable for the study area.

Table 5.10: Optimal allocation of energy resources for 2005 A.D. under scenario 3.

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	242,444.90
		Lighting	48,488.90
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	304,041.70
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	377,723.20
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.961,238.5

Table 5.11: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 3

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	+22,040.50
		Lighting	+4,408.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	-4,408.10
		Space Heating	-
6.	Agro waste	Cooking	+18,964.57
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-41,005.10
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.+30,842.50

Table 5.12 : The Policy Effectiveness Ratio for Scenario 3

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario3	LPG supply increased by 10%	1.0331	0.9982	1.0354	Unfavourable/ reject

5.12 SCENARIO 4: INCREASE IN THE SUPPLY OF BIOGAS BY 10%

The drive by the Indian Government to encourage the use of biogas as an environmentally friendly and sustainable energy resource in rural areas has been visible from the large scale programs that have been promoted in the previous five year plans.

In view of this encouragement, it is worthwhile examining the impact of promoting greater use of this energy resource by increasing the available supply of animal dung as feedstock input. The present scenario has been simulated with the assumption that the existing supply of animal dung input has been enhanced by 10%. The results of the simulated optimal resource allocations are given in Tables 5.13-5.15.

The impact of the scenario is experienced as an increase in the allocations of agro waste and a decrease in the use of solar energy for cooking applications. The use of agro waste is not advisable on environmental as well as social welfare grounds, and, this would reflect adversely on the social benefit ratio. It is also seen that the overall effect is an increase in the cost of supplying the required energy demand to the study area, despite the promotion of biogas in lieu of lesser desirable fuels. The outcome of these variations is that the *Policy Effectiveness Ratio,* as indicated in Table 5.15, turns out to represent a break even situation. Perhaps the policy would need to be re examined to make the payoff positive in yield.

Table 5.13: Optimal allocation of energy resources for 2005 A.D. under scenario 4

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	1073,929.00
		Lighting	308,449.80
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	302,134.20
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.944,376.50

Table 5.14 : Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 4

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	+97,629.50
		Lighting	0.00
		Space Heating	-
6.	Agro waste	Cooking	+18,964.57
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-116,594.10
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.+13,980.50

Table 5.15 : The policy effectiveness ratio for scenario 4

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 4	Biogas supply increased by 10%	1.0151	0.9897	1.0255	Break even proposal

5.13 SCENARIO 5: INCREASE OF 10 % IN THE SUPPLY OF AGRO WASTE FOR BIOMASS GASIFIER BASED ELECTRICITY GENERATION

The use of agro waste as an energy resource by direct combustion is not advisable on account of the high associated smoke pollution level. However, the resource is virtually free and available in plenty in areas with high agricultural activity. The resource therefore has potential advantages involving economic savings in the formulation of an effective energy plan. One way of reducing smoke pollution level is by using the fuel in a processed form (briquettes) either by themselves or for use in biomass gasifier plants that generate electricity for augmenting the electric power available to the area.

The latter application is introduced here as a scenario to examine the impact of its introduction on the resource allocation. A 10% increase in the supply of agrowaste is assumed to be made available to the study area for use in biomass gasifiers. This additional supply can be imported or purchased from neighbouring villages.

The impact of this scenario is given in Tables 5.16-5.18.

The findings of Table 5.18 indicate that the policy move appears to be favourable in terms of the *PER* for the scenario. Thus the policy move can be proposed for the study area.

Table 5.16: Optimal allocation of energy resources for 2005 A.D. under scenario 5

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,048.90
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	308,449.80
		Space Heating	-
6.	Agro waste	Cooking	20,861.04
		Lighting	-
		Space Heating	5,969.94
7.	Solar Energy	Cooking	397,867.20
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy (Rs.)			Rs.930,045.90

Table 5.17 : Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 5

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	-542.70
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	0.00
		Space Heating	-
6.	Agro waste	Cooking	+20,861.04
		Lighting	-
		Space Heating	+542.74
7.	Solar Energy	Cooking	-20,861.03
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.-350.10

Table 5.18 : The policy effectiveness ratio for scenario 5

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario5	Agrowaste supply increased by 10% For biomass gasifier electricity	0.9996	0.9962	1.0033	Favourable

5.14 SCENARIO 6: ENCOURAGING THE USE OF ELECTRICITY FOR LIGHTING PURPOSES BY ASSUMING A 10% INCREASE IN THE SUPPLY FOR THIS PURPOSE ONLY

In order to improve the standard of living of the rural population in the lower income bracket, it is proposed that electricity at subsidized rates be made available to them. However, to prevent misappropriation of this energy resource for cooking needs (which are better served with other cheaper fuel alternatives), it is recommended that the policy move emphasis the use of the subsidized electricity for lighting purposes only. The impact of this scenario is examined using the model for the projected year 2005A.D. Tables 5.19 and 5.20 show the reallocation of energy resources and the relative shifts in resources quantities with respect to the base scenario for 2005 A.D. It is seen that the scenario entails a cost of Rs. 940516.40 as against Rs. 930396.00 for the base case. The corresponding shifts favouring the greater use of electricity elevate the social welfare and as such, the *PER* needs to be evaluated in order to examine the overall acceptance of the policy move. Table 5.21 shows the *PER* to be a breakeven proposition. This implies that the policy move needs to be reinvestigated, if the object is to uplift the economically weaker sections of the rural society.

