RURAL ELECTRIFICATION IN DEEP AREAS OF INDIA AND FEASIBILITY STUDY OF SOLAR HOME SYSTEMS

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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DECLARATION

I hereby *declare* that the Research Thesis entitled **Rural electrification in deep areas of India and feasibility study of solar home systems** Which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Electrical and Electronics Engineering** is a bonafide report of the research work carried out by me. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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C E R T I F I C A T E

This is to *certify* that the Research Thesis entitled **Rural electrification in deep areas of India and feasibility study of solar home systems** submitted by **Kamalapur Gopalkrishna Dhruvaraj,** (Register Number: **040329EE04P2**) as the record of the research work carried out by him, is *accepted as the Research Thesis submission* in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy.

Research Guide
(Name and Signature with Date and Seal)

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ABSTRACT

The majority of the world's population, primarily living in rural areas, lacks a number of facilities as a result of poverty and insufficient access to energy. The conditions necessary to satisfy basic needs and to promote economic and social development cannot be fulfilled. Most of the people without access to electricity live in thinly populated areas in developing countries and the extension of the grid to these areas are not feasible mainly due to economical reasons.

Electricity is a desirable commodity in the majority of the areas, it should be noted that electricity is only one of the options to satisfy the energy needs of the rural population, along with other rural needs. Rural electrification is an integral component of poverty alleviation and rural growth of a nation. The availability of electricity can support advanced development methods such as tele-education and it could provide access to distant information and support for farmers and other entrepreneurs. Hence present study addresses electricity supply for deep rural and remote areas of India.

A study of several aspects of rural electrification in India, the role of Government of India and the feasibility of Solar Home Systems is carried out in this thesis.

CONTENTS

NOMENCLATURE

AIC : Average Economic Incremental Cost

APDRP :Accelerated Power Development and Reform Program

AT&C : Aggregate Technical and Commercial Losses

BAU : Business as Usual

BEE : Bureau of Energy efficiency

CAGR : Compounded Annual Growth Rate

CAIDI : Customer Average Interruption Duration Index

CCS : Carbon Capture and Sequestration

CEA : Central Electrical Authority

CERC : Central Electrical Regulatory Commission

CFL : Compact Fluorescent lamp

DAE : Department of Atomic Energy

DSM : Demand-side management

DST: Department of Science and Technology

ED : Electricity Department

EIRR : Economic Internal Rate of Return

ERR : Economic rate of return

ESMAP : Energy Sector Management Assistance Program

ETP : Energy Technology Perspective

GDP : Gross Domestic Product

GoI : Government of India

HDI : Human Development Index

HH : household

HVDS : High Voltage Distribution Systems

IEA : International Energy Agency

KgOE : Kg Oil Equivalent

km : kilometer

kWh: Kilowatt hours

LPG : Liquid Petroleum Gas

LRMC : Long Range Marginal Cost

LTMC : Long Term Marginal Cost

MNRE : Ministry of New and Renewable Energy

MoP : Ministry of Power

MV : Medium Voltage

NEP : National Electricity Policy

NGO : Non Governmental Organisation

NRECA : National Rural Electric Cooperative Association

NREL : National Renewable Energy Laboratory

NTP : National Tariff Policy

O&M : Operations and maintenance

PFC : Power Finance Corporation

PV : Photovoltaic

RE : Rural Electrification

RES : Renewable Energy Resources

RET :Renewable Energy Technologies

RGGVY : Rajiv Gandhi Grameen Vidyutikaran Yojana

RVE : Rural Village Electrification

SAIFI : System Average Interruption Frequency Index

SEB : State Electricity Board

SERC : State Electrical Regulatory Commission

SHS : Solar Home System

SPV : Solar Photo Voltaic

T&D : Transmission and Distribution

UNDP : United Nation Development Program

UNEP : United Nation Environment Program

USAID : United States Agency for International Development

USO : Universal Social Obligation

WCED : World Commission on Environment and Development

WEC : World Energy Council

WEO : World Energy Outlook

Wp : Watt peak

CHAPTER 1

INTRODUCTION

1.1. Research problem

1.1.1. A matter of priorities

The year 1961 contained the first manned space flight: a striking example of mankind's capabilities enabled by applied scientific research. Some 25 years later such flights have become common and now launchings on a profit basis are even being performed to bring stationary satellites to orbit.

Mankind is capable of having a number of people remaining extraterrestrial for many months. Further removed from us than the furthermost rural dweller on this planet, the astronauts have an extremely reliable electricity supply at their disposal for preparation of food, air-conditioning, heating, telecommunication, video equipment and scientific experiments.

The International Space Station Alpha for instance, will be provided with a 94 kW peak power generation system consisting of solar arrays and a nickel hydrogen battery based energy storage system. In the future the system will be complemented with solar dynamic generators. It should be noted that in orbit electricity generation by solar arrays is considerably advantaged by the local solar constant flux of 1371 W/m^2 as compared with a mean annual of 100-300 W/m^2 on earth.

The continuous power of this station amounts to 76 kW which includes an average of 20 kW for the execution of payload experiments. In their remote accommodation up to six astronauts will have an electricity supply of some 56 kW available for the space station infrastructure including preventive, diagnostic and therapeutic medical equipment and housekeeping operations (European Space Agency 1996). The power available on board the Space Station Alpha for housekeeping and medical care could fulfill the basic electricity needs of some 600 rural households in developing countries by using modern energy-efficient appliances.

Although electrification commenced some one hundred years ago, currently still about 40% of the world's population have neither access to electricity nor to sufficient other non-traditional energy forms.

It is fairly certain that the world population will grow from the present five billion to eight billion within the next 20 years or so and as a consequence the number of citizens without an adequate energy supply will further increase if business as usual (BAU) is supposed.

Most of the two billion people without access to electricity live in thinly populated areas in developing countries and the extension of the grid to these areas are for economical reasons not feasible. Thus other solutions are needed for these areas. People have managed to satisfy extraterrestrial energy requirements but not those on earth. Undoubtedly many reasons can be found to explain this inconsistency.

As demonstrated by space research, mankind is technically and organizationally capable of realising complex and impressive projects. There is no reason to believe that extraterrestrial power supply is economically more feasible, technically less complicated or socially more obvious than the energy supply to the underdeveloped rural and remote areas on earth.

The present global situation, in both positive and negative senses, is the result of the intrinsic dynamism and effectiveness of a system consisting of three components: science, technology and capital. This system has developed into a more or less autonomous system in the sense that the human objectives to be realised, are not determined in advance.

Additionally, it remains to be seen whether another order of priorities would have led to an appropriate worldwide energy supply. It is a fact that at this very moment a large part of the global village lives in poverty and suffers a lack of water, proper health care and energy.

1.1.2. Scope

There is no doubt that energy is needed to achieve an acceptable quality of life for the global village as a whole. Energy alone is not sufficient for creating the conditions for economic growth, but it is certainly necessary. Over the next few decades a wide range of energy forms will be required to satisfy the increasing global demand.

Moreover, our global energy system is such that developed and developing countries are interdependent in their efforts to provide sufficient and affordable energy and to maintain an ecologically sound planet. Emphasis should thus be on the development of a global energy and environmental policy and planning to achieve a sustainable energy supply for the world's population and the mitigation of the impact of energy-related activities on the environment.

The World Energy Council (WEC) is right in concluding that the energy and ecological issues of both developed and developing countries and the transition to a sustainable path of development will require a stronger determination by governments, energy enterprises and international organisations.

The majority of the world's population, primarily living in rural areas, lacks a number of facilities as a result of poverty and insufficient access to energy. The conditions necessary to satisfy basic needs and to promote economic and social development cannot be fulfilled. The majority of the additional 2.8 billion people predicted by the year 2020 are not even expected to have any access to commercial forms of energy at all, supposing business as usual. The lack of access to a reliable energy source is a major impediment to sustainable development, in developing countries. The idea that all nations on earth have a right-and should have the means-to pursue these benefits will become increasingly important in a world where opportunity is disproportionately divided between the industrialised countries of the northern hemisphere and the poorer nations farther south. Wider access to electricity in developing countries will be a key requirement for narrowing the north-south gap. If electricity is to truly promote human progress in developing countries, then the problem of rural electricity supply must be addressed.

The subject of energy supply to rural and remote places appears on many agendas including that of the World Energy Insight 2011(WEC report) "Energy poverty hinders development and threatens growth. We must seek to identify ways of providing electricity access for the two billion energy poor in developing and an also developed country, the renewables market has great potential but will require significant leadership to fully realise its potential: we need to promote the use of already mature technologies, while fostering R&D for technologies that are not yet mature."

This study addresses electricity supply for rural and remote areas. Although electricity is a desirable commodity in the majority of the areas, it should be noted that electricity is only one of the options to satisfy the energy needs of the rural population along with other rural needs. Bringing electricity to the people is 'in itself ' is not a contribution to reducing poverty nor does it automatically lead to rural development. However, the availability of electricity can support advanced development methods such as tele-education and it could provide access to distant information and support for farmers and other entrepreneurs.

1.1.3. Rationale of the research

The utilisation of the electricity supply industry has brought many benefits to society. Today, electricity plays a vital role in our society, socially, environmentally and economically.

Over the last few years, the sector has faced rather dynamic changes, the most salient being of an institutional nature. Today deregulation, power share, market forces, unbundling, non-utility generation and third party access to the grids are the new key words in the sector.

In a number of countries, the electricity supply sector has become the playing field of traders, economists and brokers, with standards, values, performance and procedures adapted to the new players and circumstances. In some countries industrial, commercial and residential consumers are already able to shop for electricity and therefore the electric utility operators will primarily be directed towards effective competition. Obviously, the new circumstances will force utilities to reduce costs and to reconsider their strategies and organisations.

Utilities in the poorer nations of the world are however still struggling to get electrical supply and make electricity more widely available particularly in rural and remote areas. They face problems such as institutional weakness, lack of capital, uneconomic tariffs, and substandard technical and managerial performance. These countries also have reasons to reassess their operations and in this respect they are encouraged and occasionally obliged by lending institutions.

Apart from the institutional changes, utilities in both developed and developing countries have to meet increasingly stringent requirements to protect the environment and to conserve energy.

It is noted that rural and remote areas often have substantial renewable energy potential. The IEA Renewable Energy Working Group Party argues that renewables are localised energy sources and that their deployment benefits rural and remote communities in terms of employment and income generation.

New technologies effect at both the supply side and the demand side and there is reason to believe that current developments and trends in the power sector will have an effect on the way rural electricity supply behaves. It is also likely that the developments will not only influence new systems but also existing rural electricity supply schemes.

A wait and see attitude is not the appropriate approach. Some two billion people and huge amounts of money are involved. Based on figures given Foley (1995), the average costs per connection can be roughly estimated at US$ 12000.

With an average of five persons per connection, an amount of some 500 billion dollars would be needed just to establish connection of the two billion people to the grid. If the costs for the generation and transmission facilities were included, the total amount would be in the order of 800 billion dollars.

The IEA Renewable Energy Working Party even estimated that in the next four decades over five trillion dollar would be needed for additional generating capacity only. A literature survey revealed that rural electrification has been the subject of many studies and publications and the question had to be answered whether it would be socially and/or scientifically justified to add further to this research. The answer to this question appeared to be positive. Existing literature, with a focus on developing countries, albeit comprehensive has mainly addressed the technical, financial and socio-economical aspects in isolation.

It is clear that a comprehensive historical analysis of a broad field of rural electrification cases can reveal lessons learned. An integrated analysis of the impact of recent technological and institutional developments, and other trends, on the electricity supply to rural and remote areas can contribute to the assessment of future technical and institutional arrangements.

1.2. Problem description

The electrification of rural areas is expensive. Capital costs are relatively high and revenues are frequently poor. However, rural electricity supply may have new dimensions because of recent technological advances and the ongoing power sector reform.

The developments and trends can be grouped into five dimensions: the environmental aspects of power supply and the sustainability of power resources, the technological advances, the organisation and performance of the power sector, the societal trends and the institutional aspects.

Both energy sustainability and environmental constraints will increasingly force appropriate measures onto the global power sector. The progress in the field of energy technology, including renewables, has been significant and new opportunities present themselves through both demand side and supply side management developments.

Renewables can contribute to the mitigation of environmental problems. Conventional electricity generation will still be required but, for reasons of energy efficiency, the combination with heat production needs to be pursued. This requires a closer co-operation between the utility, industrial and commercial consumers in both rural and urbanised areas. Over five trillion dollar would be needed for additional generating capacity only.

In many less developing countries the performance of electric power utilities supplying remote and rural areas has decreased gradually in spite of the provision of external financial support. Moreover the benefits and progress of a considerable number of rural electrification projects has fallen short of expectations, financially and managerially.

There is a worldwide trend towards power sector reform including the introduction of competition among suppliers. This development together with the opportunities offered by renewables could have a major effect on the way rural electrification is approached, not only in electrified countries but also in developing countries. With the emergence of a more competitive and deregulated environment, utilities are being forced to reassess the benefits and costs of many of their internal business practices and to increase their efficiency. This development is at odds with electricity supply to rural and remote areas because of their generally unfavourable contribution to the financial performance of the utilities. It is therefore possible that a drastic economic rationalism may result in a fall of interest in the electrification of rural areas.

The central hypothesis is that current developments and trends force a more advanced approach to electricity supply to rural and remote areas, which should be reflected in the operations of utilities.

This study is to analyse rural electrification issues in the light of past experiences and current developments in the electricity supply sector and aims to provide an insight into the way rural electrification is to be carried out.

1.3. Research justification

1.3.1. Objectives of the investigation

Originally, the research was initiated out of surprise that so many rural electrification projects in developing countries were considered to be below standard and also from curiosity into the possible effects of current sectoral developments and trends on rural electricity supply.

The idea that, where relevant, future electricity supply to rural and remote areas should be done following a fresh approach played a role in the decision to actually perform the research.

The research aims to prove the central hypothesis but it also seeks to contribute to the utilities could take full advantage of new technologies and better insights to meet their objectives.

In fact the research has a dual objective. In one respect it aims to make a theoretical contribution to the scientific knowledge about rural electricity supply and in the other to generate and disseminate knowledge which could support decision makers of utilities and donor agencies when deciding on policy.

With regard to the latter point, the research concerns the field of strategic planning, including the implications for utility operations. To this end the research identifies and assesses relevant trends, looks ahead to opportunities for electricity supply to rural and remote areas and translates the results into operational recommendations. In this respect the present publication seeks to complement existing literature and to act as a vehicle of technology transfer. The implementation of the recommendations suggestions will need individual tailoring to specific circumstances and this can only be done on the basis of a thorough knowledge of the situation. The results of this research are expected to contribute for the implementation, in rural and remote areas, of utility facilities that are energy-efficient, environmentally, financially optimal and sustainable.

1.3.2. Societal relevance

The societal relevance of the research is based on the following observations.

The large numbers of global villagers in rural areas that are still deprived of access to electric power but undoubtedly want to use it in the very near future. A continuation of business as usual would imply an increasing number of people deprived of electricity.

The assessment of rural electrification projects revealed that many of the existing rural electrification systems in developing countries fell short of expectations. The costs associated with disappointing projects can be very high. There is a need for an efficient, effective and affordable electricity supply to rural and remote areas.

The need is to implement ecological and energy sustainable solutions in the world's power supply. Rural areas in particular appear to offer opportunities for the deployment of renewables and these can be geared up to meet the demands.

The tendency of reforming the power sector and introducing competition could have adverse consequences but also opportunities for rural areas. A well performing organisation is extremely important particularly when the developments become more radical and significant.

Given these observations, it appears sensible to investigate whether presently available technologies and insights enable and/or require a specific organisation of the electricity supply to rural and remote areas. The results could contribute to the betterment of the situation of rural communities and in the performance of the organisations serving their areas.

1.3.3. Scientific relevance

In literature, there have been many publications on electricity supply to rural areas. Foley (1995) addressed in his publications nearly all the aspects of rural electrification.

Barnes (1988) focused in his study on the socio-economic impact of electrification. He also addressed cost-benefit ratios of electrification in both financial and social terms and the various rural electrification policies.

The National Rural Electric Co-operative Association has also been very active in the field of rural electrification.

Most of the research has addressed issues such as the technical and financial performance of both grid connected and decentralised power systems and the socio-economic impact of electrification. The implications of recent developments and trends for power utility operations seem to have received less attention. No research is known of, in which the effects of current developments and trends have been systematically and integratedly investigated as per my little knowledge. The present research undertakes such a task.

This study links existing theoretical knowledge, case studies and practical experience with the aim of increasing the specific expertise needed for organising utility operations. In this respect the publication also aims of bridging the gap between more theoretically focused researchers and managers/decision makers with a more practical approach.

1.4. Research domain

This study is confined to the electricity supply to rural and remote areas. The problems applicable to large scale systems differ from those of the electricity supply to rural and remote areas and are mainly of an administrative and technical nature.

The importance of historical research is highly valued because it creates the possibility of identifying analogies and analysing the experiences gained with alternative arrangements. These cases have been selected on the basis of the extent and quality of the available information and the diversity.

Given the scope of this study, past research and the experiences in both developing and developed countries, it is argued that there is no need for an in depth analysis of all the aspects of rural electrification. The reality of electricity supply to developing rural areas is very complicated and there are many relevant aspects. Technical developments have been analysed to identify their possible opportunities and implications on both the supply and the demand sides. The emphasis is on an integral approach and on the success factors for rural electricity supply.

1.5. Structure of the research

1.5.1. Fundamental and application-oriented research

The viewpoint has been put forward that science should serve only for the solution of societal problems and that science as such should be avoided. There is a difference between the notions of fundamental research and application-oriented research.

An important difference is that fundamental research can be considered as independent of time, place, subject/client and observer while application-oriented research is subject/client dependent. In the former case there is no direct beneficiary while in the latter case a concrete person or organisation can always be recognised.

Another important difference is that fundamental research basically aims at maximum truth and application-oriented research at maximum usefulness. In technology the applications are in fact the horizon of all research, fundamental research included and energy research is for the greater part, or even totally, application-oriented.

The notions of fundamental and applied research do not cover certain activities and the distinction is in fact meaningless because neither can exist without the other. The best solution is to avoid a distinction between fundamental and applied research; but a pragmatic approach is needed. Long term fundamental research remains necessary to further explore basic existence and there is also a need for application-oriented research to help in solving society-driven problems.

I have tried to approach the research in such a way that a synthesis of academic research and power utility practices could be achieved. In doing so, I had to balance the degree of attention paid to the various subjects.

1.5.2. Research method

Previously, rural electrification projects were treated as solely technical activities and separated from other rural aspects. Evidence suggests that rural electrical energy supply must be treated within the context of rural development at large.

To this end, thinking in processes rather than in disciplines is needed. In effect this research aims at giving policy recommendations so that, those involved can make relevant decisions applicable for their particular situation.

To transfer expertise to the industrial sector, a thematic and even more importantly-an integrated approach is necessary. Moreover, one should focus on the recognition of both problems and the directions of solutions.

The electrical energy supply to developing rural areas is an area par excellence where technology, organisational, social and economical sciences should work together. The present research does not unveil a new area but adopts an integrated approach to identify the implications of various developments for the organisation of power supply utilities in rural and remote areas.

The objective of this research is to identify and assess relevant trends, to look ahead to opportunities for electricity supply to rural and remote areas, and to translate the results into recommendations that can be used by decision makers. This study therefore analyses rural electrification issues in the light of past experiences and current developments in the electricity supply sector and discusses theoretical aspects related to the environment of electricity supply utilities.

In effect this work consists of three components: an analytical, case studies and a practical component divided between a numbers of chapters. The analysis of the developments and trends leads to three research themes: the rural market, the available technologies, and institutional aspects.

The information needed for the research has been obtained from, study of literature, survey of policy documents, project assessments and case studies. A number of case studies are used throughout the research but they mainly provide qualitative information. To the best of my knowledge, there is perhaps so far, very few studies had been done on this area.

1.6 Contents of the thesis

Chapter 2 deals with the objectives, features of rural electricity supply, benefits of rural supply namely socio-economic, political and environmental, challenges faced by rural communities, technologies commonly used and implementation aspects like costs in the world.

Chapter 3 discusses the salient features of Indian electrical power sector and reforms, state electricity boards, governance of RE, a case study of energy pattern in a village, transmission and distribution network, specific challenges, and international experiences of Argentina, Bangladesh.

Chapter 4 makes a study of features of rural electrical loads in India, a case study of load profile of urban, peri urban and rural feeders, and also comparison of three different rural feeders.

Chapter 5 elaborates the different types of renewable energy options for India like small hydro power, wind, and biomass, geothermal and solar. Few aspects of solar for India, rural home and factors considered for PV panel erection are also touched upon.

Chapter 6 identifies the technical feasibility study of solar home systems, its preliminary design, project design and economic considerations with a case study.

Chapter 7 gives insight into some economic analysis like energy payback period, net present value, life cycle cost and recycling of PV modules.

Chapter 8 concludes with observations, recommendations, and future directions.

CHAPTER 2

RURAL ELECTRIFICATION IN THE WORLD

2.1 Review of Literature

2.1.1 Rural Electrification

The importance of rural electrification (RE) in the development process is recognised in a number of studies and assessments of RE programs that have been carried out during the past decade by the third world countries. (Mohan Munasinghe 1990)

Recent interest in RE has emphasised the importance of linking its development with productive uses for energy and poverty reduction. This has been viewed as necessary to increase the pace of RE and to reduce its concentration on a relatively small number of developing countries. Despite this emphasis, progress in electrifying remote rural areas has been slow. In part this has been attributed to the emphasis on cost recovery and a reliance on the private sector to deliver electricity widely(Paul Cook 2011). The literature on the role and relation of infrastructure in rural areas, to economic growth and development. He focused on the poverty reduction by the major international development agencies and examined the arguments for increasing rural incomes. He analysed reviews the economic and social issues underlying the development of RE, drawing on the experience with both grid and off-grid applications in developing countries and assesses the impact of electrification on the ability to generate income in rural areas.

It is commonly recognised among rural energy experts and development practitioners that electrification activities in rural areas of developing countries should be accompanied by complementary services. Nevertheless, RE projects that confine themselves to hardware financing and civil works without undertaking escorting activities are observed frequently. One intriguing result is that the target group is frequently not aware of the economic potentials of electricity and hence cannot be expected to consider the grid connection decision and the usage of electricity rationally in an economic sense (Jorg Peters et al. 2011). He concludes that responsibility for complementary services should be in principle with the grid operator while the government or regulatory bodies have to assure welfare orientation of the services.

Electricity at home has now become a basic necessity of life throughout the developed and developing world. Grid connections have reached nearly all households in the developed countries; in the developing world have so far been able to connect below 50% of the households to centralised grids. RES now compete with grid-connected electricity in remote and rural locations because of the followings. (Siyambalpitiya D. J. T. 1991):-

- Rural locations have only a few consumers and they too are scattered over a wide geographical areas.
- Remote locations are mostly inhabited by domestic consumers with a little prospect for industrial and commercial growth.
- Domestic consumers are mainly peak-time consumers and do not contribute to the improvement of the poor load factors.

India accounts for a third of the world's population without access to electricity and about 40% of those without access to modern energy. Such a situation exists despite several initiatives and policies to support poor households. Alarmed by the gravity of the situation, the government has recently announced an ambitious programme of RE. The energy access situation of India, RE alone is unlikely to resolve the energy access problem because of low penetration of electricity in the energy mix of the poor. (Subhas C. Bhattacharyya 2006)

Prior to the advent of renewable energy technology, the global rural electrification process (O. Dzune Mipoun and P. Pillay 2009) was delayed for reasons such as:

- The increasing problem of dispersal of the villages.
- The complications with alternatives to grid extension.
- The relatively higher electrification cost for villages located away from grid. Therefore diesel village power supplies were used, disregarding the environmental impact and low reliability of diesel generators.

There is a strong argument in favour of putting greater emphasis on efficiency and restructuring issues, rather than concentrating solely on continued power sector expansion. More attention needs to be given to improving the quality of the service and reducing losses through rehabilitation and reinforcement of power systems. (Mohan Munasinghe 1989)

2.1.2 Grid connected RE

The RE in developing countries is fundamentally different than in developed countries. So different electrification could be made by a Medium Voltage distribution system or by an autonomous hybrid power system. (Thirault D. 2003)

Many problems associated with RE are socio-economic in nature and do not have simple solutions. There are however, a number of technical problems, which have arisen from an unplanned growth of grid. First rural electrification in India has been almost entirely carried out by extending the grid. Secondly the distribution networks have grown in a haphazard fashion. As a result, distribution losses are very large and often the terminal voltages are poor. Rarely have rural local resources been utilized for generating power. The first way is to study the already existing system and providing solutions like-express feeders, replacing transformers of relatively larger ratings, computer aided cost effective solution for loss minimization. (D P Sen. Gupta 1989)

RE is not an attractive investment options to the utility. However, the benefits to the individual consumers and to the national economy are considerably high. RE in Srilankan case with circuit configuration, consumer density, consumer distribution, potential for industries and cost analysis is carried. (Ijumba N M 1999).

The demand side management (DSM) in rural areas (in France) of transmission and distribution, involving the power load curve. DSM has been implemented from 1995 onwards to avoid the need for grid reinforcement and renewable sources dealt. (Jean Pierre Tabet 1997)

ESMAP (2005) dealt with different aspects rural electrification in Brazil like grid extension, isolated systems and decentralised systems. Social and economic benefits of rural electrification and development in the Philippines are measured.

Performance of electrical and electronic equipment at various farm rural industrial sites in and power quality monitoring of rural distributions in Canada is presented (Don O Koval 1992).

Mathematical modeling of rural distribution network, voltage drop, loss calculations and power flow studies using digital computer.(Charles W Brice III 1992) The cost of delivering electricity in remote areas considering cost of generation of electricity and also cost of its transmission and distribution in the country have been estimated. Considering electricity generated from coal thermal power plants, the delivered cost of electricity in remote areas, located in the distance range of 5–25 km is found to vary from Rs. 3.18/kWh to Rs. 231.14/kWh depending on peak electrical load up to 100 kW and the load factor.(M.R. Nouni et al. 2009) He concludes that micro-hydro, dual fuel biomass gasifier systems, small wind electric generators and photovoltaic systems could be financially attractive as compared to grid extension for providing access to electricity in small remote villages.

2.1.3 Renewables in RE

South Asia accounts for 42% of the global population without access to electricity. Such a situation continues to exist despite several initiatives and policies to support electrification efforts by the respective governments. The challenges to enhance electricity access are manifold including technical, financial, institutional and governance barriers, focussing on renewable energy based mini-grids, stand-alone systems and also conventional grid extension. The household connection needs to be improved considerably through a targeted approach and innovative micro-lending model. At the same time the electricity supply also needs to be enhanced, such as through distributed power projects utilizing locally available renewable resources, to ensure that connected households continue to receive electricity and that supply constraints do not inhibit extending electrification to new areas. Developing a regulatory mechanism to extend the tariff fixation for mini-grid projects and providing cross-subsidies to ensure long term sustainability of such projects are highlighted.(Debajit Palit and Akanksha Chaurey 2011) Finally, economic linkages, access to credit and institutional arrangements also need to be organized appropriately, especially for off-grid RE to facilitate successful outcomes.

The demand for energy in rural areas is likely to continue to rise due to the development process and increase in population. The need for bringing about efficiency in the usage of non-commercial fuels such as fire wood and agricultural residues is important, while at the same time renewable sources of energy such as sun, wind and hydal potential have to be harnessed for meeting the increasing demand of energy in the rural areas. RES of energy being decentralized in nature are cost effective in modular form and help to cut in transmission and distribution cost. (Anantha A 1996)

Promoting renewable energy in India has assumed great importance in recent years in view of high growth rate of energy consumption, high share of coal in domestic energy demand, heavy dependence on imports for meeting demands for petroleum fuels and volatility of world oil market. A number of renewable energy technologies are now well established in the country. The technology that has achieved the most dramatic growth rate and success is wind energy; India ranks fourth in the world in terms of total installed capacity. India hosts the world's largest small gasifier programme and second largest biogas programme. In spite of many successes, the overall growth of renewable energy in India has remained rather slow. (S.C. Bhattacharya and Chinmoy Jana 2009) He has dealt with the number of factors that are likely to boost the future prospects of renewable energy in the country; these include global pressure and voluntary targets for greenhouse gas emission reduction, a possible future oil crisis, intensification of rural electrification program, and import of hydropower from neighboring countries.

Hybrid energy sources are preferred because of abundant and freely available, virtually pollution free and have comparatively low maintenance costs. However, this energy has not been exploited fully, mainly due to the relatively high costs associated with the energy conversion technologies. Rural loads are characterised by low load factor, which has a negative influence on plant operating costs and makes it less cost effective to supply them from grid. In such cases hybrid energy sources become the best alternative despite having comparatively high installation costs. The cost can be minimized if there is optimal load sizing by which the source and load characteristics are effectively matched and the supplied energy is efficiently and rationally utilized. (Ijumba N M 1999)

Available distributed generation technologies and their economic performance in rural areas of India with particular emphasis on comparing the costs of hybrid distributed generation systems with conventional grid connections for remote rural villages. Modeling inputs are based on demand, fuel availability, costs and local operating conditions found in the Kachchh district of Gujarat. (Hansen C. J. and J. Bower 2003)

2.2 World rural electrification scenario

Electricity is the key to the modern world. In addition, with technical progress, the gap between the electrified and the non-electrified world continues to widen. The dilemma facing many developing nations is that while they recognise this, the required resources are in short supply. Rural electrification policy making is a challenging task. This demands clear thinking about the distribution of benefits of rural electrification, payment for obtaining, criteria to be used in the selection of areas for electrification and supply technologies.

Motivations for rural electrification programs are generally threefold: social, environmental and economic. A few governments have based their programs on explicit political objectives such as improved rural political stability but more commonly social and economic objectives are combined. Financial logic indicates that electrification should focus first on those areas with high economic growth potential and lowest cost. However, other goals such as social equity, agricultural development and reversal of rural-urban migration may force utilities to compromise their financial objectives. (Table 2.1 and Fig. 2.1 to Fig. 2.4)

Table 2.1 Electrification in the world (Source: World Energy outlook 2009, IEA)

	Population without electricity (millions)	Electrification rate %	% age Urban electrification	% age Rural electrification
Africa	587	41.9	68.9	25.0
North Africa	2	99.0	99.6	98.4
Sub-Saharan Africa	585	30.5	59.9	14.3
Developing Asia	799	78.1	93.9	68.8
China & East Asia	186	90.8	96.4	86.5
South Asia	612	62.2	89.1	51.2
Latin America	31	93.4	98.8	74.0
Middle East	22	89.5	98.6	72.2
Developing Countries	1,438	73.0	90.7	60.2
Transition economies & OECD	3	99.8	100.0	99.5
World	1,441	78.9	93.6	65.1

The pace of rural electrification over much of the developing world is painfully slow. In many African and South Asian countries, it is even lower than rural population growth. In low-income countries final consumption of energy in the residential, services, industry and transport sectors is low and is comprised mainly of biomass. In high-income developing countries, the fuel mix is much more diverse and the overall amount of energy consumed is much higher.

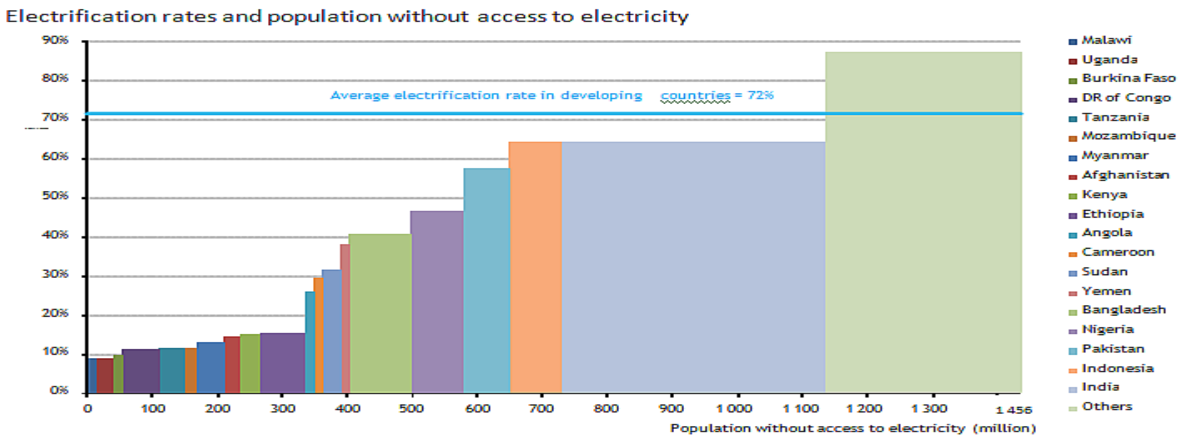


Fig. 2.1 World Population without access to electricity
(Source; World Energy outlook 2009 IEA)

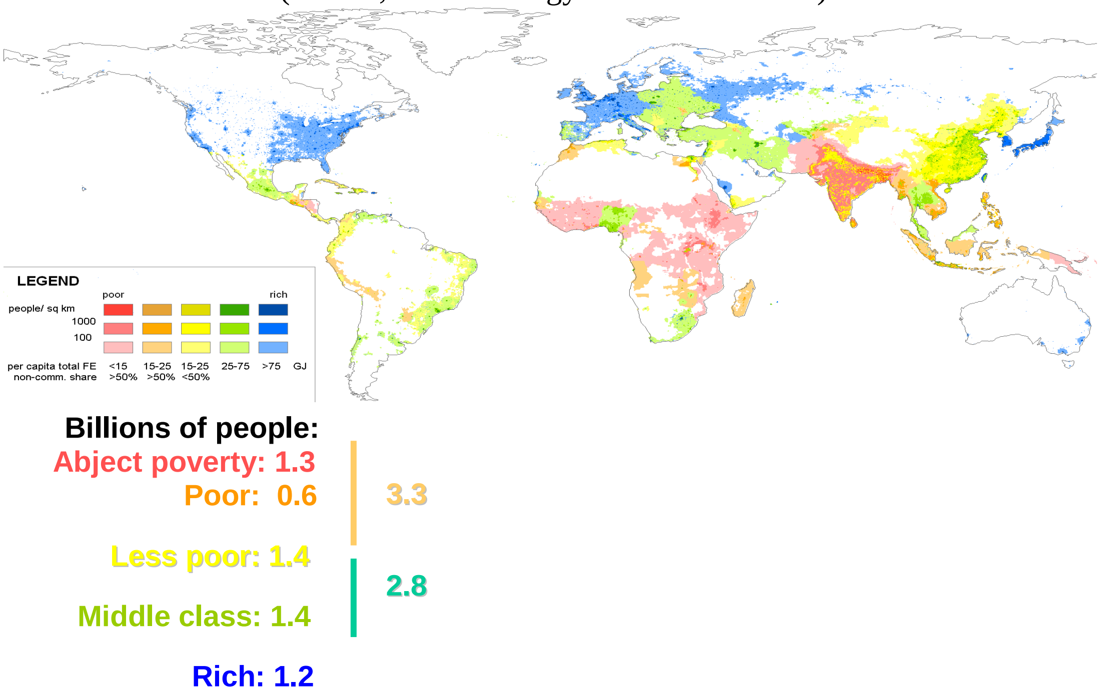
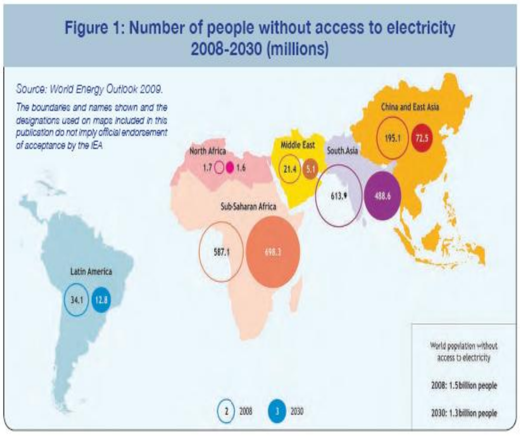


Fig 2.2 Mapping energy access taxonomy (source; Gruebler at al. 2008)



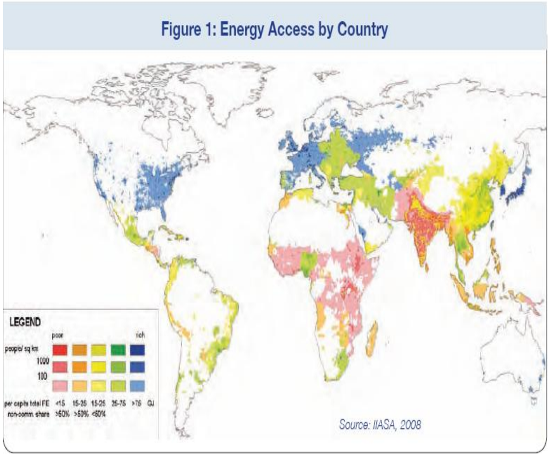


Fig. 2.3 People without electricity   Fig. 2.4 Energy access (Source; WEC 2010)

Demand for mobility, which is indicated where the share of other petroleum products in final energy consumption is high, is much greater in countries with a very low percentage of the population living on less than $2 a day (Fig. 2.5).

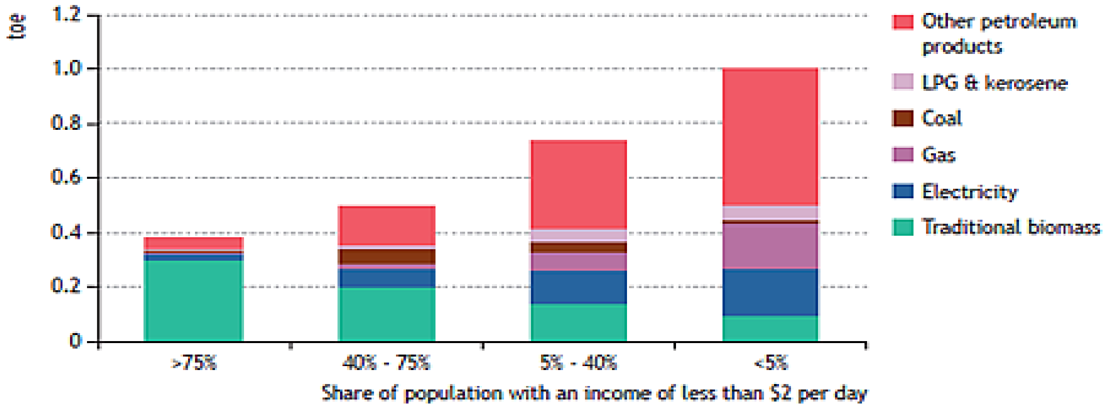


Fig. 2.5 Per-capita energy consumption (toe) and income in developing countries

About 22% of the world's population still does not have access to electricity. In 2008, this represented 1.5 billion people, most of who lived in remote areas often difficult to access and to connect to national or regional grids. The IEA (2009) estimates that roughly 85% of the people without electricity live in rural areas in developing countries, mostly in peri-urban or remote rural areas. Today, most of these people are found in sub-Saharan Africa and South Asia. The IEA predicts that in 2030, if no new policy to alleviate energy poverty is introduced, 1.3 billion people (16% of the total world population) will still be denied electricity most of whom in South Asia and Africa. Fig. 2.6 provides an illustration of the quality of energy services for cooking and lighting as income rises at the household level. The figure is reflective of energy consumption in rural households.

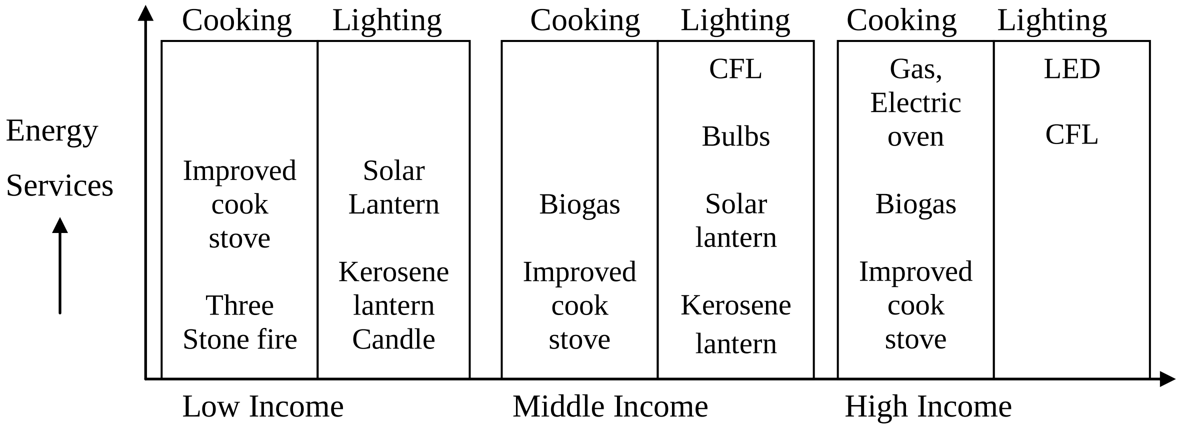


Fig.2.6 Quality of energy mix services in rural households (Source; WEO 2010)

The indicator of the quality of delivered energy services on the vertical axis (Fig. 2.6) is designed to capture a variety of dimensions, including cleanliness, efficiency and affordability. Access to electricity accordingly can reduce total household energy costs dramatically, if upfront costs related to the connection are made affordable. In addition, successful energy efficiency initiatives reduce electricity demand which has the secondary benefit that existing generation plants can be used to supply new households, thereby reducing the need for capacity additions.

Not all electrification policies target poor rural households. Some also target a mix of farms, big villages and small towns all of which call for different technologies. In fact, rural electrification policies are shaped according to the various energy needs, resources and target groups.

2.2.1 Definition of rural electrification

Basically, the concept of RE refers to the electricity supply to areas outside of cities. But many researchers have given the concept highly divergent interpretations. (Munasinghe 1990) He notes that rural electrification schemes are often defined in terms of local administrative units mainly for convenience in implementation. He also observes that most often the term RE refers to connections to a central grid.

As per the understanding of agencies such as the World Bank, the concept of RE does not only refer to strictly rural areas as defined in the country statistics but may also include small to medium-sized towns which are service centers for the surrounding rural areas within a given region.

Rural electrification is defined as “the availability of electricity for use in rural communities regardless of the form of generation”. RE comprises all activities aimed at enabling users situated outside major cities to have access to electricity. (Barnes 1988). The electrification process can be differentiated from the conventional scheme of extension of a national grid, as it covers everything up to independent configurations supplying power for a specific, determined need, and the solving of specific technical and economic problems.

In recent years, with the sustained and rapid development of economy and a huge demand for energy consumption in rural areas, the electricity’s supply cannot meet the requirements of rural electricity consumption development and turns into a bottleneck to economic development in rural areas. It became particularly important that the Wu Guangwei et al. (2011) took a research of electricity consumption in rural areas and then established a predicted model of regional electricity consumption in rural areas.

Literatures revealed that most of the RE projects in the past referred to communities of between 500 and 2000 people. The definition of rural electrification varies considerably between the countries. In one country rural also includes provincial towns with a population up to 50,000 and in another it refers to small farming villages and surrounding areas. (Foley1990) He identifies that one of the consequences of these differences in interpretation is that a comparison between rural electrification projects in different countries is extremely difficult if not impossible.

In the context of this study rural electrification encompasses the activities designed to provide people with access to electricity in those areas which show specific features. These features do not only include low loads and the need for special approaches and area specific opportunities.

The method of bringing electricity to these areas can be very different including isolated generators serving a single or several consumers, supply from a regional or national grid, and solar home systems. It is also observed that the methods can vary, depending on local circumstances and the degree of saturation of the electricity supply.

2.2.2 Objectives of rural electrification

The objectives of rural electrification programs in the latter countries have been very mixed. In one country the reduction in the growing disparity between rural and urban areas with its social consequences and resulting urbanisation was the main objective, while in other countries the improvement of social conditions or the discouragement of the unrestrained expansion of decentralised and non standardised power systems typically had priority.

The improvement of the economic situation of the population by increasing rural industrialisation and productivity, and the improvement of rural living conditions up to the level enjoyed in urban areas.

There is indeed good reason to consider both objectives simultaneously. To successfully support rural development, the appropriate circumstances in rural areas are necessary and, in this respect, electricity is a very attractive means.

Rural electrification schemes are usually justified by reference to multiple objectives and the reasons for the implementation of a rural electrification programme may vary from one country to the other.

The objectives can theoretically be grouped into four categories: economic, social, political and environmental. In practice, however, often two or more objectives occur simultaneously and are interrelated.

2.2.3 Features of rural electricity supply areas

From the energy point of view, there are important differences between urban and industrialised areas and rural areas.

- Urban and industrialised areas feature a substantial higher energy density and market opportunities for both heat and power relative to rural and remote areas. Linked with these differences are the methods and opportunities appropriate to satisfy the energy needs.
- The features of urban and industrialised areas make it economically more attractive to develop and operate connections to a local, regional or even a national power system, to efficiently deploy combined heat and power units, and to provide adequate services. These circumstances offer opportunities to provide heat and power at reasonable prices.

Rural areas show other features like characterised by scattered clusters of premises or by scattered single farms. In most developing countries rural electricity systems are characterised by dispersed consumers with often limited consumption, a low load factor and relatively low quality of power supply. Dispersed consumers require long supply lines and/or diesel-based or other generating units.

RE benefits the poor, acts as a catalyst to rural development. Rural energy problems are particularly complex and RE tries to offer an easily replicated solution, it assists in reducing rural-urban migration and thus in the alleviation of urban congestion and its associated social consequences, it helps to promote political stability in rural areas and it has, through the provision of better lighting and other gadgets, social benefits such as an improved health, the enhancement of literacy, general education and the social cohesion and development in rural communities.

RE is not sufficiently special relative to urban electrification, conventional rate of return criteria should play a stronger role in determining rural electrification expenditures and that some of the non-monetary benefits appear neither to be widespread nor as strong as supporters of rural electricity suggest. While rural electrification is nonetheless important in the development process, it is more usefully integrated into wider rural energy development schemes. On the basis of an assessment of the actual achievements of projects, that there is no or only little evidence that the expectations regarding the benefits often attached to rural electrification, have been substantiated in the past.

Rural electrical distribution projects generally cost more than urban electrical distribution projects per connected household and that government policies are sometimes directed specifically at the rural areas making it necessary to identify rural areas in electrification programs. However in some countries power distribution installations often cover the electricity supply to urban, peri-urban and rural areas and therefore a precise separation may be difficult. There are three major reasons suggested for a distinction between rural and urban power supply:

1. Rural electrification schemes generally cost more on a per connection basis as a result of dispersed loads, the rather low consumption and the poor load factor.
2. Rural electrification should be integrated or coordinated with other rural development programs.

3. Urban and industrial power supply and rural power supply need different marketing and technical approaches.

Table 2.2 summarises a number of features specific to urban/industrialised supply areas and rural supply areas.

The electricity needs of one billion rural poor, who often live in remote areas, are quite different from the urban and grid accessible populations. The information provided in the table 2.3 assumes an average family size consisting of six people. The estimates given are for end-use equipment that is currently commercially available. The estimated power use is about 0.08 kWh per day per person (80Wh/day/person). The annual power use per person is about 30 kWh (0.0035 kW per person). With rapid advances in efficient end-use technologies, such as CFL, white LEDs, the daily energy usage will be further reduced. At present, the initial costs of these technologies are prohibitively high for implementation.

Table 2.2 Comparison of urban and rural supply (Source; Munasinghe 1990)

Features	Industrial/Urban supply areas	Rural supply areas
Area load (kW/sq.km)	500 to 100,000	2 to 50
Consumer density (Connection/ sq. km)	>500	1 to 75
Number of consumers/km length (both MV and LV)	>75	1 to 75
Total cost/kWh(UScent)	10 to 15	Grid : 12 to 50 Diesel : 25 to10 SHS :50 to 500
Investment cost/ connection (US $) excluding generation & transmission	<500	500 to 700 average 1200 extremes of over 2000
Social aspects	Limited	Specific financial support and solutions needed
Technical and organisational aspects	Large projects; often heavy power technologies on supply and demand supply; Reasonable load factors as a result of mixed loads	Various technologies & small scale applications; low load factor-domestic & agricultural loads; intensive customer support
Socio-cultural aspects	Seldom important	Important
Economical aspects	Profitable business opportunities	Limited profitable business opportunities

Table 2.3 Estimated capital cost and energy use for household electrical services

Equipment(numbers)	Capital cost (US$)	Power demand (kW)	Usage (hours/day)	Daily energy (kWh/day)
Light fixtures(2)	6	-	-	-
Bulbs 2 numbers (20Watt,CFL)	10	0.040	5	0.2
TV	90	0.007	4	0.18
Other	50	-	-	0.18
Total/household	200	-	-	0.48
Total/person	34	-	-	0.08

Rural people generally do not want energy in itself, but the ‘energy services’ it provides, such as lighting etc. An estimate of the required services results in an average of 0.025 kW per person which is an order of magnitude smaller than the global average of 0.3 kW per person, significantly smaller than the 1.8 kW per person in the United States. Thus, the electric power per capita of about 219 kWh per year (based on 0.025 kW per person) would be quite small but it would be sufficient to meet basic necessities and improve the Human Development Index(HDI) considerably. While describing the energy problems of the poor, the IEA points out that about 1.6 billion people are living on less than $2 per day. Because of the lifestyle changes electricity brings, it is observed that spending about 10% of the family income towards the electricity services is quite common. The estimates of per capita income ($225) and average required electricity services (219 kWh) result in an affordable unit cost of electricity of about $0.10 per kWh.

In developing countries the majority of the people still live in rural areas but urbanisation is growing. In 1950, about 83%, and in 1975 about 75%, of the population in developing countries lived in rural areas. At the turn of the century some 60% of the population of developing countries is expected to live in the rural areas but nevertheless rural population continues to grow by 1.4% (Asia) and 2% (Africa) per annum. The measures which are effective in the long run in releasing the pressure on migration encompass a control on the population growth, the creation of employment and the education i.e. Providing Urban Amenities in Rural Areas (PURA).

2.3 Benefits of rural electrification

The idea that RE in itself substantially contributes to the development of rural and remote areas was prompted by the experience that most of the expectations were structurally not met, and on the other by a growing discomfort about the below standard performance of many rural power systems in developing countries. Economic and environmental benefits of rural electrification tend to be overestimated and the costs understated. The majority of the rural electrification projects were related to the extension of a central grid and demand forecast was often based on overoptimistic expectations regarding regional development and people's ability to pay.

Rural electrification is potentially a desirable investment in many countries but there has been considerable discussion going on about the socio-economic benefits and the costs of the electrification of these areas in developing countries. For many rural people in the Third World however, electrification of their areas means modernity, progress and, above all, 'light in the darkness.' (Foley 1990)

2.3.1. Assessment of benefits

RE can be made effective with complementary factors like: local attitudes and skills, the state of the infrastructure, levels of income, patterns of land use and land ownership, access to credit and the demand for products. An impact evaluation needs to address all the attributes of rural development: improvements in infrastructure to support local industrialisation increase in agricultural productivity and improvements to public services (Barnes 1988). A quantification of the effects of electrification in terms of these aspects is however difficult and the conclusions rather unreliable; the indicators are often debatable as they depend on many other factors. The methodologies used to analyse the costs and benefits of rural electrification have been the subject of many studies and papers. Basically there are three methods that can be used to assess the economic benefits of electricity used for productive purposes:

- Direct method- the willingness and/or ability of the consumer to pay based on the additional income generated through the use of electricity.
- Indirect method- the additional output of the production process as a result of the use of electricity.

- Intermediate method- the determination of the costs avoided by the introduction of electricity.

These three methods only measure the static, immediate benefits of electrification but that many more benefits such as the growth of small scale industries and commercial enterprises, and the social development of a community may be identified. It is very difficult to determine the socio-economic impact of rural electrification projects for two essential reasons:

- It is impossible to isolate the specific impact of electrification within a development process.
- Most available assessments were carried out by organisations that were involved in the projects and thus it was important that the conclusions of these assessments were positive.

Benefits of rural electrification are consumer, utility and country. In terms of the feasibility of rural electrification, utilities compare their costs and benefits and the result is usually negative. There are however other benefits, some of which are very difficult to quantify. (Munasinghe 1999)(Table 2.3 and 2.4)

Tables 2.3 Quantifiable benefits of rural electrification (Munasinghe 1999)

1	Industrial uses of electricity
	1.1. Motive power: replacing liquid fuel.
	1.2. Lighting: replacing liquid fuel or gas.
	1.3. Space heating, cooling and refrigerating: replacing liquid fuel, coal, gas, biomass or animal waste.
	1.4. Processing food: replacing liquid fuel, coal, gas, biomass or animal waste.
	1.5. Transport: replacing liquid fuel
2	Commercial uses of electricity
	2.1. Lighting.
	2.2. Air-conditioning and refrigeration.
	2.3. Improved audio and video opportunities.
	2.4. More attractive atmosphere.
	2.5. Longer opening times
3	Household uses of electricity
	3.1. Lighting-replacing liquid fuel, gas, biomass or animal waste
	3.2. Cooking-replacing biomass, animal waste, liquid fuel, coal or gas.
	3.3. Space heating, cooling and refrigeration-replacing biomass, animal waste, liquid fuel, coal or gas.
	3.4. Home appliances (fan, iron, radio, TV etc)-replacing batteries, biomass/ coal.
4	Agricultural uses of electricity
	4.1. Water pumping-replacing liquid fuel, coal, and gas or muscle power.

	4.2. Heating and drying-replacing biomass, coal or liquid fuel.
	4.3. Chaff cutting, threshing etc-replacing liquid fuel, hydro and muscle power, coal or biomass

Tables 2.4 Non Quantifiable benefits of rural electrification (Munasinghe 1999)

1	Modernisation, dynamic growth and attitude changes-catalytic effects.
2	Improvement of quality of life, community services and participation.
3	Income redistribution and improving social equity.
4	Employment creation.
5	Other socio-political effects such as improving political stability, reducing discontent and disparities between urban and rural areas.

2.3.2. Socio-economic benefits

Numerous opportunities exist in rural areas to improve economic productivity by means of electricity and to achieve social benefits. RE by itself has never been a catalyst for economic development. Impact of electrification on agricultural growth is often overestimated and that there is little evidence that electricity by itself results in new agro-industries and commercial activities.

RE on its own does not cause development of rural areas but it can provide a stimulus to economic activity, especially in the service sector and it can have a major impact on the form that development takes.

The tendency to overestimate productivity gains in the industrial and commercial sectors during the economic appraisal of electrification schemes has been systematic. (Munasinghe 1990) He is of the opinion that rural electrification appears to stimulate agro-industrial and commercial activity. He also reports that the electrification of rural areas in developing countries promotes agricultural development best when certain complementary inputs were included. It is best to select rural areas that are ready for sustained growth for early electrification since these will generally exhibit rapid demand growth. The more developed an area, the greater the impact of electricity on economic growth and that rural electrification is a selective catalyst in the sense that the regions already well equipped with infrastructure other than energy in fact reap the stimulating effects.

The willingness to pay was determined on the basis of the avoided costs for alternative energy resources. For domestic and small commercial consumers the willingness to pay appeared to be 30% above the actual electricity tariff. For large commercial consumers the willingness to pay was calculated at 42%. Electrification had stimulated local economic development including the establishment of new businesses.

RE should be regarded as an infrastructural prerequisite, based on an already achieved economic level, for the further promotion of rural development. It should not be seen in isolation from the overall development level and programme should not be derived from the natural, but subjective, wishes of rural people to benefit from the comfort of services requiring electricity supply. It should rather be justified in connection with factors such as:

- An identified potential of economic activities which could not, or not adequately, be realised without the availability of electricity.
- The ability and willingness of the society and their political representatives to redistribute surplus and funds in favour of the development of rural areas.
- The ability of the institutions/establishments implementing the programme and benefiting from it to cope with the organisational and financial requirements.

Thus, RE could become an instrument to diversify the economy, to create employment, to improve general living conditions and to reduce rural-urban disparities. Also it can contribute to prevent over-centralisation, congestion and growing shanty townships and informal settlements in urban areas.

Rural electrification can significantly contribute to social and economic development but that opportunities depend on complementary programs. A certain degree of economic development seems to be necessary in creating the conditions for successful rural electrification. This implies that electrification should follow and not attempt to lead, regional economic development. When RE is considered and planned in combination with other rural development activities, the social and political circumstances need to be conducive. (Barnes 1988)

Investigations have shown that electrifying areas in general gives rise to increased energy use because people begin to use all kind of appliances. Therefore argues that providing electricity to a region may actually increase overall energy use, making assumptions concerning energy cost savings somewhat difficult. He adds that with the electrification of rural areas part of the population makes a major step forward.

Besides the social benefits, decision makers tend to give more importance to the economic impact of access to electricity as an income-generating process. Electricity use is expected to lead to more productive processes; the growth of businesses or farms using electricity will then increase demand for electricity, leading to a virtuous growth cycle profitable to both electricity providers and rural communities. Electricity is indeed an important input to rural businesses, farms or other small rural structures, adequate local conditions such as organised rural markets and sufficient credit are necessary for such businesses to grow.

2.3.3 Socio-political benefits

Naturally the social objectives of rural electrification are directed at an improvement in the living conditions of the rural population including the creation of appropriate circumstances for education and health care.

Electrification of rural and remote areas in developing countries can more or less be seen as a social project: the quantity of electricity is sufficient for lighting and a few domestic appliances but insufficient to support productive uses. Electrification should help to alleviate the perceived problems and boost the priorities of the population, and it should be part of a rural development strategy. In general, the rural population attaches great importance to the domestic uses of electricity. RE programs sometime mainly benefits the higher income groups, although in some cases lower income groups have benefited as secondary beneficiaries. However without any additional productive use of power, there will be no increased income generation and thus a limit to the ability to pay for the electricity.

Despite the fact that the impact of rural electrification on security, political stability and urban/rural bias is difficult to measure, experience shows that the impact of electric lights on security, civil order and educational facilities is perceived by most rural dwellers as clearly positive. Gain in recreational opportunities such as TV and radio and over time through the use of other electric appliances are benefits. But the impact of the availability of electricity on rural/urban migration, water supply, irrigation and cooking appears to be limited.

An improvement in the living conditions in rural areas can be effected through satisfying basis needs and by promoting small-scale industrial activities aimed at increasing economic independence. Reports also indicate that children living in houses with electricity take advantage and do their homework mainly in the evening.

Studies have revealed that in many developing countries most of the industrial employment can be found in small-scale enterprises in rural areas and this is one of the reasons why sufficient attention should be paid to rural development. In this context it should be stated that an adequate provision of services, infrastructure and technology has a decisive influence on the growth of agriculture and associated industries.

Rural areas should not solely act as a supplier of raw materials but should also aim at the manufacture of products with an added value. This aspiration can only be realised if modern forms of energy, particularly electricity, are available.

2.3.4 Environmental benefits

Electrification of rural areas generally does not prevent deforestation during the early years after electrification. It appears that the expected switch from wood fuel to electricity for cooking purposes only happens on a very limited scale. In general the rural population lacks the financial resources to buy electric appliances. Also the cooking habits and the opportunity of buying small quantities of traditional fuel are cited as reasons. In rural areas, land clearing for agricultural uses is often the main cause of environmental degradation. The energy demand of the rural population is seldom the cause of deforestation and, moreover, the population has often been successful in managing the local environment.

In some countries, both urban and rural dwellers have discovered that the forests can be a means to generate income with the effect of over-utilisation of resources. It is therefore of utmost importance that any policy regarding energy supply and the associated environmental impacts should cover both the urban and the rural areas.

2.4 Rural electrification planning

In developing countries, rural electrification is either treated as a stand-alone project or as part of a country-wide distribution expansion program. In both cases it is extremely important that objective criteria for village selection are developed and applied in order to avoid interference.

"there does appear to be a general link between high levels of access to electricity in rural areas of a given country and the period of time for which serious electrification efforts have been pursued. Therefore, nations which have longstanding, well established rural electrification programs, with strong government support, tend to have fared better”. (Munasinghe 1990).

Strategic planning requires dealing with the main grid configuration and the associated future investments, from grid planning covering individual investments in the near future and construction design. The latter deals with the structural design of each network component. An important feature is the area coverage: the extent of the area, the number of consumers, and their distance to the grid to be served. The type of coverage defines, on the basis of certain selection criteria, an area in terms of number and classes of connections and a time frame.

Systematic planning of distribution systems is particularly poor in those developing countries where the utilities are attempting to meet targets for connecting a prescribed number of villages to the grid. This often results in meandering grid systems which are inadequately equipped for future expansion, prone to outages and which show excessive voltage drops and line losses.

The electrification of new areas is often seen as the first priority and so existing systems are not reinforced in time and service reliability is jeopardised. Distribution grid has been a dynamic nature and that additional investments are needed during the phases of extension process, densification of the grid and reinforcement dynamics. These phases can be recognised in every rural distribution system, since most grids were initially planned for specific end-uses. They also conclude that the price equalisation and other funding mechanisms systematically favour a single technical option ‘connect a village to nearby village’ i.e. extending the central grid system.

Less capital intensive and more flexible solutions are needed to speed up the electrification of rural areas for this purpose. A more sophisticated analysis of the most cost effective ways of meeting rural energy needs is needed that takes into account all the other possibilities. The cost of grid-supplied electricity is underestimated and that this is particularly true where small and/or distant population centre are connected.

The traditional approach using grid extension remains appropriate for urban and industrial areas and for rural areas with a well-developed demand. For rural and deep areas with a low demand, central grid based electricity supply is very sensitive to demand growth and in general is too costly. For these situations decentralised generation facilities are more appropriate. The application of hybrid systems such as diesel sets in combination with PV, a hydro and wind-turbine strongly depends on local circumstances and they tend to be technically complicated.

2.4.1 Region oriented approach

Rural development programs generally aim at improvement in infrastructure, to stimulate local industrialisation, agricultural production and social services. Rural development plans tend not to include electrification. As a consequence, and in spite of the availability of electrical energy, there are very few development projects that include a clear view of utilizing electricity for rural development for instance in the agro-industry.