Table 5.19: Optimal allocation of energy resources for 2005 A.D. under scenario 6

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	59,955.33
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	302,999.30
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	399,763.70
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.940,516.40

Table 5.20: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 6

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	+5,450.43
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	-5,450.43
		Space Heating	-
6.	Agro waste	Cooking	+18,964.60
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-18,964.60
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.+10,120.40

Table 5.21 : The policy effectiveness ratio for scenario 6

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 6	Electricity for lighting needs increased by 10%	1.0108	0.9974	1.0134	Break even proposal

5.15 SCENARIO 7: ENCOURAGING GROWTH OF ENERGY PLANTATIONS TO INCREASE THE FUEL WOOD SUPPLY BY 10%

Fuel wood is an important energy resource in rural areas of developing countries. Since the use of fuel wood places ecological pressure on the natural forests reserves, it is necessary to explore other ways of obtaining fuel wood without harm to the natural vegetation. The cultivation of Energy Plantations is one such way of achieving this objective. In the study area, there appears to be scope for the growth of energy plantations. The waste land in several land holdings can be profitably applied for the cultivation of selected species of trees that can be used as fuel wood. When such a move is promoted, the supply of fuel wood in the village can be partly met in terms of the output of the plantations. Thus the dependence on fuel wood from the forests is lessened. However, as the total fuel wood supply remains constant, the impact of the scenario on the overall benefits is unlikely to be strong. This belief is found to be supported by the findings of tables 5.22-5.24. The findings of table 5.22 show that the energy allocation is the same as that for the base case, and therefore, the *PER* for the scenario would indicate a break even situation.

Table 5.22: Optimal allocation of energy resources for 2005 A.D. under scenario 7

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	308,449.80
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	399,763.70
		Lighting	1,976.40
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.930,396

Table 5.23: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 7

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	0.00
		Space Heating	-
6.	Agro waste	Cooking	0.00
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	0.00
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.0.00

Table 5.24 : The Policy effectiveness ratio for scenario 7

Scenario No.	Policy Move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario7	Encouraging energy plantation to supply 10% of fuelwood supply	1.000	1.000	1.000	Break even proposal

5.16 SCENARIO 8: ENCOURAGE THE USE OF SOLAR ENERGY BASED TECHNOLOGY BY 10%

The government of India has been actively supporting the promotion of solar energy based devices, particularly for rural areas. Such devices include: solar cookers, solar water heaters and solar lanterns, solar electric pumps systems and photovoltaic panel based applications.

Solar energy is a clean and renewable form of energy that can be usefully applied to meet small scale needs by tapping the benefits of the universally available solar radiation. In the study area, it was felt worthwhile to examine the impact on the energy allocations when solar energy based applications are promoted in an excess of 10% above the recommendations for the base case.

Tables 5.25 and 5.26 show the revised energy resource allocations for this scenario in contrast with that for the base case.

The findings of table 5.25 show that there is a marginal fall in the cost of supplying energy with respect to the base case. The greater use of solar energy implies a favourable shift in the energy consumption pattern, and this would accordingly be reflected as an improvement in the social welfare of the rural population. The overall impact has been captured by the *PER* in table 5.27. As seen from this table, the impact appears to be indicated as favourable and hence the policy move should be given encouragement.

Table 5.25: Optimal allocation of energy resources for 2005 A.D. under scenario 8

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	308,252.20
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	399,763.70
		Lighting	2174.04
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.930,367.70

Table 5.26: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 8

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	-197.60
		Space Heating	-
6.	Agro waste	Cooking	+18,964.60
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-18,964.60
		Lighting	+192.60
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.-28.30

Table 5.27 : The policy effectiveness ratio for scenario 8

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 8	Encouraging a 10% increase in use of solar energy devices	0.9999	0.9966	1.0033	Favourable

5.17 SCENARIO 9: COMPOSITE SCENARIO DISCOURAGING SIMULTANEOUSLY THE USE OF FUEL WOOD AND KEROSENE, EACH BY 10% OF THE SUPPLY AT BASE CONDITIONS.

It was seen that the curtailment of fuel wood and kerosene independently proved to be favourable policy moves. When the supply of both these energy resources are controlled simultaneously, it would be interesting to examine whether there would be any changes in the recommendations. Accordingly, the present composite scenario has been conceived. Tables 5.28-5.30 show the main findings for this scenario.

It is seen that the cost for supplying the energy demand falls from Rs. 930396.00 to Rs. 921695.10(table 5.28). There are gains in the recommended allocations for electricity (space heating) animal dung (lighting needs) and agro waste (cooking needs).These increases are balanced by corresponding falls in the allocations to fuel wood (cooking and space heating), kerosene (cooking and lighting) and solar energy (only cooking needs) (table 5.29). The overall impact as given by the *PER* (table 5.30) turns out be favourable. The policy may therefore, be recommended.