Although adequate energy provision is not the only relevant factor in rural development, it is one of the prerequisites for improved agricultural and rural industrial productivity. Modern energy in the form of electricity, in combination with other essential conditions can help raise agricultural output by promoting innovation and improving irrigation. Electricity, in particular, has also a vital role to play in improving living standards through satisfying the basic needs of rural households such as lighting.

A broad definition of rural electrification ensures that regional planning objectives can be considered and that electrification can be regarded as a sub-programme and development tool rather than one out of many vaguely defined projects. Traditional energy technologies whenever feasible as such technologies have, in many cases, been developed over a long period of time to meet the specific needs of the rural areas.

All these considerations underline the need for an integrated and region-wide approach to rural development. Such an integrated approach in rural development schemes would of course demand close co-operation between programme developers, energy engineers, foresters, sociologists, and the participation of the local population. It is noted that there are probably few examples of such an approach, mainly because of the tendency in many developing countries to centralise planning and decision making.

2.4.2 General challenges faced by rural communities

Rural electrification is defined here as the process by which access to electricity is provided to households located in the isolated or remote areas of a country. Remote or rural regions lacking electricity supply are often characterised by well identified challenges. They may lie at a reasonable distance from central grid, remote villages, may be difficult to access (far from urban centers with a difficult terrain such as large rivers or jungles), or may suffer harsh climatic conditions that render electrification through grid extension a perilous task. Rural communities are also often highly dispersed with a low population density and characterised by low load density generally concentrated at evening peak hours and low revenues. In light of these challenges, electricity provision to the world's rural poor calls for a committed and long-term action plan. The benefits that electricity access brings to households and communities are justified not only on social and economic grounds but also on grounds of equity objectives.

At the rural household level, electricity is mainly used for powering light bulbs, fans, television sets and radio. When electricity is used for powering home appliances, household chores tend to become less tedious; when it is used for lighting, the relative brightness of the light bulb as opposed to candle light/wick lamp allows children to read or study in the later hours of the day, bringing obvious education and leisure benefits. Women and children benefit directly from these improvements, but television sets offer comfort during evening leisure time.

2.4.3 Technologies commonly used in rural electrification policies

Socially, ethically and economically beneficial, the electrification of rural or remote areas is usually high on the agenda of the leaders of major emerging economies, but the main problem to overcome is the choice of the technology. The choice of a specific energy technology for rural electrification naturally depends on the targeted country and on whether it is a whole region, community, business, farm or household that is to benefit from the process. Issues of customer and load density, relative distance to the national or regional grid, landscape, availability of natural resources such as wind, sun, water, forests, economic and financial aspects, availability and maturity of any chosen technology, all these factors influence the decision maker in his choice of the technology or technology mix.

The pool of potential energy technologies for rural electrification programs is quite large and each technology naturally varies in its generation technique, costs and in the quality of the service it delivers. When aiming to electrify a rural community, the first question is its distance from the grid. If grid extension appears to be relatively easy, is cost competitive with respect to other local auto generators, and if the region's load density is considered sufficient, then grid extension will usually be a preferred option. In India for instance, the first choice for a majority of the villages has been through grid extension. But many of the dispersed rural communities did not meet all these criteria at once. Grid extension was then the final phase of a sequential rural electrification process and other local electrification technologies were chosen in the meantime. In fact, once demand was built over the years by means of auto generation, and it became economically feasible to connect to the central grid, grid extension was chosen as a final step. Recently, however, mentalities have been changing and governments as well as rural communities are beginning to see stand-alone systems as long-term and reliable options for power generation, rendering grid extension less of a mandatory long-term means of electrification.

2.5 Implementation aspects

2.5.1. Rural electrification costs

Both investment and operation costs of rural electricity supply differ from one country to another but they are always far higher than in urban areas. These higher costs are due to the following factors:

- Dispersed loads requiring long medium voltage lines or decentralised diesel power stations.
- Line losses are often very high and the power system prone to service interruptions.
- Expensive billing procedures and control of illegal connections.
- Low load factor due to dominant domestic consumption, agricultural demand with seasonal periodicity and the absence of industrial demand.

Average costs per connection depend heavily on the structure of the medium and low voltage distribution system and particularly on the number of customers served. Cost per connection increases considerably with below 1000 connections.

Transmission system and service connection costs are generally similar, at say US$ 100 - 125/connection. An average modern central power station would cost US$ 1,000 per kW. If a modest maximum load per connection of 0.4 kW, a coincidence factor of 0.85 and a reserve margin of 30% is assumed, the total investment cost per grid connection would amount to some US$ 1,900.The cost per connection is used to compare costs of projects but it is not really a good comparator because of the different mix of consumer categories.

Grid based electricity is by far the most costly form of energy supply in low-density rural areas, when compared to the other alternatives. The real cost of electricity is very high and in most cases is underestimated because of the low load factors, the large distribution losses and the additional burden imposed during peak demand periods. The economic internal rate of return (EIRR) of rural electrification projects is generally below 15%. However the accuracy of the EIRR calculation for most projects is not reliable. If all the benefits of rural electrification projects are to be included in the economic analysis, then estimates will be required for the following:

- Revenues and connection charges paid by consumers.
- Any net cost savings realised by consumers due to electricity substituting for other fuels.
- Consumer surplus from consuming more energy than previously i.e. on created demand and increased production realised by agricultural, industrial and commercial consumers.
- Unquantifiable benefits due to improved health services and education, increased satisfaction and stability etc.
- Environmental benefits and hidden costs.

Grid-based systems are often implicitly assumed to be the least-cost solution when compared with decentralised diesel generation.

2.5.2. Tariffs and subsidies

In many developing countries tariffs are permanently very low. Munasinghe (1990) observes that in quite a few developing countries rural electricity tariffs rarely cover more than 15% to 30% of estimated costs of supply.

Subsidisation often leads to a more rapid demand growth than would occur without subsidies, making rural electrification projects appear rather successful. Also subsidised electricity prices conceal the real costs, put the electricity supply entity at risk. Today it is widely accepted that electricity should be provided economically and efficiently at a price which, on average, reflects its full cost including the actual costs of the resources employed and of the environmental detriments. Such prices give the customers the right signals to use electricity efficiently, and enable the power company to generate the financial resources needed for investments, operation and maintenance.

Given the high capital costs and operation and maintenance costs of grid-based rural supply systems, and the present ability to pay by the majority of the rural dwellers in developing countries, it is unlikely that all costs can be covered in the near future. However, tariffs should at least generate income to cover the operation and maintenance costs and part of the capital costs to allow the utility to perform normal operations. Apart from indirect subsidies, other subsidies extended are- subsidy on the investment cost, subsidy to relieve the poor and cross-subsidy to achieve nation-wide or region-wide tariffs.

a) Subsidy on the investment cost

Investment costs of rural electrification programs in industrialised countries have in most cases been subsidised. In Ireland for instance, the government paid up to 50% of the investment costs of rural grid extensions.

The success of the rural electrification programme in Thailand was the result of a combination of factors: a commitment by the government to rural development and to improve living standards in rural areas, a careful grid expansion plan with appropriate selection criteria, cost orientation, an advanced revenue collection programme, a pragmatic institutional approach and a system of cross-subsidies.

As a result of these measures, the cross-subsidisation, and a special bulk power purchase tariff, the utility was able to finance the rural electrification programme and have a reasonable return on its investments.

b) Subsidy to relieve the poor

One should be aware of the potentially perverse effects of subsidies, such as electricity revenues obtained from the urban poor being utilised to subsidise the rural rich. Better-off households benefit more than the poor from subsidised tariffs since they can afford to purchase appliances and thus increase electricity consumption. (Munasinghe 1990)

Subsidy programs should therefore be well designed and the beneficiaries carefully targeted. The effects outlined above could be avoided by a tariff system with which small consumers (up to say 35 kWh per month) are offered a low so called life-line tariff. Such a tariff does, in general, not jeopardise utility operations and the impact on larger industrial and commercial consumer tariffs is often modest.

Another method which is used (in some urban areas of South Africa) and which helps the poor to obtain access to electricity is the possibility of paying only part of the connection fee together with the use of a prepayment meter and an associated tariff. The tariff covers the energy component plus a surcharge for re-payment of the remaining connection costs.

c) Cross-subsidy to achieve uniform tariffs

In many countries, consumers in rural areas are often cross-subsidised by consumers in urban areas. In industrialised countries, rural electrification was seen as a way to modernise, and a policy was developed to subsidise rural consumers by urban consumers. The major arguments underlying this policy were:

- Equal access by all citizens to public services including electricity.
- Inter-regional solidarity for reasons of national unity.
- Positive effects of electricity on rural development and living conditions.

As long as the number of consumers in rural areas is small compared with those in urban areas, the impact on the general tariff will be modest. Without cross-subsidisation, the tariff difference between the most favourable urban area and the most unfavourable remote location could be well over 100%. The average will usually be in the order of 30%.

Cross-subsidisation from urban to rural consumers is increasingly prevented by the demographic situation in developing countries. Price equalisation to the benefit of rural regions gives grid based electricity a false appearance of competitiveness compared to less subsidised alternatives. This is notably the case with energy conservation programmes and autonomous generating facilities. The latter have the advantages that investments can be made more in line with actual demand growth and they also offer the opportunity to exploit local available resources.

Munasinghe (1990) argues that reasons for cross-subsidy must be well justified and quantified including the corresponding efficiency benefits. He also states that it may be better not to cross-subsidise but to focus on promoting the productive use of power in rural areas because these types of consumers are more likely to be able and willing to pay higher prices. The resulting revenues could then be used to subsidise tariffs to poorer households.

Conclusions

Many energy sources will become economically feasible sooner if subsidies for hydrocarbon sources of energy are eliminated and their prices include the costs of the pollution associated with their use. It is emphasised that, apart from life-line tariffs, direct subsidies on energy should be avoided and the environmental impact costs of energy internalised.

Electricity is not a primary necessity of life. The greater proportion of the population living in developing countries does not have access to electricity. Traditional energy technologies have been developed over a long period of time to meet the specific needs of the rural area and should not be ignored.

There are indications that socio-political changes, the spreading communication gadgets and other electronic equipment, will induce a growing demand for electricity, even in the deep rural areas. Essentially rural dwellers want improved lighting, video and audio; electricity can provide these services conveniently. Electricity, because of its flexibility, versatility and increasing pervasion, is essential if the rural areas in the developing world are to rise significantly above the level of subsistence.

The contribution to energy related global pollution by the industrialised world is still larger than that by the developing countries. There is no doubt that the global village will face a number of problems in meeting the expected growth in demand for energy services over the coming decades. The future challenge will be to meet the increasing demand for energy services by the efficient, sustainable, environmentally and socially acceptable ways. There is no doubt that electricity will play a major role. Electricity has a number of advantages including the opportunity for fuel diversity and deploying locally available resources, decentralised power generation and a guarded control of environmental pollution.

Rural electrification is but one aspect of rural development and it is often just one of the possible options for satisfying the energy needs of the rural population. All aspects of rural development must be considered together and it is important that the electrification of specific areas is placed in the proper context with respect to other development priorities. One of the most important issues with rural electrification is the comparison between the costs and benefits. If affordable tariffs are taken as the basis, a cost benefit analysis of a rural electrification project will usually result in a negative outcome. The electrification of rural areas, however, should not be assessed as an independent activity, but as one of the components of a rural development programme. D Barnes and G Foley (2004) identified the following key points for successful rural electrification program-

- Setting up of effective institutional support
- Dealing with the political dimension
- Criteria for rural electrification
- Importance of cost recovery
- Charging the right price for electricity
- Lowering the barriers of obtaining a supply
- Benefits of community involvement
- Reducing the construction and operating costs
- Alternatives to the grid

Experience revealed that the impact of rural electrification could have been higher if other conditions would have been satisfied. There is reason to believe that, in the past, in many electrified rural areas, further development has been limited as the consequence of a lack of credit facilities, continued use of old fashioned technology, lack of entrepreneurial and skilled labour and supporting services.

In this context it is noted that the electricity supply to deep rural areas offer opportunities for the deployment of modern decentralised renewable energy technologies. Stimulated by the liberalisation of the power sector, private capital is increasingly invested in large power projects that can give an acceptable rate of return.

To a number of industrialised countries investments in sustainable energy projects in rural and remote areas are an attractive opportunity for so-called green funds. These funds offer a limited return on investment but have fiscally attractive features. It should however be noted, and this is particularly true for the poorest countries, that sufficient financial resources can only be made available if the international community gives priority to the development of rural areas in the developing world. The energy sector in these poor countries should therefore be used as an instrument to realise socio-economic rather than political objectives.

CHAPTER 3

RURAL ELECTRIFICATION IN INDIA

3.1 Rural Electrification

Governments all across the world confront the challenge of ensuring that their people have access to the basic infrastructure services such as water, electricity etc. This challenge is particularly acute for developing countries with large rural population like India, Bangladesh, and Pakistan etc where density, distance, and resource availability raise costs above local ability or willingness to pay.

Electricity is accepted as one of the driving forces of the economic development of all the nations. The challenge of continuously generating electricity and meeting the growing demands is daunting for both developed and developing countries, exerting tremendous pressure on the energy infrastructure. From the time of India's independence in 1947, the demand for electricity has grown rapidly. The per capita consumption of electricity has increased at a CAGR of 6.04% since 1947. This sustained growth is the result of economic development and has been accompanied by structural shifts in consumption pattern.

Universal Service Obligation (USO) is an obligation imposed on the utility/service provider to ensure provision of either the full package or a basic package of service of good quality, to all users at affordable prices. Universal Service and Universal Access though are closely related concepts and are sometimes used interchangeably; hold different meanings. Therefore, it is essential to identify the subtle difference that exists between these two terms. Universal service is aimed at increasing the number of individual households with electricity connections and providing such services to all households, including those in rural, remote and high cost locations. Universal service policies also focus on ensuring that the cost of electricity services remains affordable to individual users or to targeted groups of users. Universal service policies are more commonly found in developed countries.

While universal service is a realistic policy objective in many industrialised countries, universal access is a more practical goal in most developing countries. Universal access policies work to increase access to electricity services on a shared basis, such as on a community or village-wide level. Universal access programs typically have the aim of providing a basic and initial connection to electricity in rural or remote villages or low income urban areas. USO, thus, places an obligation on the utility/operator to provide basic and initial connection to village or community.

In India also, there is a move from universal access to universal service with the Government of India (GoI) setting out for itself, the Mission 2012, which aims 'Power for All' by 2012 accordingly:

- Rural (Village) Electrification should be completed by the end of the 10th Plan, i.e., by the year 2007; and
- Access to all households should be provided by the end of the 11th Plan, i.e., by the year 2012; and
- At least one unit of electricity per day is provided to all household Below the Poverty Line.

Further the National Rural Electrification Policies also provide that the progress of rural electrification would be reviewed in terms of the achievement which provides for:

- Accessibility to electricity: Increase from the currently assessed levels to all households by 2012.
- Availability of power: Increase from the current limited levels to demand matched by 2012.
- Reliability of power supply: Increase from the currently low levels to 24 hours by 2012.
- Quality of power supply: Increase from the currently poor levels to 100% by 2012.
- Affordability of power: Pricing based on the ability of consumer to pay.

3.2 India Profile (Table 3.1)

- India is the 7th largest country of the world with the population crossed over 1 billion.
- India is a federal State divided into 29 states and 7 union territories.
- The economy is growing at a rate of over 8% Gross Domestic Product (GDP).
- Agriculture contributes less than 24% of the GDP.
- The mainland of India extends between 8° 4' N and 37° 6' North Latitude and 68° 7' and 97° 25' East Longitudes. The Tropic of Cancer 23° 30' N divides India almost into two halves. (Fig. 3.1)

3.3 Electrical power sector-a glance

India's first hydroelectric power station was commissioned in the year 1880 at Darjeeling and commercial production was started in Calcutta way back in 1889. From the last 130 years the electric power generation, transmission, distribution and utilization sectors have grown considerably in magnitude. At the time of independence, power generation capacity was 1362 MW by private companies like Calcutta Electric Company and others. There has been a phenomenal increase to 1, 86,654.62 MW as on 31, Dec. 2011.

Table 3.1 India Profile (Source; Load Generation Balance Report, 2010-11)

Population	1210193422(census 2011)	17.7% of world population
Rural	742490639(census 2011)	61.35%
Urban	286119689(census 2011)	23.64%
Population	10286103282(census 2001)	-----
Rural male	532156772: (census 2001)	51.735%
Rural female	496453556(census 2001)-	48.26%
Area	3287240 square kilometer	------
Density	382 per sq.km	

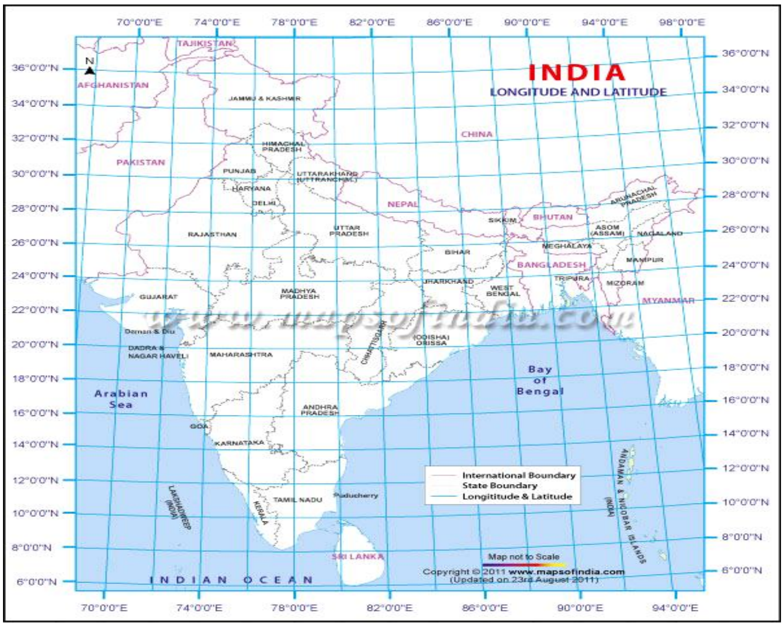


Fig. 3.1 India Map

Electricity is a concurrent subject specified in list III and VII schedule of the constitution of India under which both the Parliament (Central Government) and state legislatures have the authority to legislate on the subject. In India states have their own State Electricity Boards (SEB) constituted under Section 5 of the Electricity (supply) Act 1948. Hence they played a major role in rural electrification and are well supported by the Central Government.

In 1981, the GoI established a Commission for Additional Sources of Energy under the Department of Science and Technology. Commission had the responsibility of formulating policies and their implementation for the development of new and renewable energy apart from coordinating and intensifying R&D in the sector. In 1982, the commission was given full status of a department called as Department of Non conventional Energy Sources and put at par with other energy departments, such as coal and power. Finally, in 1992, the GoI upgraded the department to a full-fledged ministry known as Ministry of Non-conventional Energy Sources (MNES) exclusively devoted to the renewable energy promotion and it is renamed as Ministry of New and Renewable Energy (MNRE) in 2006.

Electrical power sector in India is a vast and complicated. Hence the power sector, policy setting and implementation is divided between five ministries: the Ministry of Power (MoP), the Ministry of Coal, the Ministry of Petroleum and Natural Gas, the Ministry of New and Renewable Energies (MNRE) and the Department of Atomic Energy, and government commissions and agencies. Central Electricity Authority (CEA), under the MoP, acts as an advisory body to the central government on matters of national electricity policy. (Table 3.2)

Table 3.2 Responsibilities of Indian Power Sector

Policy Making	Central Government, State Governments
Planning	Central Electrical Authority(Planning Commission under central Government),State Planning Department
Regulation	Central Electricity Regulatory Commission (Appellate Tribunal for Electricity),State Electricity Regulatory Commissions
System Operators	National Load Dispatch Centre, Five Regional Load Dispatch Centres, State Load Dispatch Centres
Generation	Central generating stations, Joint ventures-Centre &State, State Generating Stations, Independent Private Producers
Traders	Traders designated to trade across borders(PTC) Inter-State traders
Distribution	State Electricity Boards, Distribution companies, Private companies
Financial Institutions	Power finance corporation(PFC), Rural electric Corporation
Energy Conservation	Bureau of energy efficiency(BEE)

Under the MoP, the Central Electricity Regulatory Commission (CERC) regulates central and interstate-level power-related activities, while the State Electricity Regulatory Commissions (SERCs) work on state-level licensing, state level electricity tariffs and competitive issues. Among MNRE's main activities is the expansion of the use of renewable energy technologies in remote rural areas. Key objectives of MNRE are-

- To promote deployment of grid-interactive renewable power generation projects,
- To promote renewable energy initiatives for:
  - meeting energy/ lighting needs in rural areas,
  - supplementing energy needs in urban areas,
  - supplementing energy needs in industry and commercial establishments
- To promote research, design and development activities at premier national institutions and industries on different aspects of new and renewable energy technologies and help development of new products
- To encourage development of a Robust Manufacturing Industry in Renewable

The vision of Indian renewable energy program is - to develop new and renewable energy technologies, processes, materials, components, subsystems, products and services at par with international specifications, standards and performance parameters in order to make the country a net foreign exchange earner in the sector and deploy such indigenously developed and/or manufactured products and services in furtherance of the national goal of energy security.State governments also can set their own laws and regulations to be applied on their territory. Hence the implementation of power sector reforms differs in each state. Power sector scenario of India is as shown in tables 3.3, 3.4 and 3.5. (As on 31-9-2011)

Table 3.3 Electricity generation

Sector	MW	%age
State Sector	83,313.65	45.88
Central Sector	56,572.63	31.15
Private Sector	41,671.84	22.95
Total	1,81,558.12	

Table 3.4 Power sector (31-9-2011)

Fuel	MW	%age
Total Thermal	118409.48	65.21
Coal	99,503.38	54.80
Gas	17,706.35	9.75
Oil	1,199.75	0.66
Hydro (Renewable)	38,206.40	21.04
Nuclear	4,780.00	2.63
RES (MNRE)	20,162.24	11.10

Table 3.5 Power supply position in 2010-11 (Source: CEA, LGBR)

Region	Requirement (MU)	Availability (MU)	Deficit (MU)	%	Demand (MW)	Met (MW)	Deficit (MW)	%
Northern	254,231	224,661	-29,570	-11.6	37,159	31,439	-5,720	-15.4
Western	258,528	223,127	-35,401	-13.7	39,609	32,586	-7,023	-17.7
Southern	220,576	206,544	-14,032	-6.4	32,178	29,049	-3.129	-9.7
Eastern	87,927	84,017	-3910	-4.4	13,220	12,384	-836	-6.3
North-Eastern	9,332	8,296	-1036	-11.1	1,760	1,445	-315	-17.9

Region	Peak Requirement (MU)	Peak Availability (MU)	Peak Deficit (MU)	%	Peak Demand (MW)	Met (MW)	Peak Deficit (MW)	%
Northern	271,068	237575	-33493	-12.4	40000	33220	-6780	-17.0
Western	262768	236334	-26434	-10.1	40210	34732	-5478	-13.6
Southern	232907	200192	-32715	-14.1	34224	28450	-5774	-16.9
Eastern	98451	101707	3256	3.3	16202	16568	366	2.3
North-Eastern	11662	8199	-3463	-29.7	1957	1,679	-278	-14.2
All India	876856	784006	-92849	-10.6	126951	111533	-15418	-12.1

It may be seen that the anticipated energy and peaking shortage in the country would be 10.6% and 12.1% respectively. The peaking shortage would prevail in all the regions except Eastern region varying from 13.6% in the Western region to 17.0% in the Northern Region. Eastern Region is expected to be in comfortable position in terms of peak. There would be surplus energy of 3.3% in the Eastern region.

1. All other regions would face energy shortage varying from 10.1% in the Western region to 29.7% in the North-Eastern region.
2. All the regions in the country namely Northern, Western, Southern, Eastern and North-Eastern continued to experience energy as well as peak power shortage of varying magnitude on an overall basis, although there were short-term surpluses depending on the season or time of day. The surplus power was sold to deficit states or consumers either through bilateral contracts, power exchanges or traders. The energy shortage varied from 4.4% in the Eastern region to 13.7% in the Western region.

b) Per capita consumption and electricity demand by sector. (Fig.3.2, Table 3.6)

c) Progress of Rural electrification in India

From the time of independence, Government of India and State Electricity Boards have given priority for rural electrification and the phenomenal growth is evident from Fig. 3.3 to Fig.3.7, Tables 3.3 to Tables 3.6 and appendix I to appendix III.

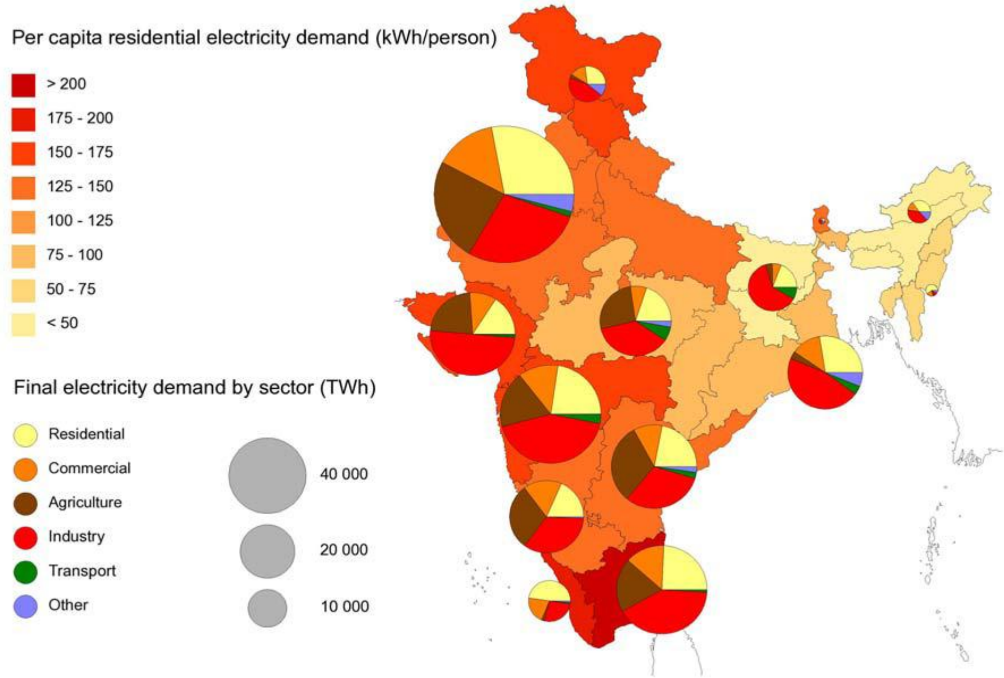
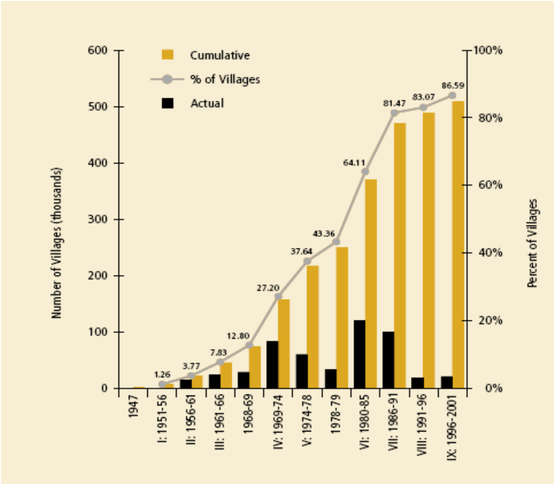


Fig. 3.2.Electricity demand by sector and by region in 2007 (Source: CEA 2009)

Table 3.6 Per capita energy consumption and T&D, AT&C losses

Year	Per capita consumption(kWh) (As per U.N. methodology)	T&D losses	AT & C Losses
2002-03	566.7	32.54	32.54
2003-04	592.0	32.53	34.78
2004-05	612.5	31.25	34.33
2005-06	631.5	30.42	34.54
2006-07	671.9	28.61	32.07
2007-08	704.2	26.91	Not available



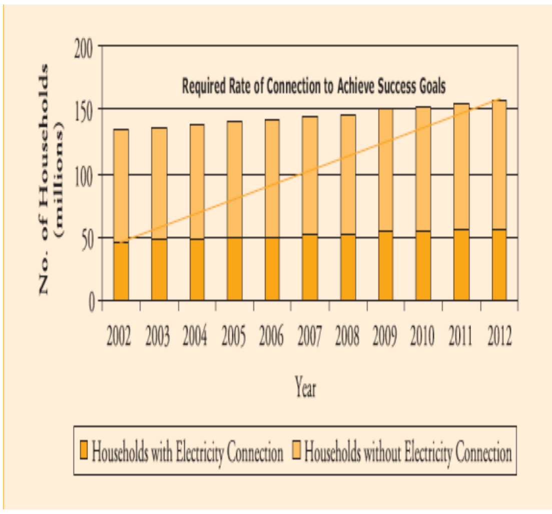
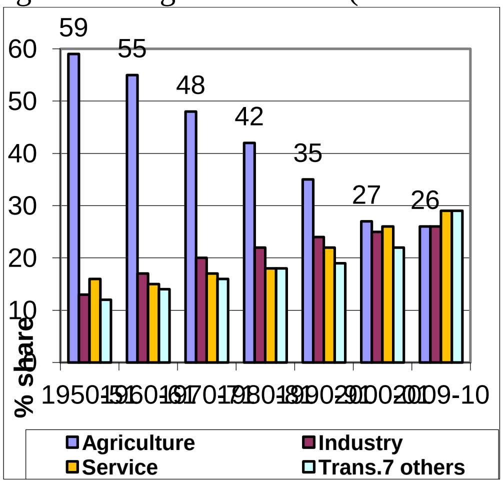
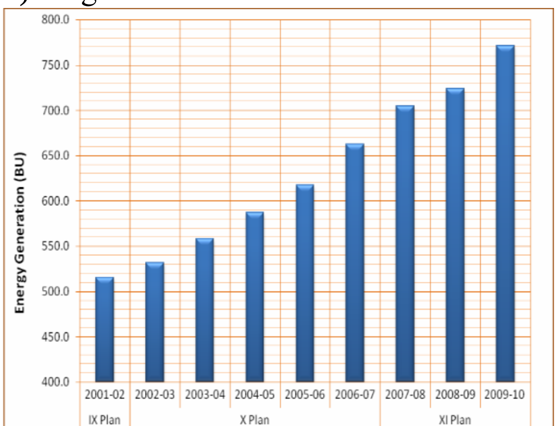


Fig. 3.3 Villages electrified (old definition) Fig. 3.4 Rural household's connection





	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
Energy (BU)	515.3	531.6	558.3	587.4	617.5	662.5	704.5	723.8	771.2
Growth (%)	3.1	3.2	5.0	5.2	5.1	7.3	6.3	2.7	6.5

Fig. 3.5 Share of sectors in GDP Fig. 3.6 Annual energy Generation and Growth Rate

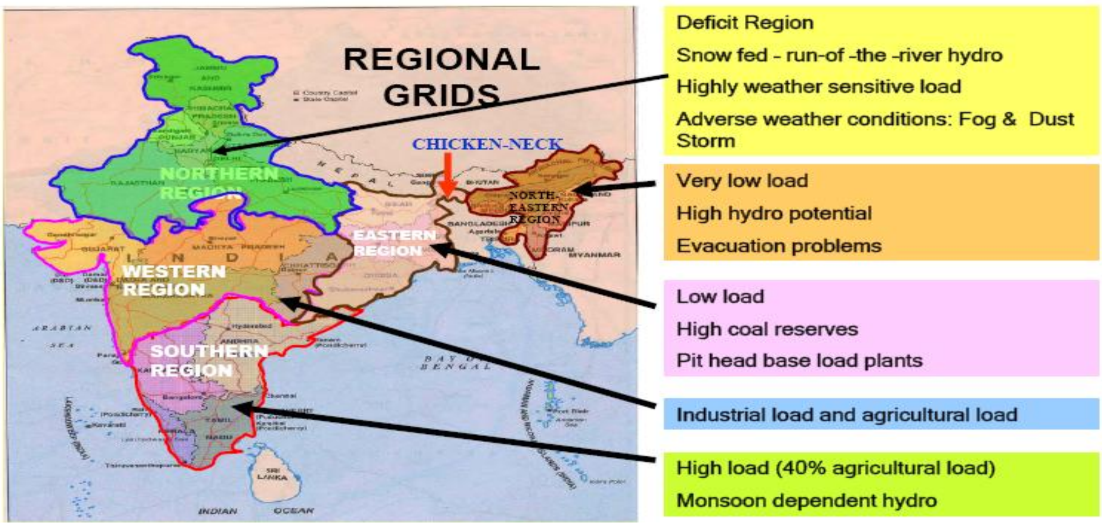


Fig. 3.7 Features of Regional grids

- It may be seen that the hydro rich States having run of river schemes on the Himalayan rivers viz. Himachal Pradesh, Jammu & Kashmir, and Uttarakhand are surplus in energy during monsoon period, while they would face severe shortage conditions during the winter low inflow months when the generation from hydro schemes dwindles to the minimum. The constituent states/UT of Delhi, Himachal Pradesh, Dadra & Nagar Haveli and Sikkim shall have both peaking and energy surplus on annual basis.(Fig 3.7,Table 3.7)
- The State of Chhattisgarh, Karnataka, Pondicherry, Mizoram and Tripura would have surplus in terms of energy whereas Orissa will be in comfortable position in terms of peak on annual basis. All other States in the country would have electricity shortages of varying degrees both in term of energy and peaking.(Table 3.8)
- Overall transmission and distribution losses vary from min.16% to max.43%.(Table 3.8)

Table 3.7 Generation of Electricity on 31, March, 2010(Source: CEA)

Region/ Category	Target (MU)	Actual (MU)	% of Target
NORTHERN REGION			
Thermal	171704.41	165063.33	96.13
Nuclear	8553.00	9591.19	112.14
Hydro	51044.00	55839.79	109.4
Total	231301.41	230494.31	99.65
WESTERN REGION			
Thermal	238109.18	236354.08	99.26
Nuclear	8601.00	10569.63	122.89
Hydro	14193.00	15041.53	105.98
Total	260903.18	261965.24	100.41
SOUTHERN REGION			
Thermal	148159.93	147200.08	99.35
Nuclear	4846.00	6123.97	126.37
Hydro	31882.00	30518.04	95.72
Total	184887.93	183842.09	99.43
EASTERN REGION			
Thermal	128594.90	111851.75	86.98
Hydro	9988.00	8991.10	90.02
Total	138582.90	120842.85	87.2
NORTH EASTERN REGION			
Thermal	4288.08	4444.59	103.65
Hydro	4245.00	3905.33	92
Total	8533.08	8349.92	97.85
BHUTAN IMPORT	6548.00	5610.05	85.68
ALL INDIA REGION			
Thermal	690856.50	664913.83	96.24
Nuclear	22000.00	26284.79	119.48
Hydro	111352.00	114295.79	102.64
Bhutan Import	6548.00	5610.05	85.68
Total	830756.50	811104.46	97.63

* Generation during 2010-11 excludes generation from plants up to 25 MW Capacity.