Table 5.28: Optimal allocation of energy resources for 2005 A.D. under scenario 9

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	54,504.90
		Space Heating	10,117.28
2.	Kerosene	Cooking	5275.50
		Lighting	58,616.50
		Space Heating	-
3.	LPG	Cooking	220,404.40
		Lighting	44,080.87
		Space Heating	-
4.	Fuel wood	Cooking	82,510.60
		Lighting	-
		Space Heating	270,818.00
5.	Animal Dung (Biogas Input)	Cooking	976,299.50
		Lighting	314,962.70
		Space Heating	-
6.	Agro waste	Cooking	18,964.60
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	409,517.70
		Lighting	1,976.40
		Space Heating	-
	Total Annual Demand (kWh)		2484,472
	Cost of Supplying Energy(Rs.)		Rs.921,695.10

Table 5.29: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 9

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	0.00
		Space Heating	+773.58
2.	Kerosene	Cooking	-586.20
		Lighting	-6,513.00
		Space Heating	-
3.	LPG	Cooking	0.00
		Lighting	0.00
		Space Heating	-
4.	Fuel wood	Cooking	-9167.80
		Lighting	-
		Space Heating	-773.58
5.	Animal Dung (Biogas Input)	Cooking	0.00
		Lighting	+6,513.00
		Space Heating	-
6.	Agro waste	Cooking	+18,964.60
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-9210.60
		Lighting	0.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.-8,700.90

Table 5.30 : The policy effectiveness ratio for scenario 9

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 9	Simultaneous reduction of fuel wood and kerosene , each by 10%	0.9907	0.9983	0.9923	Favourable

5.18 SCENARIO 10: COMPOSITE SCENARIO ENCOURAGING THE SIMULTANEOUS USE OF LPG/ DUNG (AS BIOGAS INPUT)/ELECTRICITY/ AGRO WASTE/ SOLAR ENERGY, EACH BY 10%

When several energy resources, particularly of the commercial and renewable variety are provided in excess in rural areas, it is expected that the rural population would enjoy a much improved standard of living, that would make the policy move a beneficial one.

With this in mind, it was thought appropriate to investigate the effect of a composite scenario that advocates the simultaneous increase in usage of LPG, animal dung, agrowaste, electricity and solar energy for appropriate end uses. The last scenario , therefore, analyses the impact of such a policy move. The main findings are shown in tables 5.31-5.33.

It is clear from table 5.31 that the overall cost of providing the needed energy is more than that for the base case. This is due to the relaxation of the upper bounds of several energy resources that steers the optimal allocation more in favour of these energy resources. No doubt, the standard of living has improved due to greater allocations of better energy resources (table 5.32), but the overall impact of the scenario as provided by the values of the PER (table 5.33) indicates that the policy move is an unfavourable one. Hence, this policy move should not be encouraged.

Table 5.31: Optimal allocation of energy resources for 2005 A.D. under scenario 10

S. No.	Energy resource	End use	Allocation (kWh)
1.	Electricity	Cooking	10,995.70
		Lighting	59,955.33
		Space Heating	9,343.70
2.	Kerosene	Cooking	5,861.70
		Lighting	65,129.50
		Space Heating	-
3.	LPG	Cooking	242,444.90
		Lighting	48,488.95
		Space Heating	-
4.	Fuel wood	Cooking	91,678.40
		Lighting	-
		Space Heating	271,591.60
5.	Animal Dung (Biogas Input)	Cooking	1073,929.00
		Lighting	298,393.60
		Space Heating	-
6.	Agro waste	Cooking	20,861.04
		Lighting	-
		Space Heating	5,427.22
7.	Solar Energy	Cooking	278,197.30
		Lighting	2,174.04
		Space Heating	-
Total Annual Demand (kWh)			2484,472
Cost of Supplying Energy(Rs.)			Rs.985,311.20

Table 5.32: Shifts in optimal allocation of energy resources for 2005 A.D. under scenario 10

S. No.	Energy resource	End use	Shifts in resource allocation (kWh) with respect to base case
1.	Electricity	Cooking	0.00
		Lighting	+5,450.43
		Space Heating	0.00
2.	Kerosene	Cooking	0.00
		Lighting	0.00
		Space Heating	-
3.	LPG	Cooking	+22,040.50
		Lighting	+4,408.05
		Space Heating	-
4.	Fuel wood	Cooking	0.00
		Lighting	-
		Space Heating	0.00
5.	Animal Dung (Biogas Input)	Cooking	+97629.50
		Lighting	-10,056.20
		Space Heating	-
6.	Agro waste	Cooking	+20,861.04
		Lighting	-
		Space Heating	0.00
7.	Solar Energy	Cooking	-140,531.03
		Lighting	+198.00
		Space Heating	-
Change in Minimum Cost of Supplying Demand with respect to Base Case			Rs.+54,915.20

Table 5.33 : The policy effectiveness ratio for scenario 10

Scenario No.	Policy move	Cost ratio	Social benefit ratio	Policy effectiveness ratio	Remarks
Scenario 10	Simultaneous increase in use of LPG/animal dung/electricity/agro waste and solar energy, each by 10%	1.0590	0.9914	1.0682	Unfavourable /reject

5.19 SUMMARY OF RESULTS

Analysis of the ten scenarios indicates that on the basis of the value of the Policy Effectiveness Ratio (PER), scenarios no. 1, 2, 5, 8 and 9 were favourable policy moves. Scenarios no. 4, 6 and 7 were break even proposals needing further investigations to make them paying, while, scenarios no. 3 and 10 were not favourable.