Table 3.8 Transmission and Distribution losses

		Overall T&D Loss (%)							
No.	State Name	2002-03 Actual	2003-04 Actual	2004-05 Actual	2005-06 Actual	2006-07 Actual	2007-08 Actual	2008-09 (Prov.)	2009-10 RE
1	Andhra Pradesh TRANSCO	28	22	19	20	20	20	19	18
2	Assam	39	36	38	33	33	38	34	32
3	Bihar	39	36	37	46	46	41	39	37
4	Chattisgarh	31	27	32	37	32	34	34	33
5	Delhi								
6	Gujarat	31	29	34	30	24	25	23	24
7	Haryana (HVPN)	38	36	32	34	33	33	27	24
8	Himachal Pradesh	21	22	26	21	17	16	16	15
9	Jammu & Kashmir	47	48	47	47	51	62	61	62
10	Jharkhand	47	48	47	49	45	42	43	39
11	Karnataka PTCL & Discom	32	32	25	30	29	25	22	21
12	Kerala	30	28	26	25	22	22	20	19
13	Madhya Pradesh	44	44	43	41	39	42	40	39
14	Maharashtra	38	38	35	32	34	29	27	23
15	Meghalaya	23	25	29	41	38	37	33	32
16	Orissa (GRIDCO)								
17	Punjab	24	25	25	25	26	22	20	19
18	Rajasthan	43	44	43	45	37	36	32	30
19	Tamil Nadu	18	18	18	18	18	18	17	18
20	Uttar Pradesh	42	38	31	34	35	33	29	25
21	Uttaranchal	48	45	34	32	33	32	33	30
22	West Bengal SEB	34	28	31	32	28	26	28	24

Note* : i. The figures in respect of Orissa & Delhi have not been included.

ii. The improvement shown in 2008-09 and 2009-10 may only be because the data is provisional/ estimated

iii. It is also pointed out that State Governments oftern marginally change previous year's numbers in new submission each year

Source : State Electricity Boards (SEBs) - March, 2010

Table 3.9 All India energy consumption utilities (source: CEA)

All India Electrical Energy Consumption Utilities only							
	2003-04	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	CAGR (2003-04 to 2011-12
Northern Region	97889	147923	163987	181586	201106	222668	10.8%
Western Region	116641	155659	170090	186046	203629	223035	8.4%
Southern Region	107427	146078	159708	174980	192263	211732	8.9%
Eastern Region	36968	54946	61914	69394	77869	87521	11.4%
North-Eastern Region	3742	6098	6970	7996	9176	10576	13.9%
Islands	132	195	221	249	280	314	11.5%
All India	362799	510899	562889	620251	684324	755847	9.6%

Table 3.10 All India energy consumption domestic utilities (source: CEA)

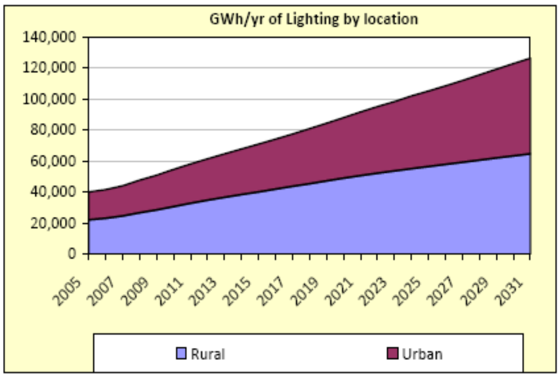
All India Electrical Energy Consumption in Domestic Utilities only							
	2003-04	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	CAGR (2003-04 to 2011-12
Northern Region	29893	45191	50729	56886	63711	71246	11.5%
Western Region	22496	32508	36307	40575	45370	50754	10.7%
Southern Region	26212	37294	41166	45514	50433	55971	9.9%
Eastern Region	9905	17174	21067	25371	30466	36373	17.7%
North-Eastern Region	1352	2683	3255	3949	4789	5836	20.1%
Islands	74	113	130	148	168	191	12.6%
All India	89932	134962	152653	172443	194937	220372	11.9%

Table 3.11 All India energy consumption commercial utilities (source: CEA)

All India Electrical Energy Consumption in Commercial Utilities only							
	2003-04	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	CAGR (2003-04 to 2011-12
Northern Region	9565	14464	16126	17982	20057	22377	11.2%
Western Region	7830	11360	12640	14089	15726	17574	10.6%
Southern Region	8573	12223	13669	15376	17394	19766	11.0%
Eastern Region	3193	3903	4137	4386	4645	4918	5.5%
North-Eastern Region	384	604	685	775	871	964	12.2%
Islands	31	43	49	54	61	68	10.3%
All India	29576	42596	47305	52663	58755	65666	10.5%

Table 3.12.Financial Performance of 20 Major States

Particulars	2005-06	2006-07	2007-08	2008-09	2009-10
Energy Sold (MU)	3,51,200	3,90,232	4,29,709	4,69,427	5,25,140
Energy Sold/ Energy Available (%)	65.40	65.41	72.42	74.72	76.27
Sales Revenue (Rs.00crore)	1014	1173	1321	1542	1777
Commercial Loss (Rs.00crore)	208	284	338	409	384
Ave. cost of supply (Paise/KWh)	368	391	405	433	429
Average tariff (Paise/KWh)	289	301	308	329	338



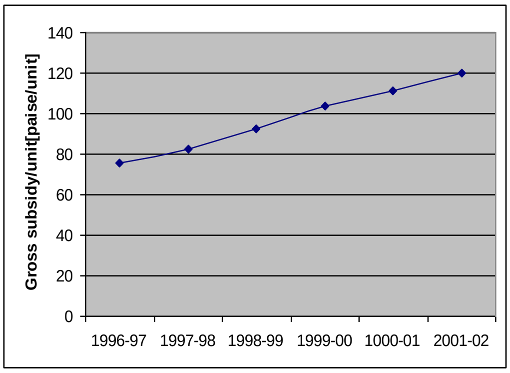


Fig. 3.8.Electricity usage for lighting (WB report)

Fig. 3.9.Gross subsidy

3.4 Status of Rural Electrification (as on 31-3-2011)

Table 3.13 Status of Rural Electrification as on 31-3-2011(Source: REC)

Total Number of villages	5, 87,258
Villages electrified	5,08,515
Villages to be electrified	78,743
Total number of households	13, 82, 71, 559
Electrified households	6, 42, 63, 719 -- (43.5%)
Un electrified households	7, 40, 07,840 -- (53.5%)
Energy consumption per capita	631kWh
Rural electricity consumption per capita	60kWh
Urban electricity consumption per capita	240kWh

Table 3.14 Transmission Sector as on 31-10- 2009 (Source; CEA)

Transmission lines (circuit kilo-meter)	Central sector	State sector	Inter State	Total
765kV	2863	409	----	3272
400kV	61,491	27,970	3,272	92,704
220kV	10,119	115,172	151	125,442
±500kV HVDC lines	5,848	1,504	--	7352
Sub Stations(MVA)				
765kV	4500	---	---	4500
400kV	57,965	56,072	--	114,037
220kV	4,776	178,609	800	184,185
±500kV HVDC converter terminal	7,000	1,700	--	8,700

Government of India has setup Rural Electric Corporation in July 1969, to stimulate the process of rural electrification. Electrical power sector was recognized as one of the Millennium Development Goals in 2000, for the upliftment of the masses and poverty alleviation. The Five Year Plans of Government of India, World Bank, International Monitory Fund etc have identified this socially relevant sector and initiated several measures like Electricity Act 2003, Deregulation, Unbundling, RGGVY, Independent Power Producers (IPP) and Electricity Regulatory Commission etc.

Table 3.15.Distribution Sector as on 31-10- 2009 (Source; CEA)

Region	33kV	22/20kV	15/11 kV	6.6kV	3.3/2.2 kV	Up to 500V
Northern	71,381	5579	598,408	--	46	917,056
Western	74,962	29,830	612,157	1,852	--	1,202,137
Southern	50,465	37,112	541,299	--	19	1,671,796
Eastern	32,668	50	223,362	4,452	62	3,616,731
North-Eastern	8,486	---	67,332	--	--	85,795
TOTAL	237,962	72,751	2,042,558	6304	127	7,493,515

A Rural Electric Supply Technology Mission, under Ministry of Power with representatives from other Ministries Rural Development, New and Renewable Energy, organizations like CSIR, BHEL, etc started its operation in September 2002. The purpose of REST Mission is to accelerate electrification to meet the goal of 'Power for All by 2012'. The mission is also to identify technologies that could be used in providing affordable and reliable power supply to rural areas and effect implementation through distributed generation schemes, wherever feasible. The purpose is to provide electrification of remaining 'one lakh villages and one crore household'.

Previously, "a village was deemed to be electrified if electricity is used in the inhabited locality, within the revenue boundary of the village for any purpose what so ever". (Fig 3.10)

Ministry of New and Renewable Energy modified this definition on 29 Sept.2006. "In accordance with the approved definition of village electrification, remote villages/hamlets will be deemed to be electrified if a minimum of 10% of the households are provided with electricity is also made available for community facilities and for dalit bastis (habitants) of the village if any."

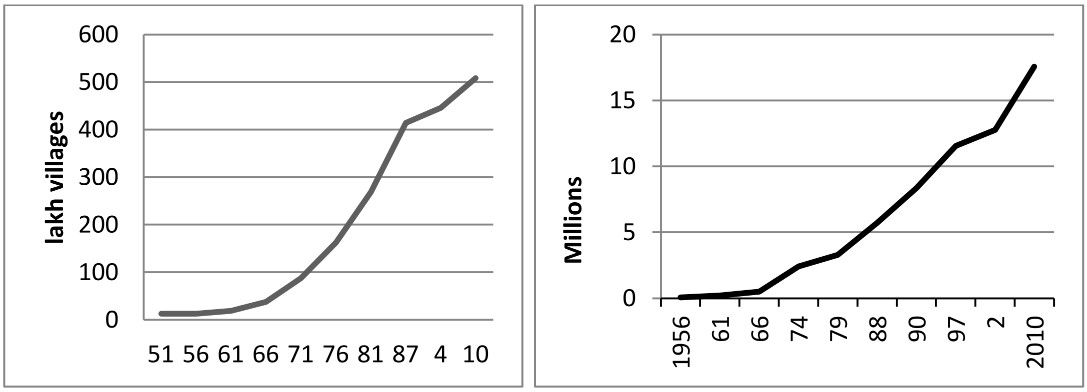


Fig. 3.10 Progress of rural electrification in India

3.5 Governance of Rural electrification

Electric power is instrumental for development, both in urban and rural sectors. RE forms the most important part of plans for the progress of India. Electric supply companies (fig 3.11) have a mammoth task of supplying energy to all.

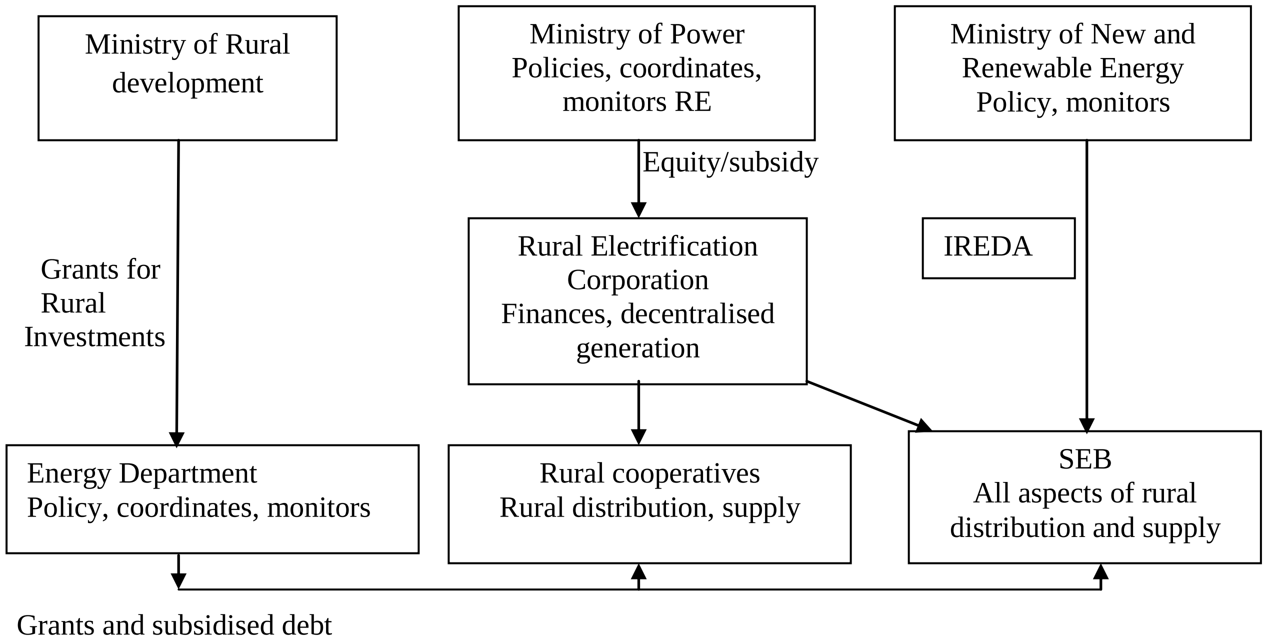


Fig. 3.11 Governance of Rural Electrification

Energy supply in rural sector has always been given low priority. Also, as per definition of an electrified village, only bare minimum need of rural households is taken into consideration. The ever increasing demand continuously outstrips the generation, transmission and distribution capacities in India.

The problems such as high transmission and distribution losses, frequent disruption in supply of grid power, practical difficulties and financially not viable of extending grid to remote and inaccessible areas, dispersed population in small villages resulting in low peak loads, poor financial health of the SEBs, etc. are plaguing the rural electrification program in India.

Rural areas are connected to tail end of transmission and distribution system, and in the absence of variety of customers, the power lines in rural areas operate at very low and highly uneconomical load factor. Hence, rural electrification programs tend to be characterized by scattered low-income consumers, high upfront equipment costs and thus decentralized electricity supply grids that are gradually being extended. These are regarded as the main reasons for low rate of rural electrification.

Another common problem for rural electrification in India is that grid extension projects are often undertaken for political reasons rather than on the basis of economically rational decision-making. Centralized power sector policy in India is characterized by many other limitations such as poor demand side management, leakages, theft of power, political and bureaucratic interference in decision-making and management, and power tariff not permitting differentiated rates for peak and off-peak consumption. As a result, most of the electricity boards in India are running under losses (Table 3.12).

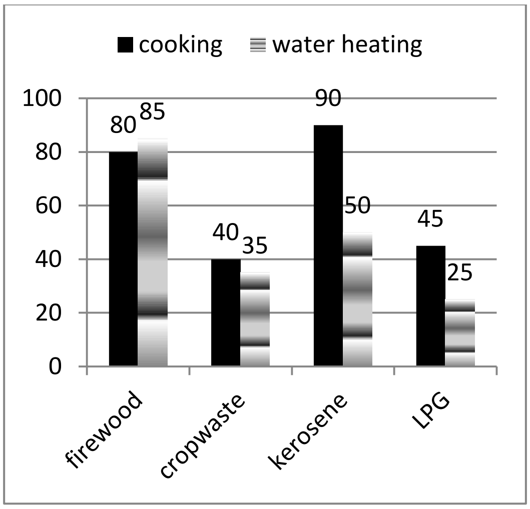
Most villages in India have access to grid; only 43.5% of the households have connected to electricity due to low levels of cash income. At a minimum, all used it for lighting, space cooling and watching TV. Lighting alone makes a dramatic difference when it comes to the ability to do household chores during the evening hours and reading for education and leisure.

3.6 Rural Energy pattern- a case study

To study the energy pattern of a village a survey was conducted in a village, Nuggikeri (Dharwad Taluk), Karnataka State, in South India.

Water heating is carried out by firewood (85%) followed by crop waste (35%); Cooking is carried by firewood (80%) followed by LPG (45%) and crop waste (40%). It is to be noted that electricity is not used for any of these purposes. The end use analysis of electricity for the same village is shown in Fig.3.12 to Fig.3.14 and Table 3.16 and 3.17. (Excluding the irrigation pump sets).

Survey study reveals that electricity is mainly used for lighting and entertainment apart from the irrigation purposes. The observation of the survey indicates the importance is to be given for RE.



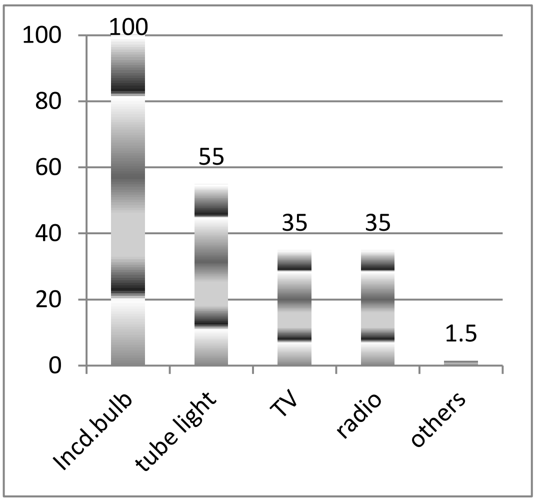


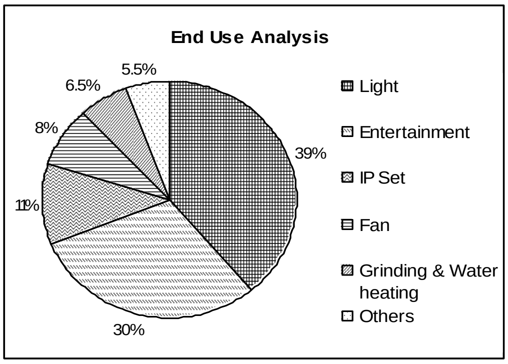
Fig. 3.12 Energy resource of rural dwellings (%)   Fig. 3.13 End use analysis (%)

Table 3.16 Average Monthly consumption of energy in Nuggikeri village per family

Sl. No	Source of Energy	Average usage per house hold / month	%age of house hold use for cooking	%age of house hold for water heating
1	LPG (Kg)	2	100	17.4
2	Kerosene (Lt)	4.22	83.9	42.6
3	Firewood (Kg)	202	84.7	84.7
4	Crop waste (Kg)	41.5	81.3	71.5
5	Biogas (m^3)	--	1.6	1.3

Table 3.17 Average Monthly consumption of energy in Nuggikeri village per family

Energy Resources		MJ	Kg Oil Eq.	Calories	% Efficiency
Firewood (kg)	202	3232	75.952	775680	15
Crop waste (kg)	41.5	560.25	13.197	134460	--
Kerosene (Lit)	4.22	147.7	3.477	35448	35
LPG (kg)	2	90	2.118	21600	60
Electricity (kWh)	15	54	1.275	12900	75



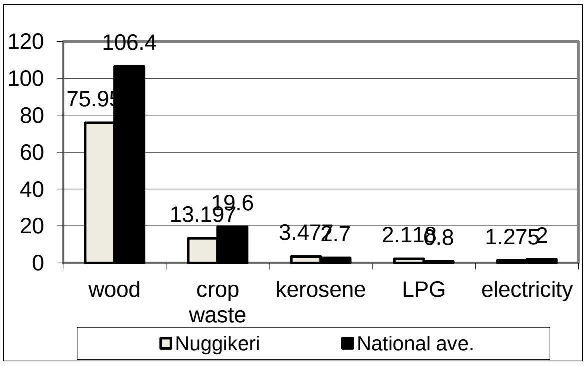


Fig. 3.14 Energy consumption/capita/ family at Nuggikeri and National ave.

3.7 State Electricity Boards

The Ministry of Power of the Government of India provides overall guidance to the sector. Central Electricity Regulatory Commission is empowered to regulate the sector at the national level, including central power utilities in accordance with the Electricity Regulatory Commission Act, 1998. (Fig. 3.19)The central power utilities own and operate 30% of the country's total generation capacity, while SEBs and EDs have 59% of the total.

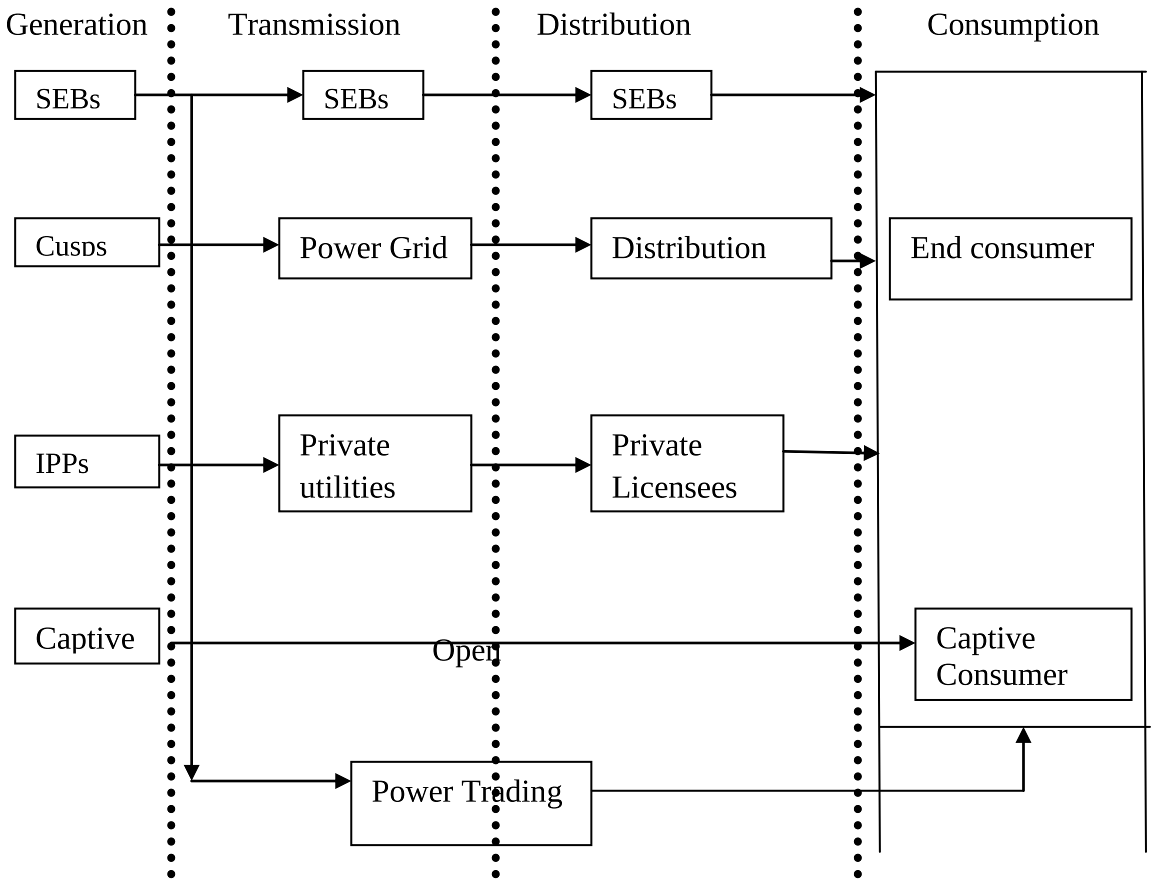


Fig. 3.16 Organization of the Power Industry

3.7.1 Power sector reforms

During the last two decades, the electric power sector has been subject to substantial changes including regulation, market formation and structure, technology mix, and political aspects. Power sector reforms were initiated in 1990 with the unbundling of the SEBs, enactment of the Electricity Act 2003; National Electricity Policy (NEP) etc. have created a strong policy framework to ensure investment in all sectors.

A) Electricity Act 2003**:** The Electricity Act 2003 has made many new provisions in the area of generation, transmission and distribution.

- The generation has been liberalized and de-licensed up to a certain extent.
- Electricity is now being treated as a commodity and trading has been identified as an important activity for a competitive electricity market.
- The Act has facilitated development of an efficient and customer-oriented distribution system.

B) National Electricity Policy (NEP):

- The policy envisages power for all by 2012 rural electrification and reduction in T&D losses, better cost recovery, improved financial support and greater private sector participation.
- It urges utilities to use state-of-the-art technologies for management, operation and control.

C) Accelerated Power Development and Reform Program (APDRP): The APDRP is a striving central government initiative in the distribution segment launched in the year 2001, with the main objectives:

- reducing AT&C losses
- improving quality of supply of power
- increasing revenue collection
- improving consumer satisfaction.

To avail the advantages of the program, it has been made compulsory for all the states to fulfill the eligibility criteria set by the central government.