Recommendation for the study area on the basis of these findings are made in the next Chapter.

CHAPTER-6

CONCLUSIONS AND RECOMMENDATIONS

6.1 AN OVERVIEW OF THE STUDY

A detailed study was carried out to design and apply an energy planning model to the study of the energy scenario in a rural setup. The present study is directed to the energy scenario in the village of *Kavashram* in *Pauri Garhwal* district of the state of *Uttaranchal* (India) and a suitable energy plan has been evolved for energy resource allocation. The study focuses on the following issues:

1. Analysis of the energy scenario in the village in terms of the energy consumption patterns in the rural population.
2. Assessment of the levels of inequality in different energy resource consumption in the population.
3. Development of optimization based models for optimal energy resource allocation in relation to the basic energy needs of cooking, lighting and space heating.
4. Application of the developed models for examination of energy allocation alternatives under different simulated conditions.

The first part of the analysis (Part A) dealt with the energy consumption patterns within the rural population. The population that was divided into three categories on the basis of the type of family structure.

These three categories are:

(i) *Joint* family households

(ii) *Nuclear* family households

(iii) *All* family households

The households were arranged in order of increasing annual per capita incomes and divided into decile categories. The mean and the percentage share of the energy resource consumption in the deciles for each type of household category was estimated.

The study of the first part was also directed to the assessment of the levels of energy resource consumption inequality in the population of the study area. The levels of inequality were estimated graphically with the help of Lorenz curves and the *Gini* inequality ratio, that is popularly used in Economics.

The second part of the study (Part B) was directed to the development of appropriate optimization models for energy resource allocations in relation to the energy needs of cooking, lighting and space heating , that were identified as the major energy needs of the study area.

Linear Programming was chosen as the most suitable methodology after an examination into the relative merits of alternative methodologies for the analysis. Accordingly, the models were prepared as *linear programming models* with a minimum cost of energy being the objective function. Relevant demand and supply constraints were computed based on the data of the field survey carried out for the study. The results of the optimization were reported for the following cases:

(a) Results of the optimal allocation of the energy resources for the year 2000 A.D. (taken as the base year).

(b) Results of the costs comparison for optimal energy allocations for the base year and the allocations in accordance with the existing energy consumption patterns in the study area.

The third part of the analysis (Part C) dealt with the application of the developed energy planning optimization model for planning for energy needs in the projected year 2005 A.D. The following results were highlighted:

(a) The results of the energy allocation for the projected year 2005 A.D. vis-à-vis the base year 2000 A.D and for interim years between 2000 A.D. to 2005 A.D.(i.e. a five-yearly planning period) assuming a population growth in the study area in accordance with the time series trends indicated in the census reports.

(b) The results pertaining to the examination of ten hypothetical scenarios aimed at the study of the impact of certain contemplated policy moves.

The overall conclusions that emerge from this study were used for arriving at appropriate policy decisions in relation to energy planning for the study area.

6.2 OVERALL CONCLUSIONS

The first part of the study (Part-A) i.e the study of the energy consumption trends within the population in relation to specific energy resources leads to the following conclusions:

The findings indicated that there exists a substantial difference in the magnitude as well as the consumption trends of energy resources in each of the considered household categories. The skewness of the consumption gauged from the cumulative percentage share of the resource consumption upto the 5^{th} decile, has also been analyzed for the different household categories. The present analysis of consumption trends in the population of *Kanvashram* would be helpful for understanding the resource preferences that exist within different categories of the population and pave the way for framing energy resource shift strategies that can lead to more effective utilization of the existing resources in relation to energy planning for the study area.

It is also seen that due to the fact that the energy consumption trends for the different decile categories varies considerably within the households, the findings cannot be generalized for the entire rural population. This conclusion goes to show the importance of carrying out preliminary energy surveys and investigations for subsequent appropriate energy planning instead of relying on the assumption of uniformity in the energy consumption trends for the entire population.

In regard to the assessment of the levels of energy resource consumption inequality, the following inferences were made:

The Lorenz curves show that the level of inequality in resource consumption differs from decile to decile in the entire population in most cases. Further, the level is generally above the egalitarian consumption level, although, in certain cases, it may lie below. The overall income inequality appears to be significantly low for electricity, fuel wood and kerosene consumption but large for LPG consumption. Again, the findings were found to vary for the different household categories.

The relative difference in consumption levels from decile to decile fluctuates erratically, but, on an absolute basis, the magnitude of the associated *Gini* ratios suggest marginal intra- decile variation trends.

The second part of the analysis (Part-B) dealt with the development of an integrated linear programming energy planning model for the study area. The major energy end uses considered were: cooking, lighting and space heating. The model results were tested for cost effectiveness against those using the existent energy consumption pattern at the prevailing unit costs for different energy resources. It was seen that the comparison of the costs involved for the existing energy allocation and the optimized recommendations indicated that the cost involved for the present consumption trend based allocation is Rs. 1966,180.00, whereas for that for the optimal energy plan is Rs. 917,249.60. This implies that the optimal energy planning strategy works out to be 2.144 times more economical. The effectiveness of applying optimization as a planning tool is clearly demonstrated by these observations.

The third part of the analysis (Part-C) involved the preparation of an optimization energy planning model for the projected year and the application of this model for the examination of the impact of various policy moves introduced as " scenarios". The following conclusions were made:

(a) The model for the projected year 2005 A.D. entailed an increase of Rs. 13,181.90 in the optimal cost of supplying energy , which increased from 2361,079 kWh to 2484,472 kWh.

(b) The ten (10) scenarios were analyzed for their overall impact in terms of the *Policy Effectiveness Ratio(PER)* and it was seen that:

   (i) Fuel wood, kerosene reduction and an encouragement of the use of agrowaste (for biomass gasifier), solar energy and energy plantation growth proved to be recommendable policy measures.

(ii) biogas usage and encouragement of electricity for illumination purposes turned out to be breakeven propositions.

(iii) LPG usage and promotion of simultaneous use of several modern energy resources were not encouraging.

The findings and the related conclusions yield recommendations as presented in the next sub section of the present Chapter.

6.3 RECOMMENDATIONS

The main findings of part A of the analysis highlight the fact that different household categories have different levels and patterns of energy consumption in relation to the four major energy resources-electricity, kerosene, LPG and fuel wood. Even within a particular household category, varying levels of inequality exist in the consumption levels of different energy resources. The observation appear to lead to the inference that in regard to the satisfaction of basic energy needs, some segments of the rural population in the study area are subjected to certain socio-economic limitations that discourage them from consuming more efficient fuels and energy resources. Thus, in order to brig about a greater level of uniformity in resource consumption trends, particularly at the lower income levels, the Government would be required to initiate the following moves:

1. Conduct of detailed investigations into the socio-economic background of different household categories to ascertain causes and remedies for the highly unequal energy consumption patterns so observed. This is possible with the assistance of *Non Governmental Organizations(NGO's)* and academic institutions engaged in social based research activities.

2. Offer subsidies (with a minimum overburden to its economic budget) in regard to promotion of certain energy resources that are more expensive but cleaner and more efficient in use.

3. Educate the rural masses in the study area on the benefits of using biogas as a clean and renewable energy alternative to fuel wood, kerosene and to some extent electricity, that involve some undesirable environmental repercussions. Demonstration oriented installations of community and individual household biogas plants (with Government assistance) are one of the best ways of promoting biogas usage. To ensure a progressive and sustainable growth of biogas energy users, the Government would have to ensure that:

   (i) Promotion schemes identify proper beneficiaries are who possess the minimum financial and feedstock resources (adequate quantity of cattle dung) for operating the plant without assistance.

   (ii) Adequate maintenance and repair facilities are made available in the study area.

   (iii) A suitable financing policy(with incentives) be evolved to encourage interested households seeking assistance in installation of biogas units in their premises.

   (iv) Community biogas units are set up for the benefit of the economically weaker sections of the population that do not have the resources to own or run their own biogas plants. Such households may be provided use of the common community plant facilities at a nominal cost, while the onus of running the community plant be laid on a special community that looks into the technical supervision of operation and makes

arrangement to procure the needed supply of animal dung on a regular basis.

(v) Households are targeted that are interested in setting up a combined dairy and biogas ventures. These households may be provided on a loan basis, the necessary cattle to run both operations. The cost of the cattle may be recovered at nominal interest rates over the lifetime of the dairy project.

Part B of the analysis pertains to the development of a *Linear Programming Optimization Model* for energy resource planning in the study area. A comparison of the effective costs using the optimization model and the existing energy consumption trends shows the optimization model to be superior in its resource allocation recommendations. However, it is also evident that the implementation of the recommendations of the optimization model would not be easy in the study area. Thus some strategies are necessary to realize this. The following are some of the possible ways in which the recommendations may be implemented:

1. *NGO's* should be invited to take up the challenging task of convincing the rural population of the merits of making the needed energy resource shifts in accordance with the recommendations of the planning model.
2. The reallocation in the energy shifts between the different household can be carried out on a proportionate basis to the original consumption patterns as indicated in Part A of the analysis.
3. Some form of incentives (financial or otherwise) can be offered in the initial phases of the energy shift program . This may help awaken the interest of the people to adhere to the model recommendations as far as possible.

Part C of the analysis involves the application of the base case optimization (for the year 2000 A.D.) for short term energy resource planning in relation to the study area. The base model is extended in application for the projected year 2005A.D. A five year period has been chosen, keeping in view the prevailing the Indian planning practice. The optimal energy resource distribution for the year 2005A.D. was split into yearly target allocations between 2000A.D and 2005 A.D. It is recommended, that the Government, along with the support of *NGO's* develop suitable strategies for implementing the recommendations of the planning.

Part C also examines the impact of ten hypothetical scenarios as contemplated policy moves aimed at improving the effectiveness of the energy resource allocation plan for Kanvashram.

The following recommendations are in order in relation to the findings of the scenario analysis:

1. Fuel wood and kerosene reduction was seen as a favourable policy move in the overall perspective. The use of agro waste as a fuel, solar energy devices and the cultivation of energy plantations were also seen to be favourable. These observations lead to the following recommendations:

   (a) Fuel wood and kerosene usage needs to be curbed partially (as it is impossible to do away with these fuels altogether, in view of the heavy dependence of the rural population on them) This move can be effected by using the following strategies:

      (i) Increasing the cost of the energy fuels (fuel wood and kerosene)

(ii) Reducing the supply made available to the open market/ Government ration depots.