D) Funding Mechanism:

- Accelerated Power Development and Reform Program (APDRP)
- Rajiv Gandhi Grameen Vidyutikaran Yojana(RGGVY)
- Power Finance Corporation (PFC), Rural Electrification Corporation Limited
- International agencies - World Bank, Asian Development Bank (ADB), etc.
- The commercial banks have also extended credit to the distribution companies

3.7.2 Status of Electricity Boards (Fig 3.17 to Fig.3.26)

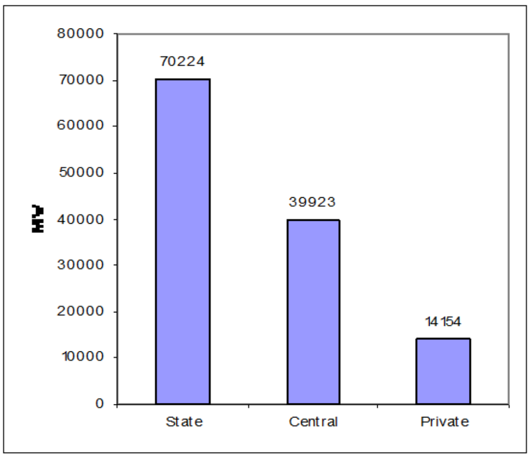


Fig. 3.17 Electricity generation

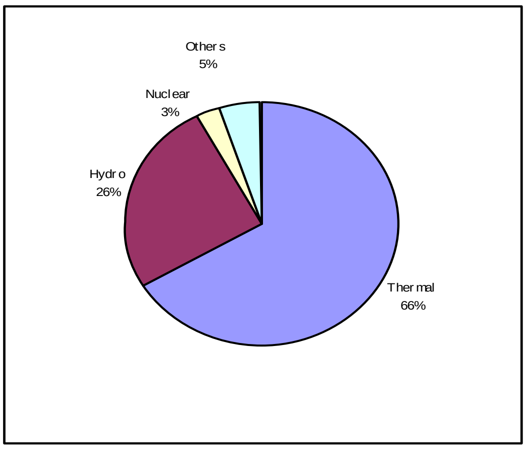
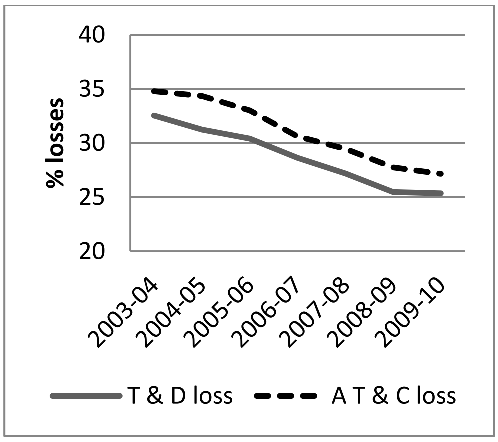


Fig. 3.18 Electricity generation



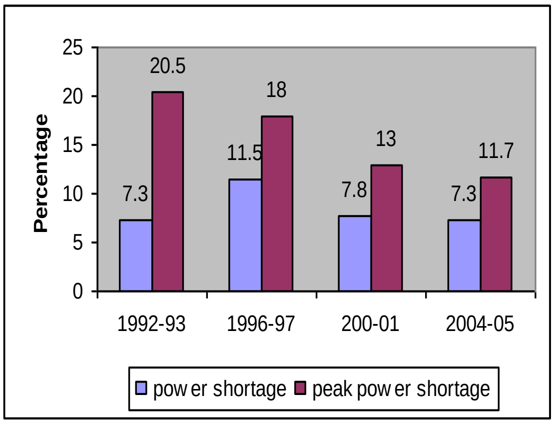
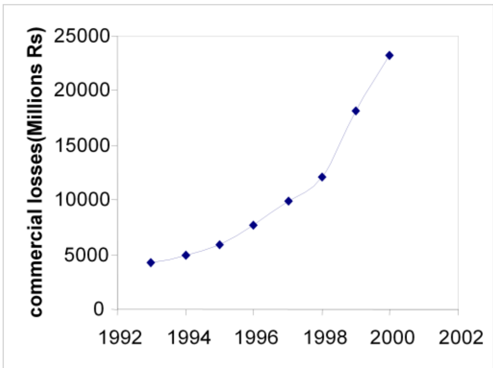


Fig. 3.19 Aggregate Trans. & Commercial losses

Fig. 3.20 Power shortage



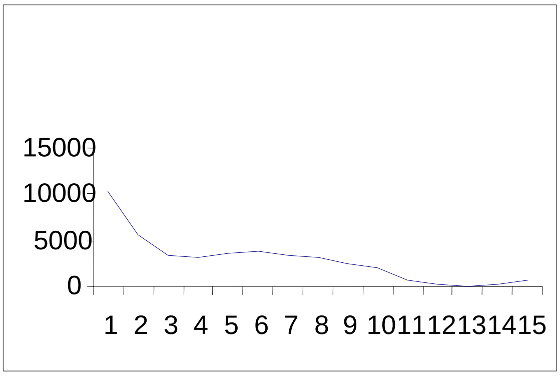
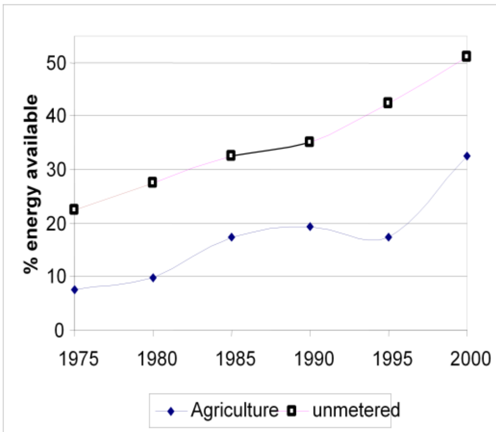


Fig.3.21 Commercial losses

Fig. 3.22 Villages electrified from 1995-2005



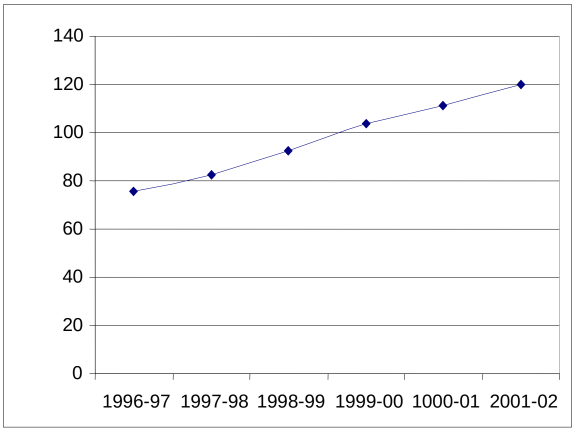
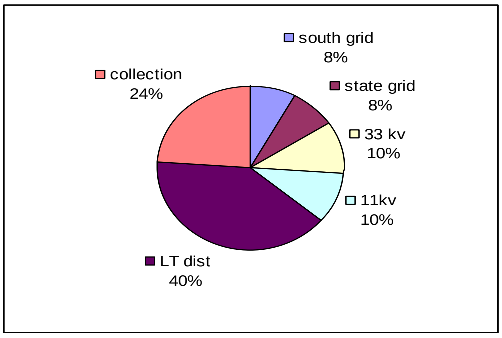


Fig. 3.23 Energy available (%)

Fig. 3.24 Gross subsidy Paise /unit



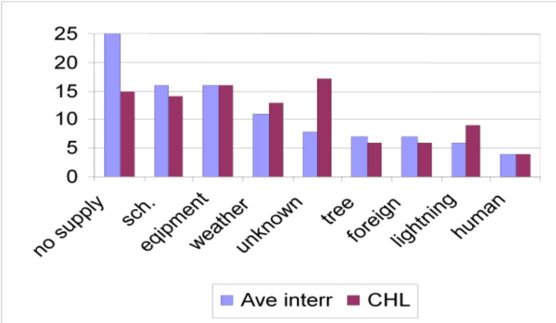


Fig. 3.25 Ave. Losses from Gen to utility

Fig. 3.26 Ave. % interruptions & CHL

a) Generation of electricity indicate that 56.5% of electricity by state governments. (Fig 3.17).

b) Higher i.e. 69% of this is by thermal generation followed by others 29 %.(Fig.3.18)

c) Aggregate technical and commercial losses are crossing 30 % (Fig. 3.19). Transmission and Distribution losses are high in 11 kV and 440 V distribution network. Hence peak to peak voltage is 256 volt instead of 415 volt. Farmers are compelled to go for higher capacity pump sets, leading to frequent motor burnouts, distribution transformer failures.(Fig.3.25,Fig 3.26)

d) Available transmission capacity currently is almost fully committed to existing generators and there is little surplus capacity. For additional uses require modification of transmission lines.

e) Commercial losses increased to above 24000 Crores. (Fig. 3.21) Grid extension to rural areas typically ranges from $ 8,000-$ 10,000 per kilometer, not including the cost of materials, which adds an additional $ 7,000. This high cost, coupled with low capacity utilization of such grids due to very small loads, makes extension economically unviable to utilities. Thirteen out of Nineteen State Electricity Boards incurred heavy financial losses in 2010.

f) SEBs reluctant for rural electrification process mainly due to high transmission and distribution losses and low Economic Rate of Return. Hence drastic reduction in number of villages electrified (Fig.3.22). However energisation of pump sets is still increasing.

g) Only 70% of energy supplied is billed; Contribution of electricity generation towards agriculture is increasing above 30% but Revenue Return is 2.5%.

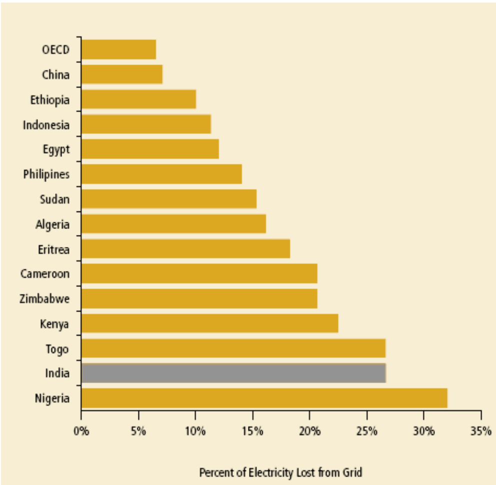
h) Subsidies introduced to promote economic development and initial impact was small and could be funded through government budgets. However over the year's element of subsidy increased manifold (Fig 3.23). Rather subsidies led to negative consequences and many unintended effects, more difficult to phase out.

i) National average cost of generation is Rs. 3.50 per unit and average realization is Rs. 2.50 per unit.

j) Peak shortage of power 11% and energy shortage 7.5%.

3.8 Electrical Transmission and Distribution Network

Electrical transmission and distribution is the weakest link of India's power supply chain as it faces substantial technical losses and commercial losses of electricity averaging 33.7% of total generation in 2006-07 with variations by state as illustrated in Table 3.14, 3.15 and Fig. 3.25, 3.27, 3.28. These losses are among the highest in the world.



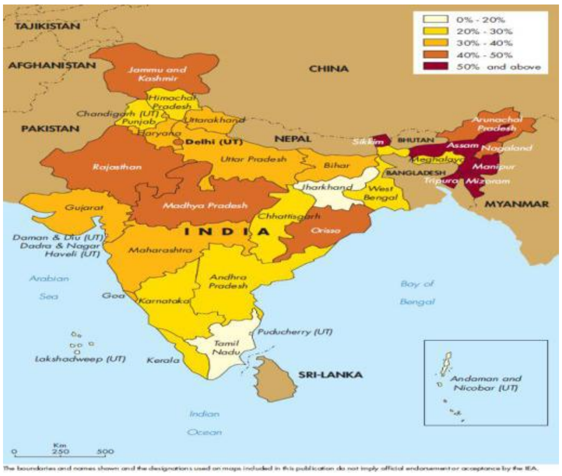


Fig. 3.27 T&D Losses in the world Fig. 3.28 T&D losses area in India (IEA 2010)

3.9 Power Sector Reforms and RE

Primary objective of power sector reforms is to achieve overall efficiencies in the performance of generation, transmission and distribution, improve financial viability, reduce the dependence on power utilities on government, reduction in transmission &distribution losses, control of theft and pilferage and provide quality service to various consumers at an affordable price. Thus by reforms rural electrification problems are effectively addressed. Following are the impacts observed in rural electrification sector due to power sector reforms-

a) Private sector participation is increased to 12% from mere 1% during 1990 to 2011. Isolated grids are established in remote and inaccessible areas with solar photovoltaic, mini/micro hydal, wind farms.

b) Power shortage reduced to 11.7% due to measures taken by stake holders.

c) Average technical and commercial losses are found to increase above 30%, because of SEBs included commercial loss to get subsidy benefits.

d) Per capita consumption was 238 kWh in 1990 to 704 kWh in 2011 i.e. increased by 294%.

e) Subsidies did not benefit eighty percent of farmers (less than 1 hectare of land) and do not possess pump sets. Thus power subsidies benefited only rich class people. (Rajadhyaksha committee report)

f) State Electricity Boards started giving the quality electricity supply.

g) Increase of electricity unit cost from Rs. 1.1 per unit in 1991-92 to Rs.4.29 in 2009-10 is mainly due to cost of fuel, establishment.

h) Average farmer pays about 10% of the cost of supply and average domestic consumer pays less than 60% of the cost of supply.

i) Rural committees are involved in bill collection and hence Economic Rate of Return doubled.

j) Costs for agriculture and residential households are far below the actual supply costs, (fig 3.29) where as electricity price to commercial and industrial consumers is cross subsidised by above cost prices.

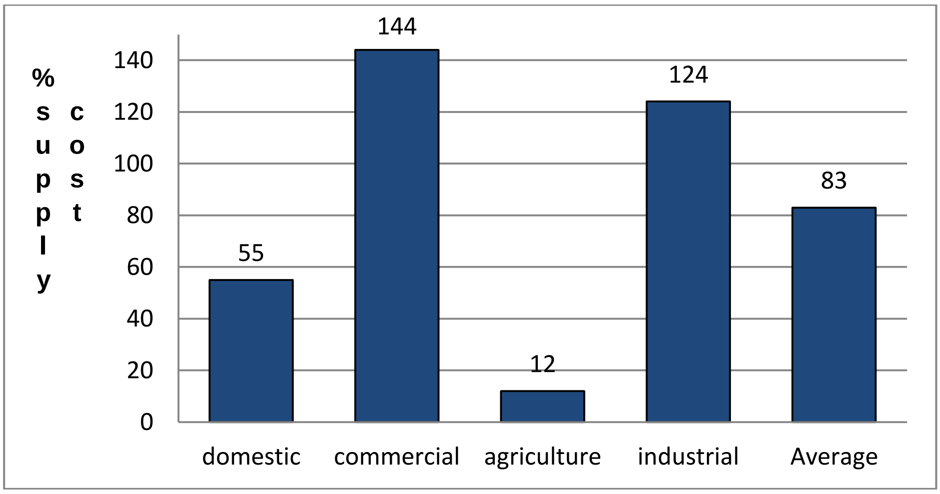


Fig. 3.29 Recovery Cost of utilities

Power sector reforms have positively influenced the rural electrification programs but still not kept in pace with the growing demand.

3.10 Specific challenges

The creation of franchisees for the management of local power distribution in rural settings is requirement under the RGGVY. Because these structures reduce commercial losses through more efficient billing and revenue collection, they ensure stable delivery of electricity. Franchisees can be different legal entities, such as NGOs, co-operatives or individual entrepreneurs. Franchisees are particularly effective in the management of electricity provision and recovery as they are in close contact with the targeted communities, and this has led to a stronger sense of ownership of the electrification process.

a) Management and reduction of losses

Illegal hooking is still rampant in India, particularly in the rural villages, are difficult to control. Indian government made a fundamental amendment to the Electricity Act of 1910, rendering theft of electricity a heavily penalised criminal offence. Moreover, under the RGGVY, to prevent illegal hooking and so reduce commercial, transmission and distribution losses, high-voltage distribution systems (HVDS) are being installed. Through HVDS, the voltage profile is also improved and electricity supply is more reliable. Corruption and mismanagement of funds have also been plaguing the system, which has caused the RGGVY to progress unevenly in the states.

b) Participation of local communities for operation and maintenance

Under the Remote Village Electrification (RVE) programme of the MNRE, effective operation, maintenance and sustainability of the projects is the responsibility of the state governments. The participation of the local community is sought at the inception of the project and efforts are made to ensure at least 15 years of operation and maintenance. However, as renewable energy systems develop rapidly, there are often an insufficient number of trained workers who know how to maintain and operate systems like PV.

c) Progress monitoring and maintenance

A Three-Tier Quality Monitoring Mechanism for the projects under the RGGVY has been put in place (MoP 2009). For the first tier, a project implementing agency works with a third-party inspection agency to ascertain that all the materials used in the projects and workmanship are conform to specifications. The REC is responsible for the second tier and will inspect works and materials. In the third tier, independent evaluators will be contracted by the MoP for random evaluations (1% of villages) of the supply and construction of the projects. The RVE also encourages the setting-up of annual maintenance contracts with a minimum 10-year warranty which includes the replacement of parts or components such as batteries, electronics, lamps, bulbs, etc. to secure proper and sustained energy supply services. After the AMCs expire, revenues could also be used to cover maintenance and repair expenses or replacement of spare parts and defective components.

3.11 International Experiences

Several countries in the world like US, UK, China, Egypt, South Africa, Cambodia, Nepal, Srilanka, Philippines, Mexico, and New Zealand etc. started rural electrification programs from 1970s. However the situations and the complexities of Argentina and Bangladesh are similar to Indian conditions.

3.11.1 Argentina

Prior to restructuring in 1992, the electrical industry in Argentina suffered from lack of investment, resulting in low availability of generation capacity; widening gap between demand and supply; poor tariff policies; dependence on government for financial support; frequent power interruptions; non-paying customers; illegal connections; increase in technical and non-technical losses, overstaffing; a demotivated work force; inefficiency and poor consumer service. The electricity industry consists of 6 public enterprises constituting 74% of generation capacity, several utility companies owned by provincial governments, a number of cooperatives and small captive-generators. The National transmission network inter-connected the State grids. The key elements are-

a) The industry was privatized and unbundled with large number of generation, distribution and transmission companies. Reforms provided for tariff reforms; new regulatory framework under which these company’s functions were separated and initiating privatization of state owned agencies. The privatization followed the joint venture route initially as 51% share by private sector, government retaining about 39% share and 10% for employees.

b) An independent Regulatory framework was created.
c) Distribution segment was split into three companies and sold on 15 year contract.
d) Transmission was brought under one company, and sold on terms similar to the distribution companies.
e) Wholesale competition is permitted as in UK.
f) The central dispatch authority arranges the dispatch of power so that they will have automatic access to the transmission system.
g) Retail competition is allowed with large customers.
h) Price cap regulation is implemented for transmission and captive customers.
i) Restructuring brought about efficiency in the system and also downward trend in the tariff.

In order to enhance monitor the restructuring and privatization programme, the Government agreed to retain some debt of the utilities with itself, which was offset partially, with the funds received from the sale of utilities assets.

3.11.2 Bangladesh

The state owned Bangladesh Power Development Board (BPDP) was sole generation, transmission and distribution authority in Bangladesh prior to the establishment of Rural Electrification Board (REB) in 1978.The progress was not very satisfactory under BPDP. Hence the government adopted the cooperative concept to implement rural electrification program covering the entire rural areas of the country in phases. Pilli Biddut Samity (PBS-Rural Electric Cooperative) is the core unit that runs the cooperatives and supplies electricity to rural areas. The consumers of the PBS are the owners of the system and are governed by a Board of directors, elected from among the consumers to run the system in a democratic, yet cost effective manner. Presently there are 55 PBSs with 27 lakh consumers nearly 15 percent of the consumers in 28,000 electrified villages. Rural Electric concept found to be suitable to socio-economic reality of the country. The business of a PBS runs on no-loss no-profit basis. The Board as a regulatory body continuously monitors and accesses the engineering, financial and management aspects of PBS and ensures that the standards set by the Board is achieved. The PBSs are not directly involved in the implementation phase but takes over the system after construction and remain responsible for its management, operation and maintenance. The routine operational activities of PBS like meter reading, meter checking, bill collection etc. is run by hired staff. Key elements of power sector reforms are-

a) In Bangladesh 80 percent population live in villages and belong to below poverty level. The participation of the poor is ensured through cooperative principle. Energy consumer in PBS area has to be member of cooperative.
b) Initial investment comes from donor loan and is nominal.
c) Transmission and distribution losses of about 16% much lower than BPDP of 30%.
d) Loss due to pilferage is distributed among the consumers, so it is not a revenue loss.
e) User-friendly 'one point' customer service.
f) Bill collection rate is about 95% and also, there exists transparency and accountability in these cooperatives.

Cooperative model is a success story due to the system being technically sound; its overall operation is transparent; there is accountability and pricing is just reasonable and is constantly monitored. PBS is becoming self-sufficient and achieving sustainable growth. The successful international experiences could serve as a guideline to India either fully or partly. India has to form its own policies, suited to its conditions, taking into consideration the experiences of other countries as useful guidelines.

Conclusions

The power sector is characterized by growing demand supply gap, inherent inefficiencies, distorted pricing mechanisms, weak institutional structure, environmental unsustainability and socio-political influences. The future economic development trajectory is likely to result in rapid and accelerated growth in energy demand, with attendant shortages and problems.

The growing energy consumption is likely to lead to increasing emissions of gases, compounding the pollution problems at the local level and increasing GHG emissions. For instance, a long term projection of the business-as-usual scenario over a forty year period (1995-2035) indicates that energy consumption shall treble; electricity generation shall rise by 5.4 times; coal shall continue to be the main source of fuel; the carbon emission shall go up by 3.6 times; and the carbon intensity shall increase. Therefore, it is imperative to develop and promote alternative energy sources that can lead to sustainability of the energy system. Although at present the contribution of renewable electricity is small, the capabilities promise the flexibility for responding to emerging economic, socio-environmental and sustainable development needs.

Government of India is committed for improving energy services in rural areas since access to electricity in itself with well being. Rural electrification is an old challenge with news ways. Any delay in reforming the sector will only make it much more difficult to tackle the task later. Thus for speedy implementation of the reforms require the following recommendations-

- All successful rural electrification programs have developed their own systems for ranking or prioritizing areas for obtaining a supply. Capital investment costs, level of local contributions, number and density of consumers and the likely demand for the electricity are among the factors considered.
- Successful rural electrification programs indicate that both large and small companies must follow certain principles. Rural families find the initial connection costs a far greater barrier than paying monthly electricity bills. Hence reducing initial charges or spreading payments over several years even if it means charging more per unit of electricity, allows many more low-income, rural families to obtain supply.
- Smaller companies that concentrate solely on electricity may be better able to address India's rural electrification problems, including low loads, low household connections rates, subsidies for agricultural consumers, poor consumer service and inadequate bill collection. Many small rural electric cooperatives are providing better services. Development of cooperative, user associations, NGOs, private rural electrification is a worthwhile goal.
- As restructuring of state power utilities is gaining momentum, appropriate institutional frameworks and incentives needs to be created to ensure that rural electrification expands in ways that are sustainable.
- Successful rural electrification programs have strongly emphasized covering their costs. Smaller, more flexible companies might encourage day time use of electricity in rural commerce and industries, encourage more people to connect to

the systems, involve local leaders in bill collection to lower costs, and provide flat rates for minimal service.

Development of community based, cooperative, Non-Governmental Organizations and private companies provides more responsive service to consumers. Rural Electric Corporation has so far promoted and financed 41 Rural Electric cooperatives in India, spread over 13 States. Presently 14 are in operation and 23 societies (3 in Rajasthan, 8 in Madhya Pradesh, 3 in Chhattisgarh, 3 in Tamil Nadu, 1 in Gujarat, 4 in Andhra Pradesh and 1 in West Bengal) have since been taken over by the respective SEBs and 4 societies (one each in the States of UP, Bihar, Orissa and J&K) stand liquidated due to lack of visionary people, political will, and resistance from State Electricity Board employees. Fourteen Cooperative Societies presently in operation are located in the States of Andhra Pradesh (5), Madhya Pradesh (6), Maharashtra (1), Karnataka (1) and West Bengal (1).

CHAPTER 4

RURAL LOAD PROFILE IN INDIA

4.1 Review of Literature

4.1.1 Feeder modeling

The cost of rural electrification is high and, as a result, the utilities are reluctant to extend their services in the rural areas. The onus of providing electricity to rural area in such circumstances falls finally on the government or government owned utilities. Due to high cost and significantly low benefit, the Benefit Cost Ratio is considerably low and sometimes less than unity in case of rural electrification schemes. a very simple method of controlling the cost of the rural electrification in one hand and at the same time improving the benefit for the utility. (Nava Raj Karki 2004)

Extension of the power grid to rural and remote locations in a country has to be considered after detailed evaluation of technical, economic and social implications. Application of conventional, economic, analytical technique to evaluate proposed by rural distribution system in oil importing developing country environment is dealt. (D J T Siyambalapitiya 1991)

A well rural distribution design minimizing the losses, voltage drop, and cost, while providing an optimum level of reliability, discussed and the general characteristics of the systems at the primary and secondary voltage levels are presented (H.V.Nguyen 2000). Overall, the analyses indicated a number of advantages that the US single phase distribution system has for rural applications. Besides the fact that system costs and losses are reduced, there are several other characteristics that make this system preferable to European designs. The main emphasis is placed on rural applications since the analysis is being focused on developing countries throughout the world.

The distribution losses can be reduced by proper selection of transformers, feeders, proper re-organization of distribution network, placing the shunt capacitor in appropriate places. The distribution companies should be ready for initial investment keeping in view of future savings in energy. High voltage distribution systems should be implemented at a faster rate. Training of the operating personal would result in improved system operation. (K.V.S. Ramachandra Murthy and M. Ramalinga Raju 2009)

As energy prices and the costs of building new generating facilities continue to increase, electric utilities have started looking for ways to reduce system losses. The secondary distribution system is under scrutiny due to the large number of distribution transformers and high secondary load currents. The secondary distribution system is modeled in terms of a few secondary circuit archetypes. The power demand of each load is derived from actual energy consumption. A computer software using Microsoft Excel has been developed to calculate the losses for all transformer secondary circuits in the pilot area, including energy losses in the service drops, secondary lines, and transformers; thus, the circuits with the greatest losses are identified for further study. (Calib A. et al. 2007) The applications of the proposed secondary distribution model and load characterization on the economic analysis and design of secondary circuits are also presented.

A study from books and local electricity distribution authority standards shows that in a rural electricity consumer it is possible and appropriate to find the best possible location for the transformer and measurement equipment. Therefore it could be also possible to find a more economical solution on building materials concerning its daily use energy losses. After the analysis of all the load characteristics and its localisation in the property, a design philosophy and a computational program were developed. (R. S. da Cunha 2004). The program gives the best transformer location obtained from the location of individual load centers, the load demands and their individual power factors. The program also gives the property average power factor, and the minimum power and location for the transformer to be used. The correct wiring is also an output in order to calculate global economic aspects of the electrical installation as a whole. An interesting aspect of this approach is the possibility of the design of new installations and the possibility of optimisation in rural electrical systems already in use.

Energy losses in distribution systems are generally estimated rather than measured, because of inadequate metering in these systems and also due to the high cost of data collection. These estimations are generally based on some rules of thumb. (P. S. Nagendra Rao 2006) The results of a joint investigation undertaken in collaboration with a local utility to study this issue. (Table 4.1and 4.2) Based on data collected from feeders specially instrumented for this purpose, true losses in some primary and secondary feeders are obtained. These losses are compared with the estimated losses obtained by the methods presently in use. In view of the large discrepancies observed between measured and estimated values, two new schemes for estimating losses in primary and secondary distribution networks have been developed. The measured values are used to highlight the reliability of the new estimation methods.

Table 4.1 Monthly measured Values

Month	Feeder input (kWh)	Energy loss (%)
Jan	923409	19.75
Feb	942696	25.79
Mar	888984	40.05
April	705177	23.64
May	898704	23.62
June	952533	28.48
July	918828	24.14
Aug	588987	20.19
Sept	656991	24.05
Total		24.94

Table 4.2 Transformer loss

Distribution Transformer Name	Energy for March 2001 (kWh)	Loss (%)
Mdodi	15998	11.8
Aboddi 1	27423	10.7
Aboddi 2	17170	9.0
Kdoddi	4030	4.6
Total	64621	10.14

Eastern Power Distribution Corporation Limited, of Andhra Pradesh State in India has been implementing some methods to reduce technical losses on rural distribution feeders. Statistical Data of two years on 80 rural distribution feeders of Visakhapatnam district has been analyzed and the results were presented. Field survey has been conducted to assess the exact conditions of feeder loading and distribution system configurations. The Rural distribution feeders considered predominantly supply the agricultural loads. Month wise cumulative percentage energy loss, power factor, length of line and line capacity were taken into consideration for analysis. Data of some sample feeders was presented. Suggestions were given for further improvement of efficiency of the system and reduction of losses based on simulation studies carried out.

4.1.2 Power quality issues

The quality of service provided rural electric customers can be improved with the accurate modeling and analysis of a distribution feeder. With the use of an analysis program developed for a personal computer, it is possible for an engineer to solve existing feeder voltage profile and loss problems and to plan feeder additions that will improve the quality of service to the customers with reduced losses to the cooperative. The accurate model of a distribution feeder and its devices that are incorporated into a radial distribution analysis program developed for the personal computer is dealt with. An example rural distribution feeder is modeled (W. H. Kersting and W. H. Phillips 1992). He demonstrated the use of program to solve typical design and operational problems.

The occurrence of power supply anomalies (e.g., voltage sags, surges and swells, sustained under and over voltages, etc.) originating on the secondary side of rural facilities and high utilization voltage levels can often damage and/or disrupt rural computerized processes, electric equipment and interrupt loads, a costly issue for rural society. Frequency and duration of voltage sags, swells and surges posed by rural customers and reveal the statistical characteristics of the utlisation voltage levels at rural sites are analysed by Don O. Koval (2003). The answers to these questions will be based on the national survey results of the frequency and duration of voltage sags and surges at rural sites monitored at their utilization voltage levels. The survey results provide a knowledge base for monitoring, operating electric equipment, designing and utilizing power quality mitigating technologies in rural electric environments.

Planned islanding application or intentional islanding is an early utility adaptation of the microgrid concept that is being promoted by major utilities around the world. The main objective of planned islanding projects in Canada is to enhance customer-based power supply reliability on rural feeders by utilizing an appropriately located independent power producer. Farid Katiraei et al. (2008) considered the process of planned islanding and the necessary steps that need to be taken in order to lead to successful projects. Some of the current experiences from Canadian utilities in this area are investigated and the additional requirements, in terms of equipment and system studies, which are needed in order to plan for the operation of a planned island project, are discussed. A case of planned islanding on rural feeders with multiple distributed generation units is also investigated, which represents the target of future projects in this area.

A study of three-year of rural electric distribution system for power quality at the low-side bus of distribution substations is done. (James C. Worley 2006). Data from 85 substations was used. The results of analysis of the data will be discussed in detail along with their implication to improving power quality on rural systems. Besides studying what influences the number of voltage sags, the correlation between the voltage sag index (SARFI) and interruption frequency index (SAIFI) was also investigated. A very strong correlation of an inverse relationship between the two was seen. This implies that by only concentrating on improving power quality one can increase the number of system interruptions. The discussion will explore what further studies are needed to find means to improve one without degrading the other.

A methodology for the evaluation and improvement of supply reliability indices presented. (Jose A. Rosendo et al. 2008). Based on statistical failure rates associated to each individual component, and other recorded information, such as restoration and reparation times, expected reliability indices related with the number and duration of interruptions are obtained for a feeder or set of feeders within a given area. If the resulting indices are not satisfactory, they can be improved by implementing several corrective actions, such as the addition of protecting devices or the modification of the feeder topology.

Network planning methods will be changed in future because of the economic regulation and importance of reliability of electricity distribution. Usually rural area networks are carried out with overhead lines but overhead lines are vulnerable to faults caused by the weather and therefore new strategies are needed to develop rural area networks. Reliability increasing actions could be profitable if interruptions are taken into account as outage costs. With the advanced reliability analysis tool, the effect of different strategies of rural area network development can be studied. The calculations show that traditional strategies are no longer profitable. In future climate change and major storms might have bigger influence on the reliability of electricity distribution. (Mika Marttila et al. 2009). He made a study of the impact of major storms and some calculations have been made with different climate change scenarios.

Continuity of supply is playing an increasingly important part in our everyday lives, and has generally raised the user's expectation of the quality of supply. Customer minutes lost per year is becoming a critically important criterion for rural people by which Electrical Supply Companies are judged. Previously unnoticeable power interruptions are now highlighted to the user and can result in problems. (J. S. Stewart 1997)

Power supply utilities offer a variety of measures that can reduce energy consumption and consumer energy expenses. To mitigate the acute shortage of power in the country, utilities are faced with the challenge to enhance end-use efficiency and manage the power demands of the country for sustainable and environment-friendly development. (Arup Sinha et al. 2011)

4.1.3 Cost analysis

The technical and economic feasibility of different systems is highly dependent on a diverse set of design criteria: local energy demands (daily, seasonal); available renewable resources (quantity and quality); location relative to conventional fuel supplies and/or grid power; plus how these factors may vary overtime. Dynamics among technical and institutional aspects are key factors, as understand the relative economic value of staged electric service introductions.(S. R. Connors 2007) He identified and assessed key design factors towards the deployment of electricity services.

A tool for calculating the electrification cost over a period of 20 years (investment costs and yearly costs) for the different mentioned strategies allowing choosing the less expensive strategy. Afterwards the second step is the optimization of the chosen structure solved a dynamic programming algorithm. (D. Thirault 2003)

The energy supply cost to the rural loads includes the capacity and operating costs of generation, transmission and distribution and these costs are compared with energy supply from renewable sources of energy for their economic viability. (Satish Sabharwal 1990) He suggested a new method that determines the contribution of rural loads to the system peak demand. Due to low load and high T&D losses in the rural areas, the costs are higher for rural loads than the urban loads (Table 4.3).