(iii) Encouraging (by means of subsidies, etc.) the use of better energy fuels alternatives/substitutes.

(b) Solar energy based conversion devices are clean and eco-friendly. They are ideal for routine energy end tasks like water heating, low grade thermal cooking and illumination. The model recommends the use of such devices and the following strategies can be used for popularizing them:

(i) Conduct of awareness and demonstration camps in the village to promote the use of solar cookers, solar water heaters and solar lanterns.

(ii) Provision of incentives for the purchase of these devices.

(iii) Provision of a reliable service center that promptly caters to repair and maintenance work. Also there should be a technical cell that advises on matters related to the installation of these devices.

(iv) As an alternative, the devices can be made available to the rural population on a rental basis, and the satisfactory operation of them be looked after by a local energy committee specially created for the purpose.

(c) Agro waste as an energy resource is not advisable for direct combustion on account of its high smoke content. It would be better to use this fuel in the processed form(as briquettes) and, particularly for biomass gasifiers as fuel feedstock. The village should therefore be provided with some means of enabling mechanical processing of agro-waste into briquettes. This will also generate some employment opportunities for a part of the rural population.

2. The encouragement of the use of biogas, energy plantations and electricity for lighting purposes were found to be breakeven proposals, presumably due to the low socio-economic benefits that accrue by their use vis-a'-vis their operating costs. Nonetheless, these options for energy planning are known to be beneficial in general, and it would be worthwhile, to investigate the causes for the break even and identify the key factors which, if controlled, would make the policies paying. Electricity used for lighting purposes is desirable with a view to improving the standard of living of the rural population, as such, should be encouraged, even if the proposition turns out to be break even.

Although the cultivation of energy plantations turns out to be a break even proposition, energy plantations should nonetheless be encouraged as a means of fostering some degree of self sufficiency in the study area in relation to fuel wood and farmers should be given some incentives to make optimal use of wasteland in the land holdings for the cultivation of high yielding varieties of wood species. In the context of energy plantations, it may be pointed out that the average farmer is reluctant to take upon himself the additional burden involved in the cutting, transporting and marketing of fuel wood from the plantation apart from his other agricultural activities. Thus, a system of wood "harvesting", collection, transportation and sale, if arranged through private agencies would be helpful in kindling interest in farmers in taking up this auxiliary farming project.

3. LPG usage and the composite scenario encouraging the simultaneous use of LPG/biogas/agrowaste/electricity(lighting needs) and solar energy, turned out to be unfavourable policy moves. It is recommended that these policies be abandoned for energy planning in the projected year 2005 A.D.

6.4 SUGGESTIONS FOR THE EXTENSION OF THE PRESENT WORK

The following are some of the possible directions into which the present work can be extended:

1. The present study focuses on micro level energy planning on one specific rural area in the district of *Pauri Garhwal, Uttranchal* (India) , lying at an altitude in between those typical for hilly and plain terrains in the district. It would be of interest to contrast the findings of this study with similar studies carried out for pure hill or plain terrains, and using the cumulative information for overall planning of energy planning needs within the entire district of *Pauri Garhwal.*
2. To make the energy plan more flexible, it is proposed to improve the present work by including additional simulation exercises involving other methodologies like system dynamics, econometric modeling and time series forecasts that highlight other aspects of energy planning.
3. The present study did not attempt to identify/isolate the socio-economic determinants for the energy consumption habits of the rural population in *Kanvashram*. This investigation appears to be necessary in order to obtain a sound working background of the socio-economic peculiarities that characterize energy consumption in the study area, and, help in formulating more effective energy

plans. Such studies can therefore be taken up as additional exercises for micro level energy planning of rural areas.

4. The policy moves for the present study were evaluated in terms of *PER*, which is essentially a "cost-benefit" ratio. It is possible to use alternative concepts/methodologies for the evaluations like: systems dynamics, input-output analysis, where causal effects due to changes in energy resource recommendations are quantified. The evolution of suitable policy evaluating methods on the above lines could also be tried out as an extension exercise.

APPENDIX A

SCHEDULE/ QUESTIONNAIRE USED FOR THE ENERGY SURVEY

Household questionnaire number/code____________________

Village______________________________

Block______________________________

District______________________________

[A] General Information of the Household

(i) Name of head of the household__________________________________

(ii) Age of the head of the household(years)____________________________

(iii) Type of family structure (joint or nuclear)___________________________

(iv) Religion of the household(Hindu/Muslim/others)_____________________

(v) Caste of the household (low caste/middle caste/upper caste)______________

Family Size

(i) Number of men in the family_________________________

(ii) Number of women in the family_______________________

(iii) Number of boys in the family(age < 15 years)____________

(iv) Number of girls in the family(age < 15 years)____________

(v) Total number of adults____________________

(vi) Total number of children__________________

Literacy Status of Household

(i) Number of men in household who can read and write________________

(ii) Number of women in household who can read and write______________

(iii) Number of children in household who can read and write_____________

(iv) Educational qualification of the head of the household________________

Occupational Activities

(i) Main occupational activity of the major part of household(mention if it is agricultural/nonagricultural based activity) _________________________

(ii) Main subsidiary occupation activity of household (if any)_____________

(iii) Size of land holdings, if any in acres (write "nil" if household has no land holdings) ____

Income Earnings of the Household

S. No.	Family member(s)	Earnings contribution (monthly)	Approximate no. of months of employment /year
1.	Head of household		
2.	Other men in household		
3.	Women in household		
4.	Children in household		

(i) Total income earnings/year______________________________

[B] <u>**Information Pertaining to Energy Consumption Habits**</u>

(i) Do you own a biogas plant? (yes/no)_______________

(ii) If "yes", how much dung do you provide it on a daily basis? ______________

(iii) Do you purchase this dung or do you obtain it from your cattle? ___________

(iv) Do you use the dung for any other purpose? (e.g. manure for fields/making dung "cakes" as fuel for periods when biogas supply is bleak)_____________

Energy Resource Consumption Habits of Households

S.No.	Energy End Use Application	Main Type of Energy Resource Used	Secondary Energy Resource (if used)	Tertiary Energy Resource (if used)
1.	Cooking			
2.	Lighting			
3.	Space Heating			
4.	Space Cooling			
5.	Irrigation			
6.	Rural Industries			
7.	Others (specify)			
	____________			
	____________			
	____________			
	____________			

Energy Consumption Estimates of Households

S. No.	End use	Resource device used	Average no. of hrs. used/day	Average no. of days used/year	Specific fuel consumption rate (kWh/hr.)	Total average energy consumed/year
1.	Cooking	(a)				
		(b)				
		(c)				
						Total
2.	Lighting	(a)				
		(b)				
		(c)				
						Total
3.	Space heating	(a)				
		(b)				
		(c)				
						Total
4.	Space cooling	(a)				
		(b)				
		(c)				
						Total
5.	Others (Specify)	(a)				
		(b)				
		(c)				
						Total
	Total annual energy demand					

[C] **Energy Resource Shifts in Rural Population**

(i) If the economic status of your household improves, indicate (by ranks:1, 2, etc.) your preference for different fuels for various end use applications as given in the table: (Note: 1= highest rank, 2=next highest and so on)

S.No.	End Use Application	Energy Resource									
		Electr-icity	Kero -sene	LPG	Diesel	Biogas*	Anim -al dung	Agro waste	Fuel wood	Solar PV*	Solar Thermal*
1.	Cooking										
2.	Lighting										
3.	Space Heating										
4.	Space cooling										
5.	Rural Industries										
6.	Irrigation										
7.	Other (specify)										

* **Note:** Rank to be filled only if respondent is aware/ familiar with the scope/ limitations of such energy resources

(ii) Indicate (by use of terms: very important/important/ fairly important/ unimportant) your views on the following attributes of energy resources:

(a) Cost ________ (b) Availability_________ (c) Dependability______ (d) Ease in usage_______ (e) Pollution involved_________ (f) Performance Quality_________

APPENDIX B

PER CAPITA INCOME RANGES AND THE CORRESPONDING DECILE GROUPS FALLING WITHIN THE RANGES

S. No.	Per Capita Income Range (Rs.)	Percentage of *Joint* family Households (%)	Decile groups falling within the Income Range	Percentage of *Nuclear* family Households (%)	Decile groups falling within the Income Range	Percentage of *All* family Households (%)	Decile groups falling within the Income Range
1.	3000-6000	0	Nil	0	Nil	0.0	Nil
2.	6000-9000	45.0	1-4,5(part)	15.0	1,2(part)	30.0	1,2(part)
3.	9000-12,000	25.0	5(part),6,7	5.0	2(part)	15.0	2(part)
4.	12,000-15,000	10.0	8	0.0	Nil	5.0	3(part)
5.	15,000-18,000	10.0	9	15.0	3,4(part)	12.50	3(part)
6.	18,000-21,000	10.0	10	10.0	4(part),5(part)	10.0	3(part),4
7.	>21,000	0.0	Nil	55.0	5(part),6-10	27.5	5-10
	Total	100		100		100	

APPENDIX C

COST/kWH OF VARIOUS ENERGY RESOURCES AT CURRENT PRICES

S.No.	Resource	Prevailing Price/Unit	Prevailing Price/kWh
1.	Electricity	Rs 2.00/KWH	Rs 2.00/kWh
2.	Kerosene	Rs 7.00/Litre	Rs 0.6717/ kWh
3.	LPG	Rs 16.19/Kg	Rs 1.19/ kWh
4.	Fuel wood	Rs 3.00/Kg	Rs 0.645/ kWh
5.	Animal Dung	Rs 0.50/Kg	Rs 0.1432/ kWh
6.	Agro Waste(direct fuel)	Rs 0.00/Kg	Rs 0.00/ kWh
7.	Solar Energy	Rs 0.00/Kg	Rs 0.00/ kWh

Note: Conversion of Units to kWh is done on the basis of calorific values as given in Kishore(1988)

APPENDIX D

COMPUTATION OF POLICY EFFECTIVENESS RATIO *(PER)*

The following steps are carried out to evaluate the ***PER*** for each scenario:

Step 1: Decide on the number and type of energy resources to be used for the energy plan.

Step 2: Decide on the multi-criteria to be used for evaluating the energy resources.