The cost comparisons are performed for four categories of rural loads-water pumping, LT industries, domestic/commercial and street lighting. The comparison also includes the hill districts, plains and electrified and un-electrified villages.

1) In electrified villages the distribution network already exists, 10% -15% extra capacity which can be used for additional loads.

a. Distribution cost for extending available grid line in unelectrified plain village areas is Rs 55/kW/ year estimated.

b. Distribution cost for extending available grid line in an unelectrified hilly and inaccessible village area in an unelectrified village is Rs 152/kW/year estimated.

2) Load factor and All India annuitized costs (Rs) in 2000 are available in Table 4.3 and Table 4.4.

Table 4.3 End use Load factor

End use	Load Factor (%)
Pumping	10.4
LT industries	11.4
Domestic/ Commercial	11.4
Street light	22.8

Table 4.4 All India annuitized costs in Rs. 2000

Annuitized generation capacity cost	1,286 to 1,458
Annuitized generation capacity for peak demand cost	1 890 to 2 143
Annuitized T&D cost	793 to 901
T&D loss factor	1.7
Annuitized supply cost to LT rural peak load	4,006 to 4 544
Annuitized supply cost to LT Rural connected load	1,294 to 1468

3) Cost reduction in rural electrification study presents a variety of options for reducing the cost of grid extension includes: using higher voltages, using higher quality poles to reduce life-cycle costs, wider use of single -phase distribution, considering the life-cycle costs of transformers rather than the initial capital cost, properly sizing and placing transformers, considering alternative pole designs, standardizing materials and designs, implementing quality assurance programs, developing manuals and specifications for staking and design and using small transformers to serve small load centers adjacent to MV lines.

4.2 Features of Rural Electrical Loads

The United Nations Millennium Development Goals at UN in 2000 set clear and ambitious target for improving conditions of around 2 billion people, who do not have access to adequate clean water supplies, electric lighting, primary health care and education and other basic services. India has 742 million people live in villages and 280 million (census 2011) are still below poverty line.

- The primary objective of the GoI in its drive for rural electrification is to ensure increased agricultural output by providing reliable power for irrigation pumps, involving mostly ground water pumping by individual farmers. Agricultural pumping currently accounts for about 17% of India's total annual electrical energy demand.
- Secondary objectives are the provision for domestic, commercial and rural industrial consumers in the villages to improve employment possibilities and the quality of life in rural areas.

Electrical demand in the rural sector is characterised by a low annual utilization of the connected load. This, together with the long and scattered distribution lines for small scale irrigation pump sets, is the major reason for the high cost of electricity supply. Thus the features of rural electrical loads are as follows:

- Dispersed loads require long medium voltage lines.
- Unreliable supply of about 6-8 hours per day and phase imbalance.
- Average rural load varies from 5kW to 25kW per village and load factor around 0.2. (Average demand/Maximum demand) (Table 4.3)
- Rural grids are often weak and high peak loads and relatively large inductive loads can occur.
- Low load factor due to dominant domestic consumption in particular lighting and absence of industrial demand.
- Low quality of power supply, scheduled and unscheduled load shedding, and low voltage and frequency fluctuations adversely affected agricultural, domestic and industrial consumers.
- Expensive billing procedures and control of illegal connections.

- Farmers go for higher capacity pumps use capacitors/or phase converters leading to higher energy consumption.
- Poor quality of power increases their cost due to frequent motor burnouts, interruptions due to transformer burnouts, unscheduled power cuts.

4.3 Rural Load Profile - a study

Rural distribution systems are characterized by having only one path for power to flow from the source/distribution substation to each customer. A typical distribution system will consist of one or more distribution substations with each substation consisting of one or more feeders. A study of urban, periurban (with partial urban and rural connections) and rural feeders of Dharwad is carried from 1st January 2009 to 31st December 2009, are shown in the Fig. 4.2 to Fig. 4.7 and Table 4.5.

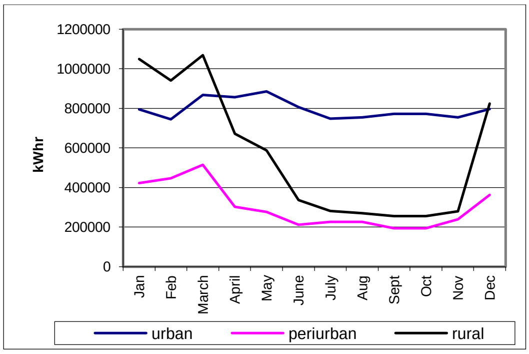


Fig. 4.2 Energy consumption

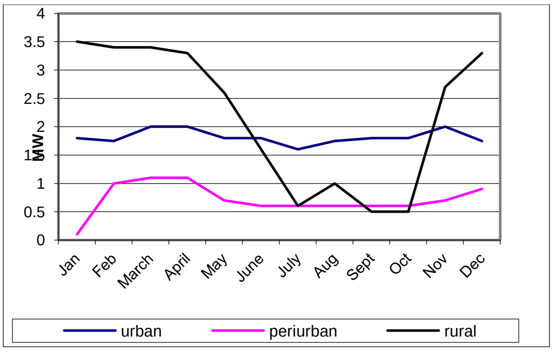


Fig. 4.3 Peak load

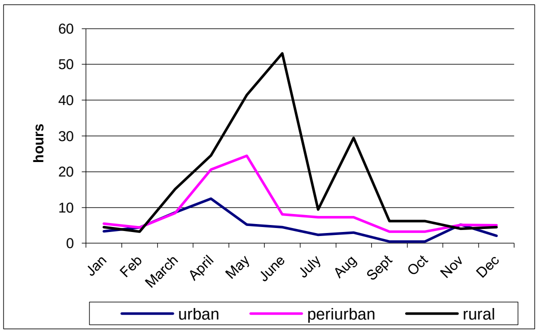


Fig. 4.4 Unscheduled load shedding

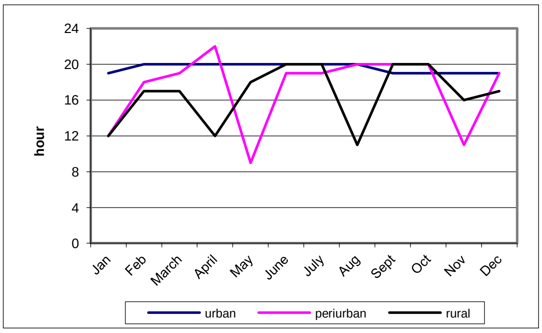
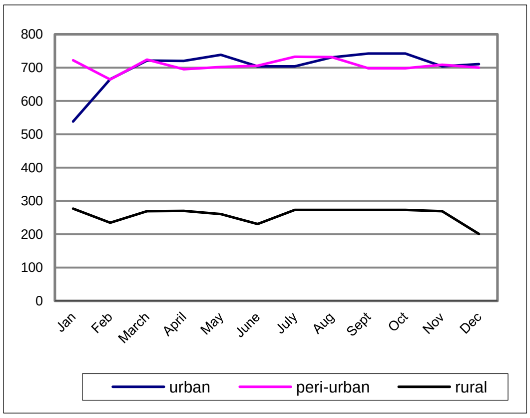


Fig. 4.5 Peak load



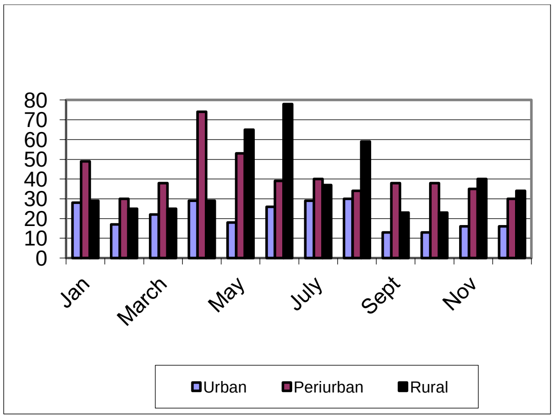


Fig. 4.6 Three phase supply

Fig. 4.7 Number of Interruptions

Table 4.5 Urban, periurban and rural feeder details

Feeders	Types	Length (km)	Distribution Transformer Centers	Distribution transformer centers per km	Average Max Load (MW)
UAS	Urban	17.84	7818	438.22	1.82
Yerikoppa	Periurban (a villages & urban)	44.68	1033	23.11	0.7167
Uppinbetageri	Rural-I, 8 villages	49.15	4890	99.49	1.433
Amminbhavi	Rural - II, 3 villages	39	5681	145.67	1.181
Hebballi	Rural-III, 12 villages	60.12	4941	82.18	1.271

a. Variation of urban load 128%, peri-urban 150% and rural 366%.

b. Frequency and duration of using irrigation pump sets increases during summer due to decreased underground water table. Constant energy consumption is found in urban and peri-urban because of dependency on electricity.

c. Peak load is constant throughout the year in urban; It varies in rural by 700%.

d. Scheduled load shedding hours are high in urban during rainy seasons of July and August; during April and June for rural feeder.

e. Rainy season has more unscheduled power outages due to heavy wind, rains and more time required for restoring power in rural feeder.

f. Peak load time is constant in urban 20.00 hours but varies from 11 hour to 20 hour for rural feeder depending upon load shedding period.

g. Three phase supply is available for 20 hours per day in urban and periurban; whereas 8 hours per day in rural.

h. Density of distribution transformer centers per km is higher i.e. 438.22 for urban feeders compared with 23.11 in rural due to concentrated electrical loads.

4.4 Rural Feeders- a case study

Rural electrical loads consist of domestic lighting, irrigation pump sets, rural industries, water supply, streetlights and education. Several causes of rural power supply disturbances and interruptions can originate within the utility primary distribution and /or within the customer's service networks. Three different rural feeders of Dharwad are also studied to know the different parameters from Fig 4.8 to Fig. 4.18 and Table 4.6.

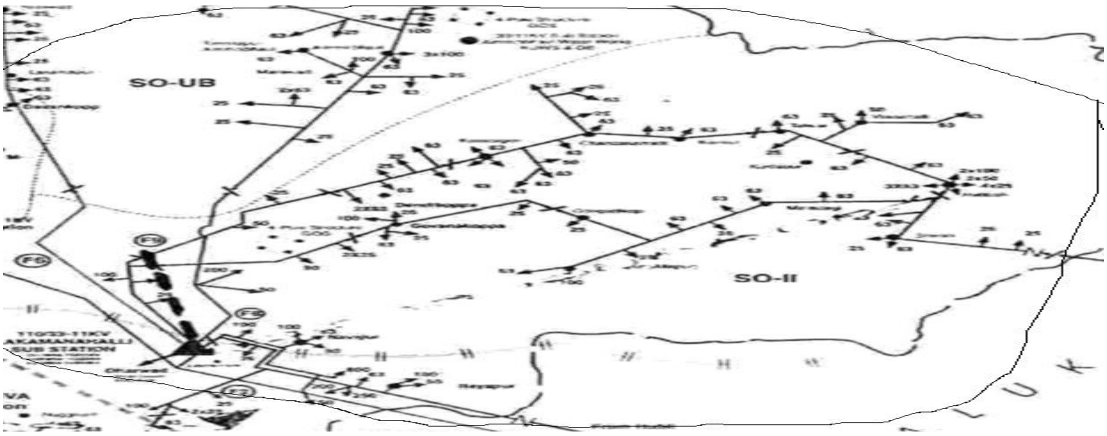
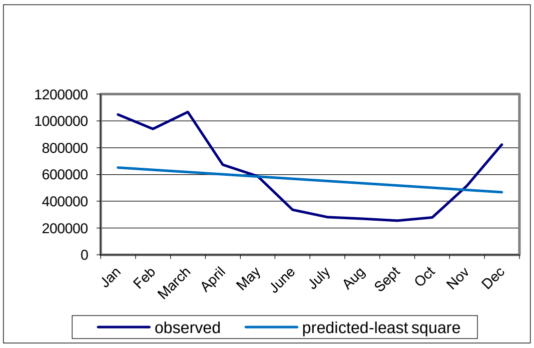


Fig. 4.8 Map of distribution feeder for Dharwad



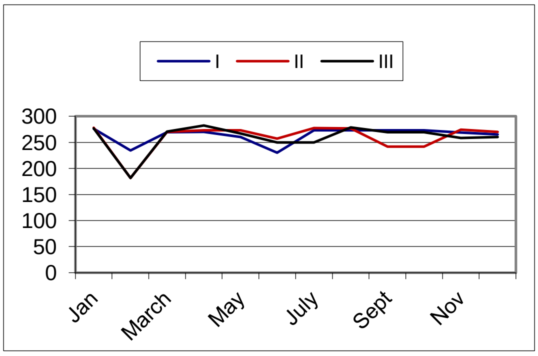
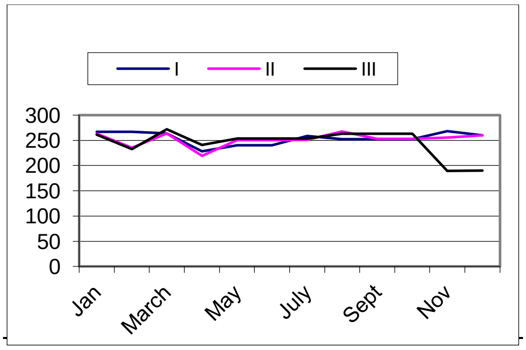


Fig. 4.9 Monthly consumption (kWh)   Fig. 4.10 Three supply hours



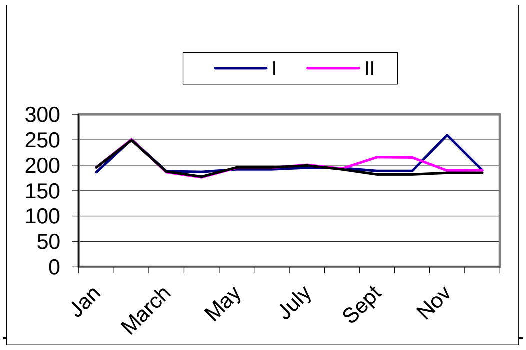


Fig 4.11 Single phase supply yearly hours   Fig 4.12 Load shedding yearly hours

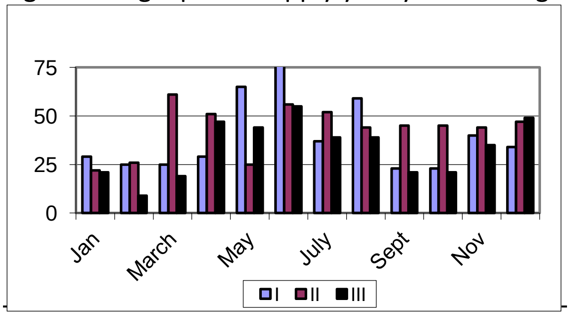


Fig 4.13 No. of interruptions hrs

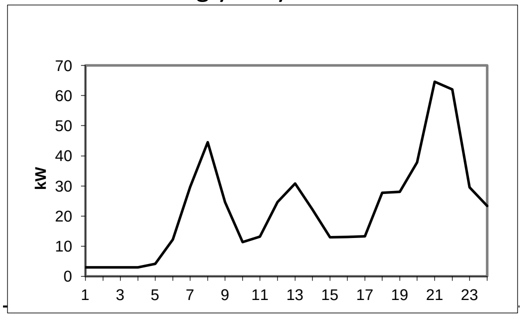


Fig.4.14 Rural load pattern of village (10,Sept.2009)

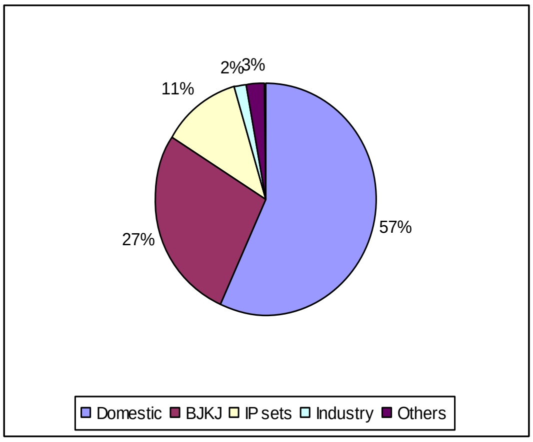


Fig 4.15 Consumers of feeder -I

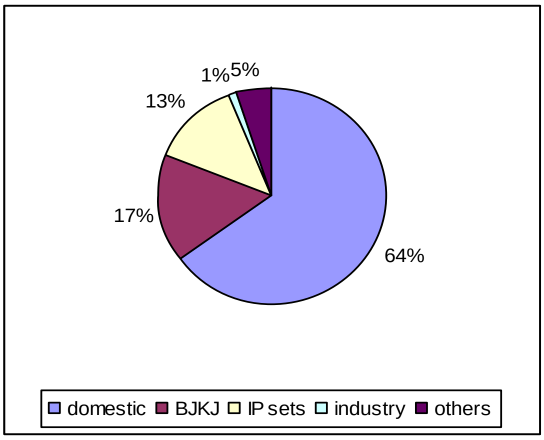
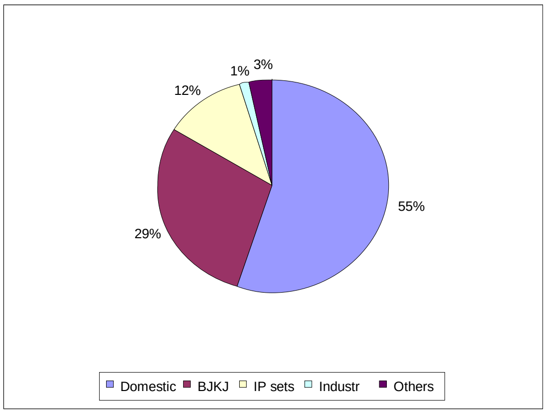


Fig 4.16 Consumers of feeder-II



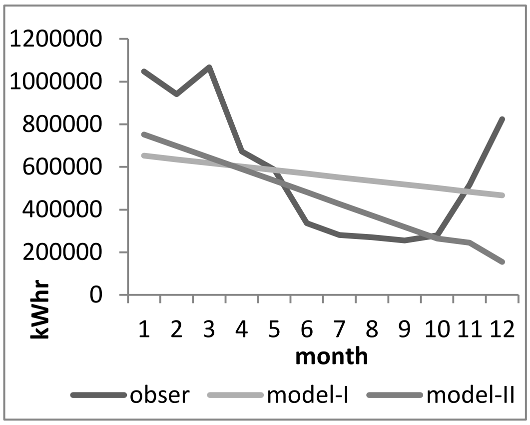


Fig. 4.17 Consumers of feeder-III   Fig. 4.18 Load profile of feeder-I (least square)

- Monthly energy consumption is high from January to April during summer. It decreases during July to August during rainy season. Again increasing trend from November onwards.
- Scheduled load shedding pattern is cyclic in nature for one week. Thus peak hour load is shifting depending upon load shedding pattern.
- An average supply of three-phase supply of 8.60 hours, single-phase supply of 8.25 hours and power outages of 7.11 hours per day is observed.
- Average number of interruptions is high for more length feeder III (Hebballii).
- Load pattern of a day indicates first (medium) peak at 8.00 hours and second(lowest) at 13.00 hours due to pump sets operation and maximum peak at 21.00 hours due to lighting.
- Electricity supply was not available for 2600(average) hours in 2009 due to several reasons like, unscheduled load shedding, lack of staff, etc.

Table 4.6 Rural distribution feeder interruptions in 2009

Feeders / hours	Hours No Supply		Hours Single phase supply		Hours Three phase supply	
	Year	per day	Year	per day	Year	per day
I-UppinBetgeri	2519.42	6.921	3049.6	8.37	3166.98	8.7
II-Amminbhavi	2596.22	7.132	3023.4	8.33	3116.36	8.56
III-Hebballii	2686.48	7.38	2935.82	8.06	3113.37	8.55

Table 4.7 Details of feeders UppinBetgeri -I, Amminbhavi-II and Hebballii –III

Rural feeder	I UppinBetgeri	II Amminbhavi	III Hebballii
Population	24644	15685	26136
Total houses	4290	2833	4793
Electrified houses	2663	2328	4235
Un-electrified houses	1627 (37.92%)	505 (17.82%)	558 (11.64%)
Residential	3763	2326	4370
LT-3(I)	134	38	37
LT-3(ii)	12	81	70
0-5HP	27	2	15
Above 5 HP	48	32	64
Street light	21	15	17
water works	41	11	48

CHAPTER 5

RENEWABLES IN INDIA

5.1 Review of Literature

Provision of electricity to rural areas is considered uneconomical by many utility companies, because of the low consumption and poor load factors. On the other hand, renewable energy sources, such as solar, wind and mini-hydro, are suitable for supplying small loads operating independently. Also, they are, in most cases, available in abundance in rural areas. The main disadvantage of such sources is the initially high capital costs of the energy conversion equipment, and the variable power output. However, if appropriately applied individually or in combination, renewable energy sources have the potential to be cost-effective sources for some of the rural loads. An assessment of mini-hydro and solar energy sources shows that the energy unit cost decreases with increasing load factor and it is lower for the mini-hydro sources. In areas where grid supply is uneconomical or not available mini-hydro sources can be used to supply groups of households while solar energy sources are more suitable for supplying individual households. (N.M.Ijumba 1996)

Low load factors, long distribution lines with low load densities and the associated high transmission and distribution losses in most rural areas of India make many of the rural electrification programs economically unattractive. Decentralised energy technologies based on local resource availability can be a viable alternative to rural electrification through the extension of the grid. The cost of grid electricity to the end user is quantified (Sinha and Kandpal 1993) and compared with the cost of electricity from decentralised energy systems to obtain the specific distances from the grid, the level of demand, and the load factor conditions, under which using decentralised energy systems for rural India makes economic sense. It is found that for small and isolated villages with low load factors, decentralised energy technologies make sense. An example on the application of the long term marginal cost concept to decide on the viabilities of two options for rural electricity is dealt with.

Rural electrification within the Caribbean has mainly centered on the extension of grid supplies due to the relatively short distances involved, while the use of renewable resources has remained experimental. However, grid extensions are not always viable for some communities due to either their small size or location. (T. Chambers 2006) A software tool that is being developed for application in the design of suitable power generation systems for small isolated rural loads based on standalone wind-diesel hybrid systems. Inputs to the program include the expected annual load profile, site-specific data on the renewable resource and diesel generator operating costs. The software applies dynamic programming techniques to arrive at a suitable selection of diesel generators and corresponding annual operating cost for given load and renewable resource profiles.

Development of Renewable Energy Sources (RES) is necessary for the sustainable development of a country due to depleting fossil fuel level, climbing fossil fuel prices across the world and more recently pressure for reduction in emission level. In India, several schemes and policies are launched by the government to support the use of RES to achieve energy security and self-sufficiency. S. N. Singh (2009) discussed the present scenario and future prospects of RES in India. Various schemes such as financial assistance, tax holiday, etc. for promoting RES development and utilization are also discussed. The present situation is seen to be very promising and favorable for RES in India. Although at present the contribution of renewable energy is small but future developments might make RES technology more competitive to displace conventional energy sources. Prospects for RES are steadily improving in India towards a great future. It is destined to take a leading role in the global renewable energy movement aiming towards sustainable development. The strategy for achieving these enhanced goals will mainly depend on the active participation of all players i.e. from government agencies to NGOs, from manufactures to R&D institutions, from financial institution to developers and of course a new breed of energy entrepreneurs.

There are still some rural communities in the world where there are no medium to large electrical energy transmission systems. The state of electrical transmission systems in different countries depends heavily on whether the economy is developing or industrialised. The total world electrical energy usage today is 18 TW-hr (1 Trillion Watt hour = 10^{12} Whr). Total electrical loads are forecasted to rise to over 30 TW-hr by 2030 but this estimate could be low. Solar resources are great enough and high-efficiency multi-junction PV concentrating solar power tracking systems could convert enough sunlight into electrical energy to meet forecasted world electrical load growth (Stephen W. Jordan and Tugrul Daim 2011).

China is still a developing country by world standard but her industrial and economic growth is developing at an unprecedented rate. This has resulted in huge consumption of electrical energy, a large percentage of it being produced by fossil fuels. Over-reliance on fossil fuels has caused concerns on a global scale and China is under great pressure to cut down greenhouse gas production. Increased deployment of renewable energy resources on a national scale provides a feasible solution to address environmental issues and to increase energy security. The pros and cons of various renewable technologies are discussed. (Tze-Fun Chan and Lei Lai 2011).

There is a temptation to compare future potential growth of PV to wind energy since PV seems to be on a development curve similar to wind power but about 10 years behind wind on a cost and capacity basis. While this appears to be true, there are some big differences between wind power and PV energy.

1. Wind has evolved mainly into a bulk power resource rather than a distributed generation resource –i.e, wind turbines are installed in large wind farms that are on the order of 100 MW or larger and interconnected to the grid at the transmission system level. At this system level, wind must compete with bulk power market prices of 2-5 cents per kilowatt-hour. On the other hand, solar PV energy is more likely to remain a distributed generation resource connected in much smaller increments well under 1 MW at the distribution feeder or customer level. The retail value of electricity at this level is 6-20 cents per kWh.
2. Even though PV appears to be 10 years behind wind power on a cost basis, since it is competing in a higher price market, it actually is much closer to reaching a competitive cost point than is widely recognised. PV only needs to get to about 12 cents per kilowatt-hour to see huge market growth at current retail utility prices.
3. PV energy is much more compatible than wind energy with urban and suburban environments due to zoning restrictions and aesthetics. It is also more easily integrated into residential and commercial building designs.

For these reasons, once market conditions are ready, PV is much more likely to see explosive growth in the mainstream consumer market than wind power ever will. However, the consumer market that PV is targeting is much less predictable than the bulk power market associated with wind power. The consumer market is as much driven by consumer preferences as it is by economics (Philip P. Barker and James M. Bing 2005).

A characterization procedure for crystalline silicon PV modules has been developed (E. Caamafio 2000), which can be used for quality control purposes by local laboratories of countries where PV Rural Electrification actions are being implemented. The method is simple both in the measurement and processing phases. It relies on the performance of outdoor measurements using basic equipment and reference PV modules as sensors for the operation conditions. Results are referenced to the Standard Test Conditions and have uncertainty smaller than ±5% for a PV module maximum power determination which is good enough to be considered within the frame of contractual procedures. No other specific equipment (variable loads, etc.), is required. Results are referenced to STC with the following uncertainties: ±2.5% for short-circuit current, ±1.5% for open-circuit voltage and ± l % for the fill factor parameter, leading to ±5% for the PV module maximum power determination.

Progress of the implementation phase of the Luz Solar program-utility initiative for rural electrification using photovoltaic is dealt with. (A.S.A.C. Diniz 2002) reports This program has been specifically designed as a larger-scale use of photovoltaic by CEMIG-Energetic Company of Minas Gerais, in collaboration with state and federal governments. The analysis is based upon 8 years CEMIG's experience with PV, which has shown that this technology can be both reliable and cost effective in remote, rural areas-as well in urban environments. The main objective has been to find an energy and lively alternative to grid connection for dispersed rural communities. Starting July, 2002, electric utilities in Brazil will be obliged to electrify the entire area it serves. PV will facilitate the access of lower-income people to lighting, communication, as well as education. The major conclusion of this 8 year CEMIG investment is that an adequate service infrastructure is required to make projects viable mainly characterised by a technical network that will embrace the whole area. This network will guarantee the system's technical performance, system design, qualified technical performance, and will also avoid a lack of ongoing and unrealised user expectations. The Luz Solar program has benefited from the lessons learned during these solar-electricity experiences, avoiding potential failures in the sustainability model.

In the present study, a solar (PV) home power system integrating with conventional DG sets has been proposed(S. N. Singh 2010) for a grid deprived areas for rural India. The main objective of this scheme is optimal design of a solar (PV) powered power supply system to produce green power and reduce the use of conventional DG sets resulting in reduced cost of operation and maintenance. The cost of logistic by minimising diesel runtime and fuel consumption thus will have a better impact on environment. The prototype unit for daily load energy requirement varying from 1200-1800Wh of a rural home has been developed. Performance tests were carried out for quality of power and efficiency of the converter system.

Table 5.1 Cost evaluation of PV with Diesel-Generator set

Diesel Generator Cost (Rs)		Cost of PV system (Rs)	
Fuel Cost X Month Rs 1000 X 8=8000 Rs 1500 X 4 = 6000	14000	PV 4 X 75 W_p Inverter 300 VA Battery 2 X 80Ah	30000 5000 10000
Operational Maintenance Rs 1000 X 12= 12000	12000	Maintenance Misc. Expenses	500 4000
Total	26000	Total	49500

Payback period=PV cost/DG cost= 2 years (maximum)

Different technological options available for DG, their current status and evaluates them based on the cost of generation and future potential in India are dealt with. The non-renewable options considered are internal combustion engines fuelled by diesel, natural gas and micro turbines and fuel cells fired by natural gas. The renewable technologies considered are wind, solar photovoltaic, biomass gasification and bagasse cogeneration. The cost of generation is dependent on the load factor and the discount rate. Gas engines and Bagasse based cogeneration are found to be the most cost effective DG options while wind and biomass gasifier fired engines are viable under certain conditions. PEM Fuel cells and micro turbines based on natural gas need a few demonstrations projects and cost reductions before becoming viable. A strategy involving pilot projects, tracking of costs and dissemination of information is likely to result in DG meeting 10% of India’s power needs by 2012. (Rangan Banerjee 2006) He calculated annulised cost of generation of different DG options depending upon the load factor. (Table 5.2) For some of the renewable options the system load factor is constrained by the supply availability.

Table 5.2 Renewable options with load factor and Cost, D=Demonstration, I=Indigenous, C=commercially available, N=Not constrained by supply

	Technology status-capacity factor	LF	Unit cost (Rs/kWh)	Remarks
Non- renewable				
Diesel	C,I-N	0.5	5.10	Existing base of more than 10,000MW as back up
		0.8	4.85	
Gas engine	C-N	0.5	2.62	Relative price of natural gas
		0.8	2.29	
Micro turbine fuelled by natural gas	D-N	0.5	3.24	Technology still in progress
		0.8	2.82	
Fuel cell fuelled by natural gas	D-N	0.5	6.64	Technology demonstration required
		0.8	4.68	
Renewable				
wind	C-I, 13% max	0.2	8.71	installed
		0.3	5.84	
PV	C-I, 25% max	0.25	17	installed
Biomass gasifier	C-N	0.5	3.16	installed
Gas engine		0.8	2.59	
Bio mass-cogeneration	C-I 50%	0.5	2.40	installed
		0.6	2.27	

Hybrid renewable energy systems are becoming attractive for remote areas power generation applications due to advances in renewable energy technologies and increase in the oil price. (Abdullah H. Al-Badi 2009) A feasibility study of wind penetration into an existing diesel power plant of an isolated Duqum area in the Sultanate of Oman. HOMER software has been used to perform the study for the hybrid system with no battery storage. For Wind speed less than 5m/s the existing diesel plant seems to be is the only feasible solution over the range of fuel prices used in the simulation. Moreover, the proposed hybrid system becomes feasible at wind speeds of more than 6 m/s and a diesel cost of 0.368 US $/L or more, which is the current diesel cost in Duqum.

The decentralized power is characterised by generation of power nearer to the demand centers, focusing mainly on meeting local energy needs. It can function either in the presence of grid, where it can feed the surplus power generated to the grid, or as an independent/stand-alone isolated system exclusively meeting the local demands of remote locations. Further, decentralized power is also classified on the basis of type of energy resources used-non-renewable and renewable. These classifications along with a plethora of technological alternatives have made the whole prioritization process of decentralized power quite complicated for decision making. There is abundant literature, which has discussed various approaches that have been used to support decision making under such complex situations. With such a felt need 102 articles were reviewed and features of several technological alternatives available for decentralized power, the studies on modeling and analysis of economic, environmental and technological feasibilities of both grid-connected (GC) and stand-alone (SA) systems as decentralized power options are elaborated(Deepak Paramashivan Kaundinya et al.2009).Salient features of grid connection and stand alone systems-

Grid connected systems:

- Centralised generation depending upon mainly fossil fuels and operation capacity determined by the supply.
- Grid acts as a battery with an unlimited storage and hence takes care of daily / seasonal load variations; overall efficiency is better.
- Connectivity to the grid enables large scale systems and operates at high plant load factors. This improves economic viability of operation.
- Operates on higher scales of MW and hence used for centralised or dense load making the system efficient.
- High cost of transmission and distribution when extended to remote places.
- Depletion of fossil fuel, emission of obnoxious gases rising concerns about the climate change and other health hazards.

Stand alone systems:

- Decentralised system and operate at few kW
- Suitable for remote locations where grid cannot penetrate and there is no other source of energy.
- Need storage system like battery for storage of electricity produced during off-peak demand periods.

• Need based and operational capacity is matched on the demand.
• System output varies with time, seasonal variations and sometimes not available for throughout the year.
• Ideal for low plant load factor
• Easily accessible, environmentally benign, sustainable and reliable energy supply for small and medium loads.

5.2 Renewable energy in India

The term “renewable energy” comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). There are various forms of renewable energy, deriving directly or indirectly from the sun, or from heat generated deep within the earth. They include energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, solid biomass, biogas and liquid biofuels. (Fig.5.1)

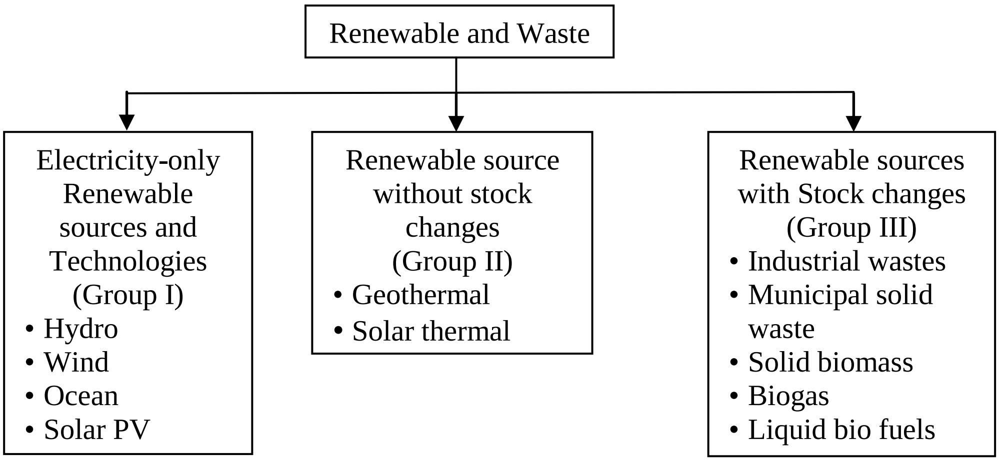


Fig. 5.1 Renewable and waste classification (Source: IEA Manual 2005. pp116)

• Group I-products which need to be transformed into electricity in order to be captured (such as hydro or solar photovoltaic).
• Group II-products which are produced and then can be input for multiple uses in the transformation and final consumption sectors (such as geothermal or solar thermal); because of their nature these products cannot be stored in a conventional sense and therefore are products for which no stock change data can be reported.
• Group III-products which are produced and used for multiple purposes in the transformation and final consumption sectors (such as wastes, fuel wood, biogas

and liquid biofuels); because of their nature they can be stored in a conventional sense and are products for which stock change data can be reported.

Four seems particularly promising for rural electrification in India: small hydropower, wind, biomass and solar and they share several characteristics such as:

- RES are capital-intensive, with low running costs. Relatively high capital requirements are a major obstacle in India, where finance is expensive. All except biomass have no fuel costs at all, so running costs are essentially just maintenance. While biomass does require fuel much of this is available on a non-cash basis.
- RES are relatively unfamiliar technologies. While many of the technologies, particularly in the case of hydro, have existed for a long time, they tend to be less familiar and are thus seen as more risky.
- RES do not rely on outside fuel supply and preferred for more remote applications.
- In some cases they are relatively benign in terms of local impacts on the environment, though some hydro and biomass use can have significant impacts.
- RES produce very low GHG emissions, even considered over the whole life cycle.
- RES have tended to be more expensive on a per kilowatt hour (kWh) basis than conventional energy sources. However, technology improvement and economies of scale have brought costs down dramatically over recent decades. (WEA 2000)

India is one of the few countries to have a ministry dedicated to renewable energy promotion-the Ministry for New and Renewable Energy (MNRE) and the present status of Renewable Energy Programme/ Systems up to 31.08.2011(Table 5.3) Since its formation, the MNRE (previously MNES) has launched one of the world's largest and most ambitious programs on renewable energy and has been successful in generating about 12% of renewable energy mix. Renewable energy is well positioned to play a critical role in addressing this growing energy demand for the following reasons:

Table 5.3 Renewable Energy Systems on 31-8-2011

Renewable Energy Programme/ Systems	Target for 2011-12	Achieve ment during Aug,'11	Total achievement 2011-12	Cumulative achievement up to 31.08.2011
I. Power from renewables:				
A. Grid-interactive power (MW)				
Wind Power	2400	266.00	833.00	14989.00

Small Hydro Power	350	21.00	111.30	3153.93
Biomass Power	460	25.00	86.50	1083.60
Bagasse Cogeneration		12.5-	111.50	1779.03
Waste to Power -Urban		1.20	1.20	20.20
-Industrial	25	-	-	53.46
Solar Power (SPV)	200		8.50	46.16
Total	3435	325.70	1152.00	21125.38
B. Off-grid/ captive power (in $MW_{eq)}$				
Waste to Energy -Urban		-	-	3.50
-Industrial	15.00	0.75	10.18	72.30
Biomass(non-bagasse) Cogeneration	80.00	2.55	31.99	327.95
Biomass Gasifiers -Rural	3.00	0.72	1.20	15.55
- Industrial	10.00	2.96	4.50	125.88
Aero-Generators/Hybrid systems	0.50	-	0.12	1.24
SPV Systems (>1kW)	20.00	0.42	3.50	72.50
Water mills/micro hydal(No.s)	400	143	143	1818
Total	128.50	7.40	51.49	618.92
II. Remote village electrification				
Remote Villages provided with RES	500	688	742	8846
III. Other renewable energy systems				
Family Biogas Plants (Number in lakhs)	1.50	.07	.12	44.16
Solar Water Heating, Collector Area (Million sq.m)	0.60	0.04	0.20	4.67

- India has abundant, untapped renewable energy resources, including a large land mass that receives among the highest solar irradiation in the world, a long coastline and high wind velocities that provide ample opportunities for both land-based and offshore wind farms, significant annual production of biomass, and numerous rivers and waterways that have potential for hydropower.
- India's use of its indigenous renewable resources will reduce its dependence on imported expensive fossil fuels.
- Increased competition for limited fossil resources is projected to push prices up, while increased deployment of renewable technologies pushes prices down in line with technology improvements and economies of scale.
- As a distributed and scalable resource, renewable energy technologies are well suited to meet the need for power in remote areas that lack grid and road infrastructure.

- Renewable energy technologies offer the possibility of providing electricity services to the poor and urban areas; while addressing India's greenhouse gas (GHG) concerns and goals.

Considering the limitations of conventional centralised power sector policy, many researchers are highly optimistic about decentralised power generation with renewable energy source. Powerful forces are driving a similarly rapid transition to distributed electric generation, where the power plant shifts from a large remote station to rooftops, basements, backyards, or driveways.

5.3 Sources of renewable energy for rural electrification

5.3.1 Small Hydro power

The hydroelectric power refers to the energy produced from water (rainfall flowing into rivers, etc) and it is the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. Hydro power projects (Fig 5.2) are generally categorized in two segments i.e. small and large hydro. In India, hydro projects up to 25 MW station capacities have been categorized as Small Hydro Power (SHP) projects.

Table 5.4 Classification of hydro projects

Class	Station Capacity in kW
Micro Hydro	Up to 100
Mini Hydro	101 to 2000
Small Hydro	2001 to 25000

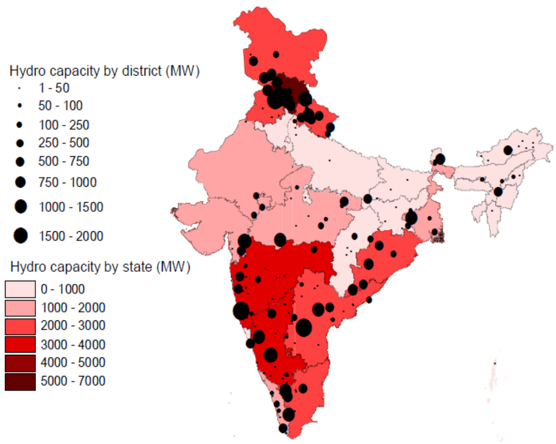


Fig. 5.2 Existing Hydro capacities

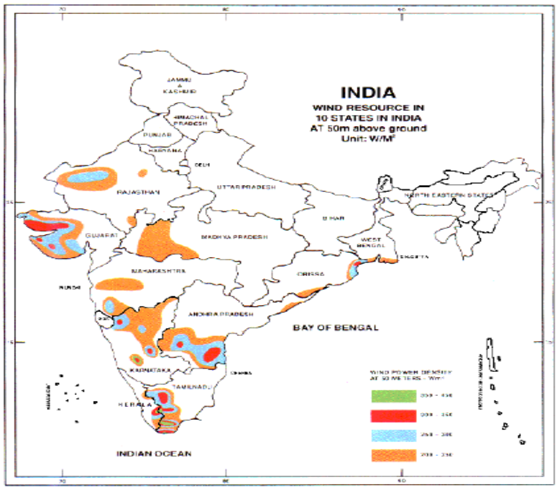
While Ministry of Power, Government of India is responsible for large hydro projects, the mandate for the subject small hydro power (up to 25 MW) is given to MNRE. Small hydropower accounts for some 3153.93 MW (Fig.5.4) and are further classified as in Table 5.4.The main advantages of SHP are, technologically mature, easy to maintain, reliable and has low operating costs. The investment costs for small rural and remote hydro power projects in India vary between Rs 1, 24,310-Rs 2, 33,335 per kW.

This includes the cost of power evacuation and distribution system (Nouni et al. 2005). At a discount rate of 12%, the energy delivery cost ranges from Rs.3/kWh up to around Rs.9/kWh, dependent on the plant load factors. Seasonal variation in water flow and under utilization of the produced electricity can threaten the viability of hydro plants. Traditional approaches have suffered barriers to environmental factors like:

- Building a dam across a river floods the land that would otherwise be available for use, alters the landscape, affects the local community that would have lived and worked on the flooded land, alters the character of the river.
- Diverting a river affects the nature of the countryside and does not lend itself to use on a large scale.
- Permanent complete or partial blockage of a river for energy conversion is adversely affected by variations in flow.
- Building large/medium-scale hydro power plants can be polluting and damaging to surrounding ecosystems. Changing the course of waterways can also have a detrimental effect on human communities, agriculture and ecosystems further downstream.
- Hydro projects can also be unreliable during prolonged droughts and dry seasons when rivers dry up or reduce in volume.

5.3.2 Wind Energy

India is already a leader in wind energy production. It is the fifth-largest wind power producer in the world, behind Germany, Spain, United States, and China. India is surpassed only by Germany as one of the world's fastest growing markets for wind energy. (Fig 5.3 to Fig 5.5)



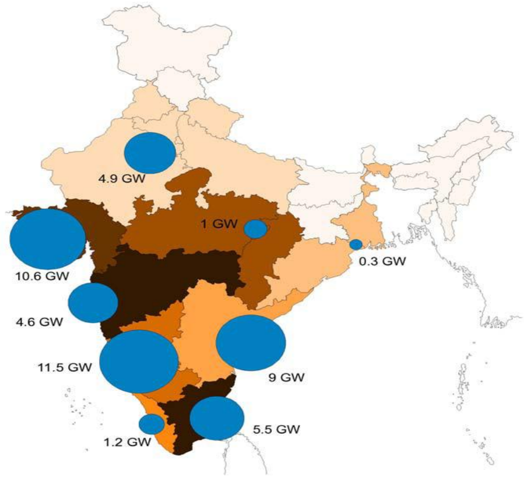


Fig. 5.3 Wind Energy map   Fig. 5.4 Regional wind resources (Arora et al. 2010)

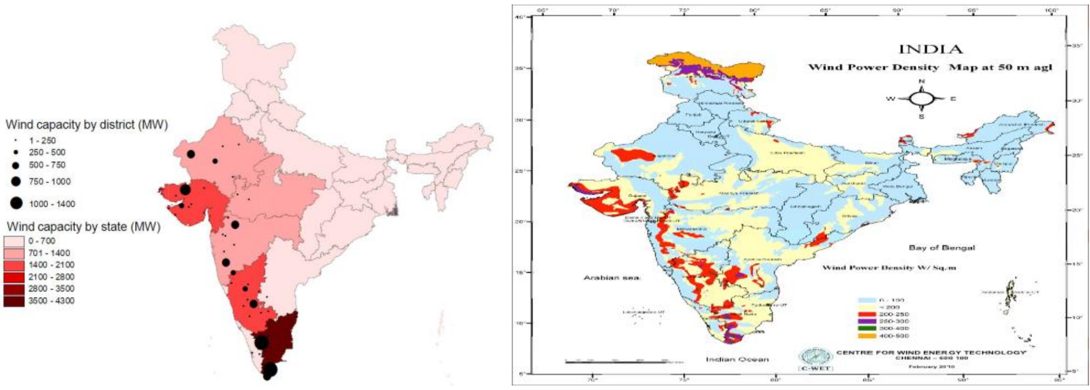


Fig. 5.5 Existing wind resources

Small systems can use battery storage to provide power on demand, but larger applications off-grid will use some combination of solar, biomass, and/or diesel to ensure a more consistent output. An estimated 80% of the value chain is located in the country, and the Indian wind industry has an annual production capacity of about 500 MW per year because of the following factors:

- It is environment friendly, clean and safe energy resources.
- It has the lowest gestation period as compared to conventional energy.
- Equipment erection and commissioning involve only a few months.
- There is no fuel consumption, hence low operating and maintenance costs.
- The capital cost is comparable with conventional power plants. For a wind farm the capital cost ranges between 4.5 Crores to 5.5 Crores, depending on the site and the wind electric generator selected for installation.

Among the renewable technologies considered wind energy is growing significantly because of the supportive policy environment. For sites where the capacity factor is 30% or more, wind is competitive at present prices. Even though the comparison shows a price of Rs. 5.84/ kWh, the accelerated depreciation and tax benefits provided make it a viable investment even at a selling price of Rs. 3/kWh along with the challenges:

- Wind machines must be located where strong, dependable winds are available most of the time.
- Winds do not blow strongly enough to produce power at all the time, energy from wind machines is considered intermittent. Hence utility companies can use it for only part of their total energy needs.
- Wind towers and turbine blades are subject to damage from high winds and lighting. Rotating parts, which are located high off the ground can be difficult and expensive to repair.
- Electricity produced by wind power sometimes fluctuates in voltage and power factor, which can cause difficulties in linking its power to a utility system.

Most of the wind energy deployment is grid connected. Due to supply variations it is less suited to off-grid stand alone generation. However, when considered part of a hybrid system, alongside diesel, biomass or solar generation, wind turbines can be economically appealing.

- As of 31,August 2011 the installed capacity of wind power in India was 14989.31 MW (Table 5.3). States with wind power capacity are Tamil Nadu, Maharashtra, Karnataka, Gujarat and Rajasthan.
- Total potential for wind power in India was estimated by the Centre for Wind energy technology (C-Wet) at 48.5 GW.
- Government of India has announced generation-based incentive of Rs 0.50 per unit of electricity from wind power projects, subject to maximum of Rs 6.2 million per MW to increase investor base.
- Wind Energy Outlook 2009, also indicates that wind energy can provide up to 24% of India’s power needs by 2030, while creating 213,000 green jobs and cutting 5.5 billion tons of CO_2 emissions.

- Government of India is planning to infuse around Rs.600 billion in next few years under 11th five year plan in this industry, which will boost the growth of this sector.

5.3.3 Biomass energy

Biomass includes solid biomass (organic, non-fossil material of biological origins), biogas (principally methane and CO_2 produced by anaerobic digestion of biomass and combusted to produce heat and/or power), liquid biofuels (bio-based liquid fuel from biomass transformation), and municipal waste (wastes produced by the residential, commercial and public services sectors and incinerated).

The most successful forms of biomass are sugar cane bagasse in agriculture, pulp and paper residues in forestry and manure in livestock residues. Biomass may be used in a number of ways to produce energy and most common methods are: combustion, gasification, fermentation and anaerobic digestion. India is very rich in biomass (Fig 5.6 and Table 5.3).

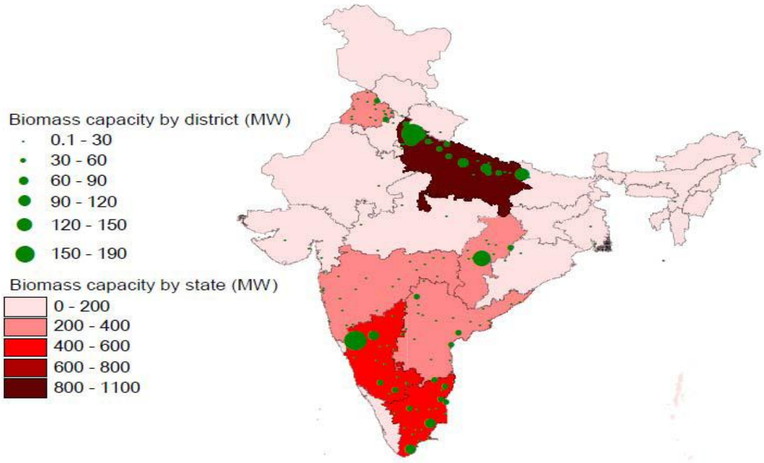


Fig. 5.6 existing biomass capacity

- It does not suffer from intermittency and can therefore be used as a basis for power on demand without need for additional storage or backup technology.
- It offers substantial advantages for rural communities, which are mainly engaged in agriculture. Most villages have a ready supply of agricultural residue that can be used as fuel, although there are complex social questions of ownership of this resource, particularly where village commons are involved. Agricultural residue can be traded on part-barter basis for electricity; an important advantage over commercial fuels in communities that are poor in cash.

- Fuel supply plays a crucial role in determining the financial viability and sustainability of biomass gasifier power plants. Competition with food produce makes biomass a potentially contentious fuel supply, precluding the dedicated use of existing farmland for biomass production (Ravindranath et al. 2005). Mismanagement or unforeseen shortages of managed crops can put pressure on forests or common property resources and can threaten the viability of distributed power plants.

Rural India has an abundance of wasteland and marginal farmland. Successful projects have helped local communities to effectively utilise energy plantations or common land for the growing of suitable biomass fuel crops. Agricultural residuals can supplement fuel crops for small-scale gasification plants. Where the community can regulate the use of scarce ground water, farmers can grow cash crops and drought sensitive crops.

For small-scale electrification, particularly community loads in rural areas, biomass gasification represent a sustainable and relatively low cost option for fulfilling basic electricity needs. Past studies have put the typical cost per unit between Rs.2.5 per kWh and Rs.7.5 per kWh, with cost sensitive to load factor and fuel availability (Nouni et al. 2007). Biomass gasifiers operating dedicated gas engines is a DG option that is almost cost effective and seems suited for rural areas.

5.3.4 Solar Energy

India is the world’s seventh-largest producer of solar photovoltaic cells and also exports. India has huge solar potential because of its location between the Tropic of Cancer and the Equator. The average daily solar radiation varies between 4 kWh per sq.m to 7 kWh per sq.m for different parts of the country. There are on an average 270 to 300 clear sunny days in a year. Thus, it receives about 5,000 trillion kWh of solar energy in a year. (MNES 2005)

PV cells find applications in individual home rooftop systems, community street lights, community water pumping and areas where the terrain makes it difficult to access the power grid. PV cells produce DC power directly from sunlight and the efficiency of cells with single crystal silicon is about 13%-17%. High efficiency cells with concentrators are being manufactured which can operate with low sunlight intensities. However, for small-scale applications, particularly in remote areas, this becomes cost-competitive. Their lack of moving parts also means that they require little maintenance, though they do require batteries in order to deliver power on demand.

- India is among top 5 countries in the world with potential for solar energy day time production peak coincides with peak electricity demand making solar ideal supplement to grid.
- Solar energy generation in India broadly falls into Solar Thermal Energy and Solar Photovoltaic Systems
- High Capital Costs of solar power plants (Rs.17 Cr /MW and Rs.4 Cr for thermal) and generation cost (Rs.13.45-Rs.18.44 per kWh) historically restricted its growth versus thermal power; however things are fast changing in the last few years.
- As of 31,Aug 2011, grid interactive solar photovoltaic power plants, with aggregate capacity of 46.16 MW, and off-grid 72.50MW, installed in the India.(Table 5.3)

5.3.5 Off-grid generation based on diesel

Entrepreneurs are operating diesel-based electricity provision in small towns and rural areas as a back-up supply to the grid. Diesel generation sets are in widespread use for off-grid power due to followings:

- The technology is a familiar one, with large established vendors for both the generators and the fuel.
- Compared with alternatives such a renewables, a relatively low proportion of the life cycle cost is upfront capital (Table 5.5)

Table 5.5 Cost of diesel generation on site (Source: Framework from CDM project in Renewable Energy MNRE report, May, 2009. pp 128)

Diesel Price	Rs.34.86 / litre
Electrical energy produced in diesel-generator set per quantity of diesel used(kWh/litre)	3.2 kWh/litre
Cost of power generation by diesel-generator set	Rs.10.89 /kWh
Cost of Power from grid supply	Rs.3.5 /kWh

- Maintenance and repair skills are widely available in both cities and rural communities.
- They can provide high-quality AC power on demand.

To weigh against this, diesel presents a number of challenges:

• Large-scale use adds to India's growing dependency on oil imports and foreign ex-chequer.

• Diesel engines emit noxious fumes, as well as carbon dioxide.

5.3.6 Comparison of options

Table 5.6 Renewable options for India (Source: MNRE)

Technology	Application	Pros	Cons
Small biomass	Water pumps Mills Refrigeration Lighting	Allows for income Generating activities, Base load operation, Continuous operation possible	Noxious emissions
Mini-hydro	Mills Lighting Communication	Long life, High reliability, Allows for income Generating activities	Site-specific, Intermittent, Water availability
Wind	Lighting and Communication, Mills, Pumps	No fuel cost	Expensive batteries, Intermittent energy services
PV/Solar	Lighting and electronic equipments	No fuel cost	High capital costs, High cost of batteries and replacement

Table 5.7 Comparison of renewable options for India (Chaurey et al. 2005 p20)

RES	Degree of maturity	Penetration	Advantages	Disadvantages	Minimum requirement	Cost $/kW
Small Hydro	High	Medium	Low capital and maintenance cost, Minimum Maintenance, Low cost	sites are inaccessible, very less power in lean period	For 1kW, 30m head is, then minimum flow rate is 4 litre/sec^2	2500-3000
Solar PV mini grid	High	High	availability of resource, O& M minimum, Local manufacturing of components, Environment friendly,	High initial cost, Replacement of batteries	Minimum 4-5kWh per square meter insolation	7335-7780
Biomass gasifier	Medium	Low	Low cost of Installation, Local manufacturing of components, Low energy cost	Community mobilization needed	1.5-2kg of biomass for producing one unit of energy	2225-2250
Wind mills	High	Medium	-	-	Start up wind Speed of 2.5-3 m/s	2225-2250

Table 5.8 Options for rural electrification in India (Ref: Christopher Joshi Hansen & John Bower Oxford Institute for Energy Studies EL 05 October 2003)

Suitable Options	% age Efficiency	Approx. cost [Rs/ kWh]	Influencing Factors
SHS	13-18	10-12	on site generation, modular in size, battery life
Diesel	15-25	10-15	availability, escalating fuel cost, environmental concerns
Wind	25	4-8	seasonal ,bulk power source, away from load, medium wind profile low plant load factor
Biomass	15-20	2 -4	availability, maintenance
Grid	--	5	voltage profile, Consumers Hours loss

Table 5.9 Renewable energy lower bound on installed capacity scenario of India (Source: National Energy Map for India: Technology Vision 2030.TERI)

	2006-07	2011-12	2016-17	2021-22	2031-32
SHP(GW) Business-as-usual	2	8	8	8	8
SHP(GW) Aggressive	2	8	10	10	10
SPV GW_p	0.5	0.14	0.39	1.04	7.46
Biomass(GW)	0.25	0.5	1.00	2.00	8.0

Thus, India enjoys abundant potential to all of the renewable energies.

5.4 Solar for India

The advantages of decentralised electricity generation are numerous: avoiding reliance on state utilities, decreased reliance on fossil fuel-based electricity generation and direct employment opportunities within the villages, the sites of equipment and operation. Hence power planners are forced to think of supplementary/ alternative electrical energy supplies to these areas. Indian conditions are best suited for solar energy because of -

- Availability of solar energy for about 270 to 300 days in a year (Fig. 5.7 to Fig.5.13).
- Reduction in the cost of PV cell from Rs.1000 in 1998 to Rs.170-200 per watt in 2011.
- No transmission and distribution losses.
- Solar energy has less geographical limitation.

• Customer is the owner of his own power-generating system.

• No fuel cost is involved and the production of power is environmentally friendly.

• Suited for roof top generation, generation at site and hence proximity to utilities.

• Proven technology of panel, battery and controller.

• PV systems are durable with little maintenance.

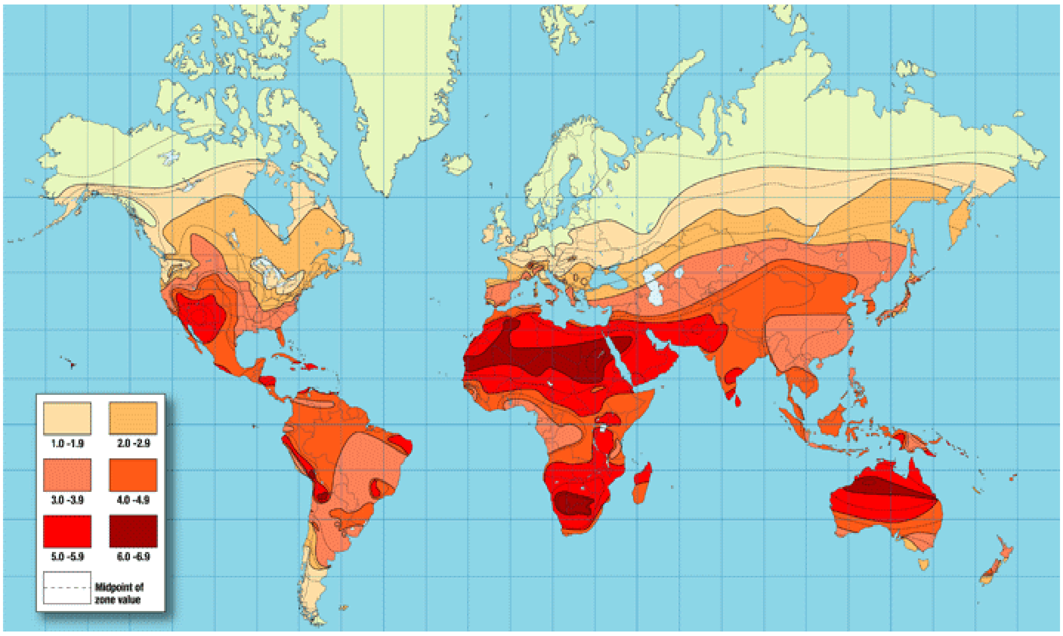


Fig. 5.7 World solar insolation data NASA

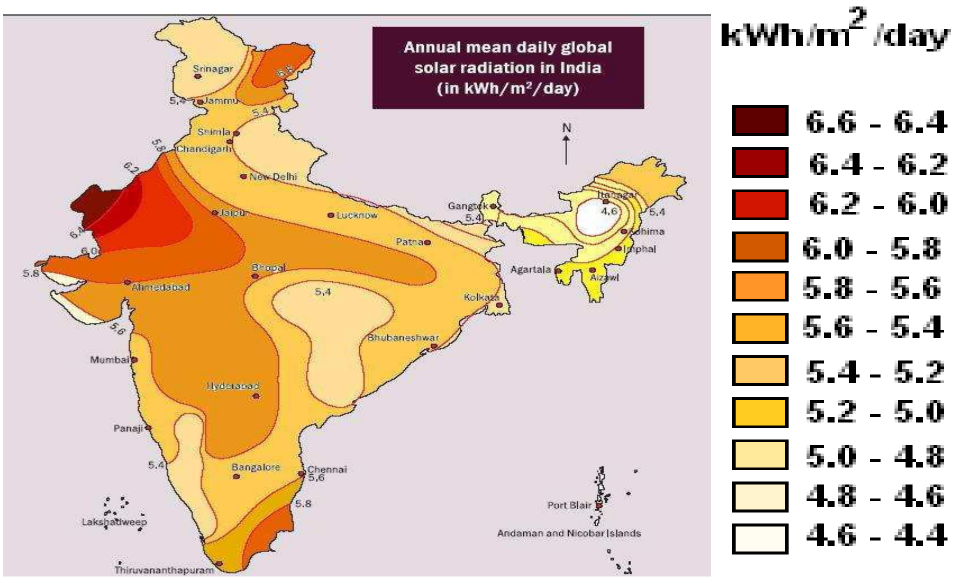


Fig. 5.8 Annual mean daily global solar radiations in India (Ref: MNRE report)

Table 5.10 Solar radiations in the regions of India

Solar Insolation level (kWh /sq.m/day)	CUF (%)	States
6.0 and above	18.97 and above	Rajasthan, parts of J&K (Leh)
5.75	18.18	Parts of Gujarat, M.P.
5.50	17.39	Parts of A.P., Tamil Nadu, Karnataka, West Bengal, Bihar
5.25 and less	16.60 and less	Rest of India