Step 3: From a team of energy experts obtain the average scores (on a scale of 0-10) for *each of the multi criteria to be used in the assessment.*

Step 4: Evaluate each energy resource on a score rated from 0-10 *on the basis of the each of the multi criteria chosen.*

Step 5: The *Total Score* of each energy resource can then be computed from the relation:

$$S_{Ti} = \sum S_{ij} * S_{j\,avg}$$

Where: S_{Ti} = *Total Score* of the ith energy resource

S_{ij}= *Effective* score awarded to ith energy resource in relation to jth criteria

$S_{j\,avg}$ = Average score of energy experts for jth criteria

Note : S_{ij} = S for a criteria that is has positive repercussions

=(10-S) for a criteria that has negative repercussions, S being the score awarded.

The weightage of the ith energy resource has been obtained as a relative weightage in comparison with the total score for agro waste, the lowest type of energy resource in the "Energy Ladder" hierarchy.[Reddy and Reddy(1994)].

This is given as:

$$W_i = S_{Ti}/S_{T\ agrowaste}$$

Step 6: The energy resources are arranged in the form of an "Energy Ladder" [Reddy & Reddy (1994)] The energy ladder of traditionally used energy resources [TEDDY 1999/2000] has been modified to include certain energy resources that have hitherto not been considered for the generalized energy ladder (solar energy and biogas). The relative position of these energy resources within the ladder was arrived at after seeking opinions of the villagers in the study area, in relation to their energy resource preference should their income level experience an improvement (see questionnaire/schedules in *Appendix A*).

Step 7: Each scenario will result in a revised energy resource allocation for the energy resources in question. The weights of the energy resource as obtained in step 5 are then used for computing the "Social Benefit Ratio". This ratio is simply a measure of the overall recommended shift of energy resources from inferior ones to superior ones,(or vice versa) and, as such, an indication of the change in " social welfare" advocated by the scenario. The change in social welfare is to be balanced by a change in the overall cost of supplying the required energy demand to the area. – The "Cost Ratio" The overall ratio of these two independent ratios will yield the "Policy Effectiveness Ratio". Relevant relationships are given as below:

Policy Effectiveness Ratio= Cost Ratio/ Social Benefit Ratio

$$\text{Cost Ratio} = \sum C_i * RA_{i\ scenario} / \sum C_i * RA_{i\ base}$$

$$\text{Social Benefit Ratio} = \sum W_i * RA_{i\ scenario} / \sum W_i * RA_{i\ base}$$

Where:

C_i = Cost of ith energy resource in Rs/kWh (see table of costs of energy resources)

W_i = Weightage of ith energy resource (**step 5**)

$RA_{i\ scenario}$= Resource allocation for the ith energy resource in accordance with the model allocations for scenario

$RA_{i\ base}$ = Resource allocation for the ith energy resource in accordance with the model allocations for the reference case (year 2005 A.D.)

Ideally,

If *PER* <1.0, the policy is to be recommended

If *PER* >1.0, the policy is to be rejected

If *PER* ≈ 1.0, the policy needs to be reconsidered for recommendation or rejection.

However, realizing that absolute rigidity is not mandatory in energy planning exercises, a little leeway may be introduced in setting cut off limits. Accordingly, the following revised limits for policy acceptance/rejection are chosen:

If *PER* value is upto 1.01 (i.e a 1% increase), then policy move is to be accepted

If *PER* value lies between 1.01 and 1.03 (i.e. a maximum of +3%), then the policy move may be treated as a break even situation needing reconsideration as to its implementation.

If *PER* exceeds 1.03 (i.e exceeds +3%), then the policy move may be rejected.

APPENDIX E

WEIGHTS OF ENERGY RESOURCES WITH RESPECT TO AGRO WASTE AND IN ACCORDANCE WITH THE ENERGY LADDER

The traditional energy ladder hierarchy indicates the rank order of different energy resources with the cheapest energy resource occupying the lowest "rung" of the ladder and the most expensive energy resource occupying the uppermost "rung". Other energy resources occupy intermediate positions in between these two extremes. The position of any particular energy resource depends on its unit cost relative to that of the others. It is evident that the unit cost of a particular energy resource will depend on the superiority of its performance characteristics as a fuel. Therefore certain criteria can be used to evaluate the "superiority " of different energy resources in the ladder. This can be use as a proxy indicator for the "weight" of an energy resource vis-a vis the others. In the present case, it was thought appropriate to use the following four criteria:

(i) Reliability of energy output of resource-associated conversion device

(ii) Quality of output

(iii) Pollution

(iv) Ease of obtaining repairs and general maintenance

The table of weights Wi (relative to energy resource on the lowest rung of the energy ladder) was obtained in relation to the following additional four criteria for which energy experts awarded scores on a scale 0-10:

This is given below:

Table showing Weights of Energy Resources with respect to Agro Waste and in accordance with the Energy Ladder

S.No.	Energy Resource (In descending order of the Conventional Energy Ladder)	Weight (W_i) (with respect to agrowaste, the lowest energy resource "rung "of the energy ladder)
1.	Electricity	1.945
2.	Biogas	1.382
3.	LPG	1.746
4.	Kerosene	1.118
5.	Solar energy	1.636
6.	Fuel wood	1.264
7.	Agro waste	1.000

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