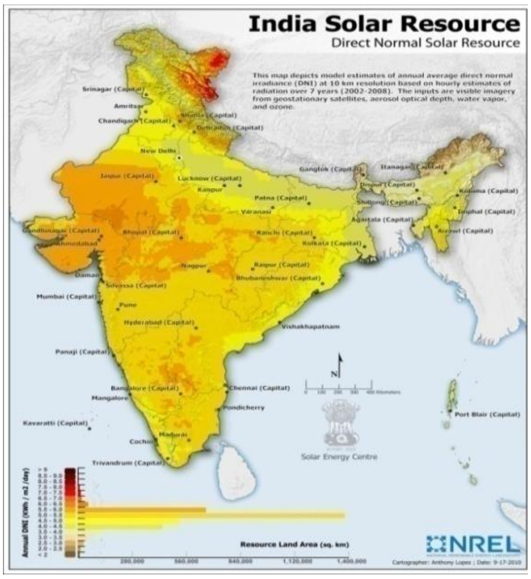


Fig. 5.9 Direct Normal Solar Resource

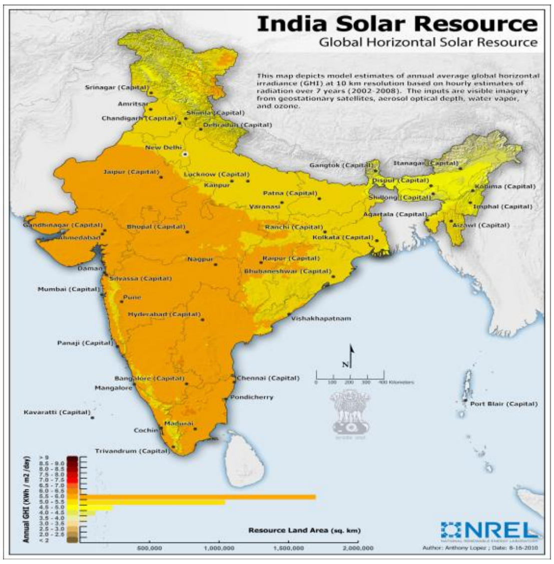


Fig. 5.10 Global Horizontal Solar Resource

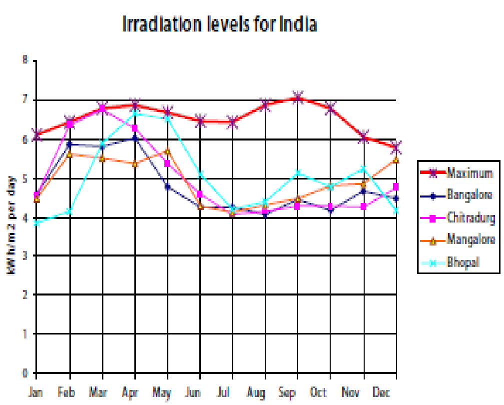


Fig. 5.11 Average Insolation levels
levels in four different regions of India

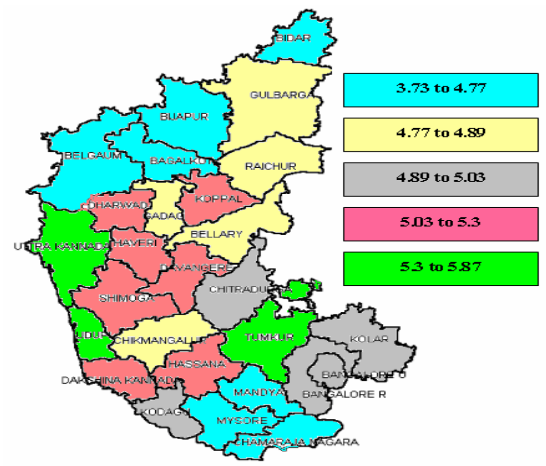


Fig. 5.12 Average Insolation
in Karnataka during winter

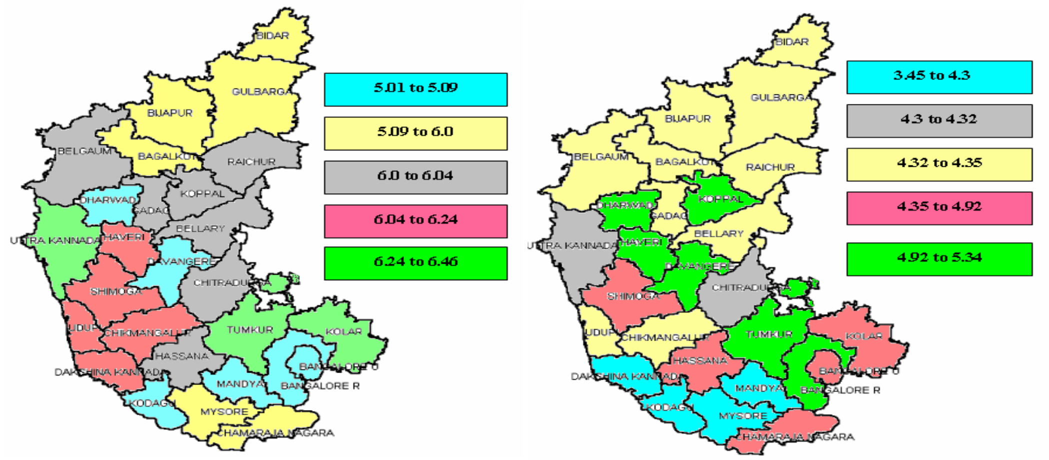


Fig. 5.13 Average Insolation levels in Karnataka during summer and monsoon (Source: Ramachandra T.V., Shruthi B.V., (2007), Spatial mapping of renewable energy potential, Renewable and Sustainable Energy Reviews, 11, 1460-1480)

5.4.1 Photo Voltaics

The term photovoltaic's derives from the Greek word "phos" meaning light and the word "volt" (named by Alessandro Volta). Photovoltaic is a science, which examines light-electricity conversion, respectively, photon energy-electric current conversion. Both direct and diffuse solar radiations take part of the process.

- 1839- Edmond Becquerel accidentally discovered photovoltaic effect when he was working on solid-state physics.
- 1878-Adam and Day presented a paper on photovoltaic effect and in 1883 Fxitz fabricated the first thin film solar cell.
- 1941- Ohl fabricated silicon PV cell but that was very inefficient and in 1954 Bell labs Chopin, Fuller, Pearson fabricated PV cell with efficiency of 6%.
- 1958 -PV cell was used as a backup power source in satellite Vanguard-1 and this extended the life of satellite for about 6 years.

The light to current conversion takes place within solar cells. There are many competing technologies such as thin film, mono crystalline, polysilicon, and amorphous and concentrating solar power, etc. (Fig 5.14)

A photovoltaic module is the basic element of each photovoltaic system. It consists of many jointly connected solar cells. Most commercial modules consist of 36 or of 72 cells. Solar cells are connected and placed between a tedlar plate on the bottom and a tempered glass on the top. Placed between the solar cells and the glass there is a thin ethylene vinyl acetate (EVA) thermoplastic polymer foil. Solar cells are interconnected with thin contacts on the upper side of the semiconductor material.

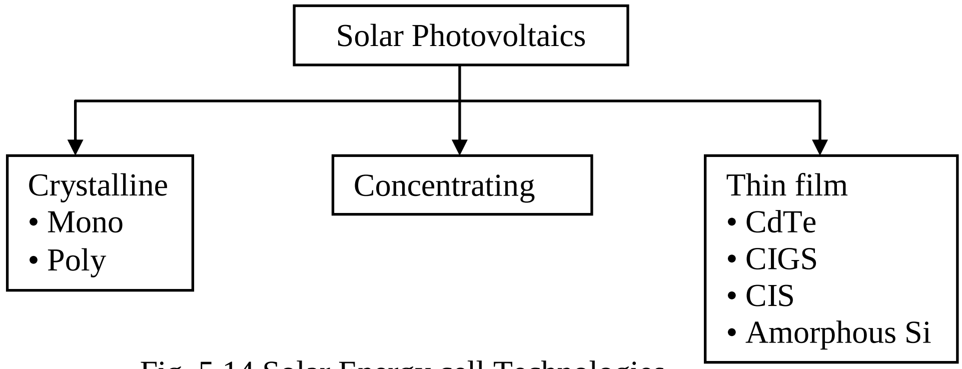


Fig. 5.14 Solar Energy cell Technologies

The typical crystalline modules power ranges from several W to up to 150 W/module due to the following factors:

1. Environment friendly as they do not emit gaseous and liquid pollutants.
2. Can be easily transported, assembled and installed in remote areas.
3. Produce DC electricity that can be stored in batteries.
4. Zero fuel usage and Noise free.
5. Robust, reliable, weather proof and having long life of 25 years with proper maintenance.
6. Solar energy has the high energy density of $15mWp/cm^3$ commercially available energy.

Despite these advantages PV system has following challenges:

- High capital cost, makes the system cost-prohibitive.
- Few types of devices can be operating using PV.
- PV systems being less competitive compared to other sources and are not suitable source for meeting large loads.
- Higher potential of these systems is mainly in remote rural areas where grid connection is not cost effective.

Advances in photovoltaic module technology, inverters, system installation practices, and design standards are improving the performance of PV systems and have led to PV becoming established as a strongly competitive energy source for off-grid energy applications. PV is also on the cusp of becoming competitive in grid connected configurations and is currently experiencing strong growth in this type of application. Substantially reduced PV module cost and higher module efficiency compared to products of just a decade ago are playing a key role in this expansion. The introduction of modern inverters that are more efficient, have higher reliability, and improved utility system interface features are also facilitating market growth. Overall, PV energy costs have fallen by a factor of about 2 over the past decade and the prospects for continued improvement are strong.

PV modules can be purchased currently for only 2.5 to 6 dollars per watt and since systems are being installed for 6-12 dollars per watt, clearly there are significant other balance-of-system factors that impact the total system cost. In fact, on a 25 year life cycle basis, inverter costs may contribute nearly as much as PV module costs since they need to be replaced 2-3 times over the 25 year lifecycle. As module costs have improved, there is pressure building to reduce the costs in the balance of the system components. Inverter suppliers need to reduce the prices of their products from the current typical $0.5-1.0 per watt to less than $0.25 per watt.

5.4.2 PV for a rural home

The average energy consumption of a household is influenced by much factors-like construction, size of house, climate, season, and size of family (census 2001 average 5.3 persons per house in rural area with 3 rooms).

- Arid regions in India receive plentiful solar radiation (Ave. solar insolation is 5 kWh per sq. m) with the potential availability of 20 MW per square kilometer (source: IREDA)
- Availability of solar insolation in Dharwad, (Karnataka state) rural indicates that there is ample scope for using PV in rural areas (fig 5.12 and fig.5.13)
- Government of India provides central financial assistance (CFA) for remote village electrification programs as per No15/6/2006-07-RVE (Table 5.11).

Table 5.11 Central Financial assistance for remote village electrification programs (Source: Government of India notification No.15/6/2006-07-RVE)

Home lighting Models	Specifications	General Category States(Rs)	Special category States(Rs)
Model-I	$18W_p$ module, 2 light	5895	6165
Model-II	$37W_p$ module, 4 light	11250	11250

- Electric lighting (up to 200 times brighter than kerosene lamp) directly improves the quality of life. It allows children to study in the evening and women to gain some precious time for them or to extend income generating work into the evening hours.
- It is logical to operate a small unit delivering rated output when the load demand is light. Then as load increases another unit is connected with the one already in operation. This keeps the plant loaded up to their rated capacity and increases efficiency of operation. Several smaller units are more reliable than a large single unit and additional units can be installed as and when required with the growth of load on power station.
- Fig. 5.15 is an illustration of the multi-sectoral linkages of solar PV influence on quality of life in off-grid rural communities and also indicates some social and economic benefits that may accrue to rural beneficiaries. (UNDP 2004)

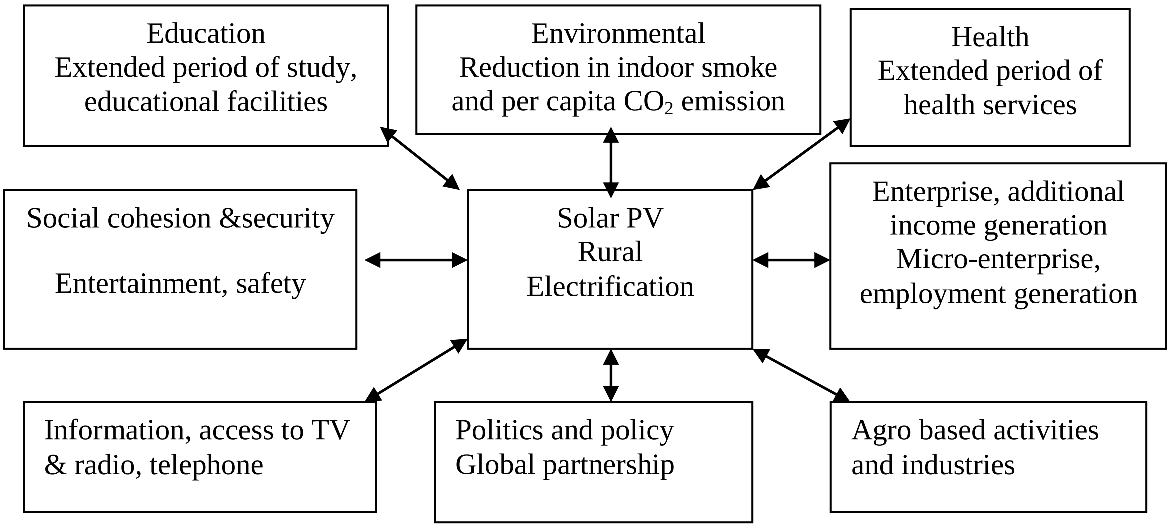
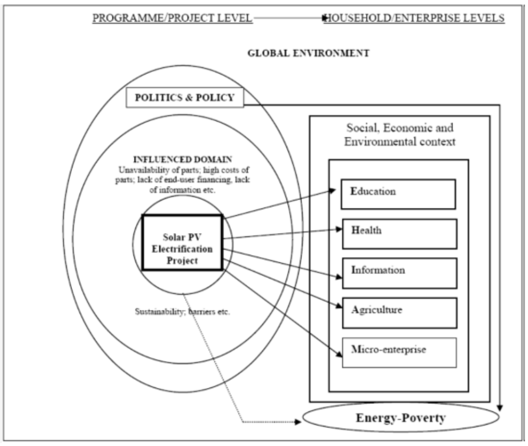


Fig. 5.15 Energy quality of life in off-grid rural areas

- In order to show data on the different dimensions of energy-poverty, some indicators could be identified and selected taking into consideration the social, economic and environmental dimensions of sustainable development and goals relating to education, health, information, agriculture and microenterprises. (Fig 5.16)
- Fig. 5.17 presents the time variation of cumulative number of solar home lighting systems and reduction in cost installed in India (MNES 2008).



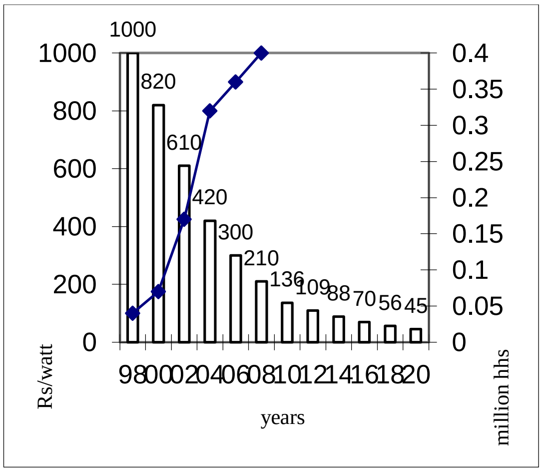


Fig. 5.16 Conceptual frame works Fig.5.17 SPV Cost Reduction and Increase (India)

Table 5.12 Projected values of cumulative SHS, installed power and CER

Year	SS million	OS million	SS MWp	OS MWp	CER SS million	CER OS million
2008	0.6	1.8	22.1	66.0	0.1	0.4
2012	2.0	5.9	75.1	219.7	0.5	1.4
2016	6.7	18.3	247.8	675.5	1.6	4.4
2020	15.6	37.4	575.8	1384.2	3.7	9.0

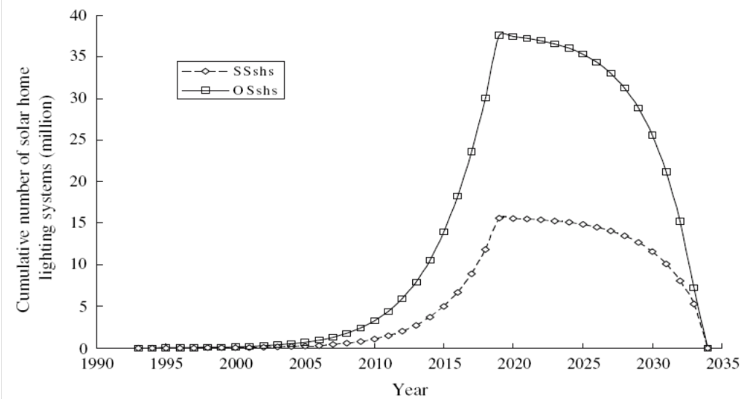


Fig. 5.18 Cumulative numbers of SHS

OS (Optimistic scenario), SS (Standard Scenario), CER (Certified Emission Reduction)

- Pallav Purohit (2007) estimated the time variation of cumulative number of installation of SHS lighting systems in India using Logistic model as in table 5.12 and fig 5.18.
- As per the fuel cycle analysis, Green House Gas Emissions are very low for RES. (Table 5.13)

Table 5.13 Green House Gas Emissions
(Source: John Holdren Kirk Smith, World Energy Assessment, UNDP, 2001)

	CO_2 g/kWh		CO_2 g/kWh
Coal Conventional	960 -1300	Biomass	37-166
Advanced Coal	800-860	PV	30-150
Oil	690-870	Hydro-electric	2-410
Gas	460-1230	Wind	11-75
Nuclear	9-100		

The main barriers to large penetration of PVSHS consists of-

a. Intermittent nature of the solar energy resource.
b. High initial investment and still higher costs of these systems to the end users as compared to their conventional counterparts.
c. Lack of strong marketing network and excellent market-support infrastructure.
d. Poor access to adequate financial resources including working capital and lack of innovative financing mechanism including micro and retail financing.
e. The market for SPV home lighting systems is currently supply driven as user's needs have not been fully addressed by the suppliers.
f. Emphasis is more on technology development rather than product development to effectively meet the user's need.
g. Access to these products is currently poor and rural reach has not been impressive so far.
h. Awareness level of the benefits of PVSHS is low (Purohit and Kandpal 2005).

5.4.3 Factors considered for PV panel erection

For maximum daily output, PV modules should be exposed to the sun for as much of the day as possible, with southern exposure during the peak sun hours of 10 am to 3 pm.

- Southern exposure must be free from obstructions such as trees, mountains and buildings that might shade the modules.
- The unobstructed southern exposure must also have appropriate terrain & sufficient space to install the PV system.
- Solar panels are fixed with no sun tracking facility and the charge controller is simple ON/OFF type with no Maximum power point tracking facility.

- Several environments have detrimental effects on the long term performance capability of solar cell arrays like high wind, snow, ice loading, and corrosion by moisture, high temperature and air born contaminants.
- In case of SHS supply for households, each family will be responsible to manage and monitor its own loads within the available source rather than metering every house. This can lead to much better energy management and saving.
- To increase insights into the use of solar PV in households, monitoring and evaluation activities are required, using as main instruments, data loggers & household surveys. Monitoring needs to be continued after solar home system projects end.
- Batteries and fluorescent lights are the two components with the most frequent failures in solar home systems. Protection of the battery can be enhanced by improved charge regulators, which are currently of simple design. To enhance product quality, improved designs of fluorescent lights, inverters and charge regulators need to be developed.

The experience with the use of renewable energy sources has so far delivered mixed results. Larger scale deployment of renewable energy technologies for rural energy has been prevented and hindered by a range of barriers, even where technologies exhibit with economic advantages. Indeed across past programmes and policies, a range of social, political and institutional constraints are often cited as key determinants in the dissemination of modern energy technologies in developing countries and similarly across India.

CHAPTER 6

FEASIBILITY STUDY OF SOLAR HOME SYSTEMS

6.1 Review of Literature

Chapin and his colleagues at the Bell Laboratories in Murray Hills, New Jersey announced in 1954 first cell working on solar light. This first silicon device, called a solar cell for its ability to convert solar radiation directly into d c electricity, had a 4% conversion efficiency, which was soon improved to 6% and then to 11 %. In the very next year, a small solar cell powered rural telephone carrier system was put into operation in Americus, Georgia, in the United States.

Early applications of solar cells (PV) devices were in space beginning in 1958. (Ref.1.1.1). Almost every space mission under taken by the United States and the former Soviet Union was powered by PV. These include fly-by missions past Venus, Moon, Mars, and Jupiter the early communication satellites and the Skylab manned space station. Stimulated by the dramatic happenings in the global energy scene since the first oil embargo of 1973 and with the investment of significant private and government funding in the United States and elsewhere, PV has grown to become one of the more promising renewable energy technologies with a potential to impact the future electric power generation mix.

China is rapidly emerging as an important player in the global photovoltaic market. By adopting a technology innovation systems framework of analysis,(Ying Guo et al. 2009) identifies the technological and institutional actors and relations of the innovation systems for SPV in China and assesses the extent to which these are likely to encourage or constrain the technological development and the market diffusion of this technology. Policy lessons can be derived for the management of innovation in the energy sector and helps understanding of how such innovation could contribute to economic development.

Low-carbon off-grid electrification for rural areas is becoming increasingly popular in developed nations such as the UK. However, many developing countries have been electrifying their rural areas in this way for decades. Case study fieldwork in Nepal and findings from UK-based research will be used to examine how developed nations can learn from the experience of developing countries with regards the institutional environment and delivery approach adopted in renewable energy off-grid rural electrification. (Annabel Yadoo and Heather Cruickshank 2010) He dealt with a clearer institutional framework and more direct external assistance during project development is advised. External coordinators should also engage the community in a mobilization process a priori to help alleviate internal conflicts of interest that could later impede a project.

The performance test results of SHS according to IEC 62124: Photovoltaic Stand-alone System-Design verification is carried out.(Xinjing Zou and Li Bian 2010). The performance test evaluates solar home systems in the several aspects such as battery usable capacity, functional test, recovery test, system balance point, days of autonomy, etc. The results show that unreasonable design is a main reason to cause failure. The other reasons are considered as battery quality problem, inappropriate setting for controller and controller quality problems**.**

India is a highly diverse country with regard to its electrification status, covering all from well developed cities to rural areas without access to electricity. It has identified renewable energy sources as the long-term solution for future energy and progressing in the direction of electrifying the unreachable pockets. The prospects of sustainable energy and off-grid options, rural electrification, smart grids and various policy and regulatory affairs of India are dealt. The role of existing technologies, automation, and communication for sustainable development is explained. A roadmap to fulfill the urban and rural needs for sustainable future is presented. (V. S. K. Murthy Balijepalli and S. A. Khaparde 2011)

It is known that the important factor for photovoltaic system is cost of a system, and because of several kinds of the photovoltaic array we have the right to elect the best array with the best efficiency. The popular types of materials are crystalline and thin films, which have differences in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production. Different kinds of crystalline materials like a mono-crystalline, polycrystalline are available. The generated current and generated power by the photovoltaic array is calculated. (Hadi Nabipour Afrouzi et al. 2011) according to daily solar irradiation in the case study of Malaysia. Think over generated power of each array's and also according to required energy for a typically building, the number of photovoltaic array is estimated then the cost of the solar array is calculated. System is simulated by MATLAB software, and the results are discussed. The simulation is about sizing in order to select the best array for photovoltaic system to have a optimize system according to size of the system.

People living in extreme poverty may not be able to afford donated solar home lighting systems. These systems improve quality of life but they may not lift people out of poverty. Users must participate in savings programs, maintain savings themselves, or be able to arrange credit to pay for substantial future costs, such as battery replacement. However, some households cannot always afford to buy traditional lighting sources. In these cases, the solar home system may increase their energy cost burdens or force the systems to fail when components need replacement. Before implementing home lighting programs in poor communities, sponsors must realistically assess household's ability to pay the ongoing system costs necessary. If households will not be saving money by using solar lighting, the development agenda should be reviewed to determine if the provision of electricity is the most urgent need (H. J. Corsair 2009).

6.2 Solar Radiation Estimation

- The estimation of solar energy at the earth's surface is an important study in the present scenario to meet the energy requirement from green energy sources.
- In India, only India Meteorological Department (IMD) Pune provides data for quite few stations, which is considered as the base data for research purposes.(Fig.6.1)
- The network activity on radiation measurements is increased to the present level of 45 stations. The parameters measured vary from station to station, through global solar radiation is the common parameter monitored at almost all the stations. The very important components like the direct solar irradiance, diffuse solar irradiance and the net terrestrial radiant energy are not measured at many of the stations. Direct solar irradiation is measured at 21 stations whereas the diffuse irradiances are monitored at 23 locations. The net terrestrial radiant energy is measured at 12 stations only. However, hourly data of measured irradiance is not available, even for those stations where measurement has already been done.

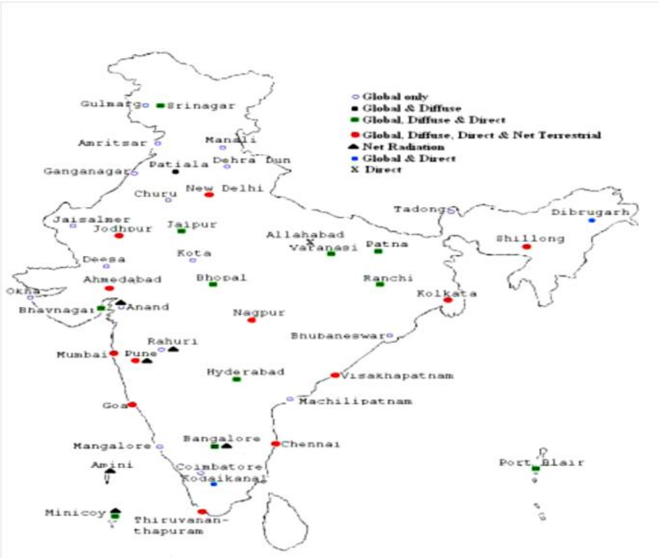


Fig. 6.1 solar radiation measurement centers in India (IMD)

- MNRE has already started from February 2011, many initiatives like Automatic Solar Radiation Monitoring Systems (ASRMS) in 51 different places of India (Ref.8.2).

6.3 Simulation approach

Despite all the available solar technologies and the opportunity to reduce energy demand, solar energy systems are less preferred in rural areas today. According to the IEA report, the lack of technical knowledge among engineers is one of the main barriers. In fact, several challenges faced by engineers during the presizing e.g., the complexity and uncertainty of estimating the PV performance.

The most efficient approach to optimise the system performance is through mathematical modeling. The mathematical model maps the abstract real world into a world of comprehendible and interpretable numbers. The decision support systems based on the models can be used to optimise the system operation, to design a favourable design and operational characteristics of the energy system. Modeling and policy formation activities complement each other.

The aim of the present study is to help engineers to acquire an idea of the potential of PV as an energy source. A preliminary study of the existing and available 13 softwares has been made, which indicates that most existing PV estimation software are focused on electricity generation prediction and cater more for engineers and researchers.(Appendix IV)

- HOMER, RET screen, Hybrid2, NREL SAM, C.SP-r, Solar GIS and INSEL, are generic software packages mainly developed for hybrid system optimization and cost analysis. These tools support resource side calculations and they can be used for solar energy and PV production level estimations. Free availability is the main advantage of all these tools.
- PVSYST, Solar Design Tool, PV F-chart, Solar Pro, PV Design Pro, PV*SOL basic, and PV*Sol Expert are PV system design tools that are specifically designed for an urban/rural applications. Due to their three dimensional CAD environment, they are capable of considering the effects of the surrounding obstacles in their calculations.

Salient Features of PVSYST

The PVSYST software package is more suitable for the detail design phase when the system components are going to be chosen to have the highest possible outcome. Also the estimated production of electrical energy is more accurate in this tool. (Arbi Gharakhani Siraki and Pragasen Pillay 2008)

The tool is based on a simulation database built using PVSYST and underlies research considering PV technology parameters and local climatic conditions of India. PVSYST is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. It is suitable for grid-connected, stand-alone, pumping and DC-grid (public transport) systems, and offers an extensive meteorological and PV-components database. This software is oriented towards engineers, researchers, and holds very helpful tools for education.

1) Location details are specified in terms of longitude, latitude and altitude

The Meteonorm software (version 5.0, 2003, Version 6.0, June 2007, 6.1, 2009) provides basically monthly meteorological data for any location on the earth. These are based on more than 7700 well-established meteo station data, from which about 1500 (named "stations") avail of Irradiance measurements. Data for any location on the earth, specified by its geographic coordinates, may be obtained by interpolation between measuring stations, taking altitude and region typology into account. In this software:

- "Stations" design the meteorological stations which avail of irradiance measurements.

• 'WMO/OMM" is the meteorological stations recording many parameters, but which don't avail of irradiance data.

• "Towns" are a set of some main big cities, for which the data are interpolated.

The PVSYST database includes only "Stations" with well-measured irradiations. Meteonorm provides its data in monthly values and in hourly values. The hourly data are built by a stochastic model, quite similar to the "Synthetic Hourly Generation" performed in PVSYST. These data may also be directly imported in PVSYST. Moreover Meteonorm proposes other prestations like irradiance computation on tilted planes, but these are not useful in PVSYST, which uses its own models. Meteonorm often gives lower values than the average. This means that simulations with default values in PVSYST will be rather conservative, and give prudent results for the final yield of the customer's systems.

As meteo hourly basis, the programme uses binary files with a special format for PVSYST, and characterised by the extension ".MET". The meteo file includes a complete geographical site object, followed by hourly values of the meteo parameter, that is horizontal global and diffuse irradiations, ambient temperature, and, if available, wind velocity.

The data are recorded for whole days (0H ... 23H). Step labels are referred to the beginning of the interval (i.e. the 12 h label corresponds to the 12-13 h interval). When importing own measurements, the meteo file can be restricted to limited periods, and even have full-days holes. In this case the date is included in each record on the file. Generation of synthetic hourly values from monthly metro values of global irradiation and temperature is done. The physical basis of this generator follows directives of Meteonorm'95 using Aguiar/Collares-Pereira et al. and Scartezzini algorithms.

2) Meteorological data are often available for several individual years, and aggregating them for obtaining an average situation is not straightforward. Only Monthly meteo values may be averaged, as the seasonal distribution is not very different from one year to another one. Hourly or Daily values cannot be averaged. It would not make any sense to construct an average year by aggregating each day of different years, mixing sunny and cloudy days. This would result is a time series with only mean days, without neither clear nor bad days, which has no physical meaning.

The right way for obtaining average conditions for hourly data is the construction of Design Reference Years (DRY), which should obey statistical constraints and is a matter of specialists.

3) The annual available irradiation [kWh/m²/year] is relevant for PV grid systems, as the PV output is quasi-linear with the solar energy input. For stand-alone systems, the monthly distribution may also be of interest, but comparisons would require much more complex statistical methods.

4) The button "Show optimization" opens a little tool which shows the winter yield according to the plane orientation. For stand-alone systems, the plane orientation should optimise according to the worst conditions, i.e. for winter irradiance.

5) Defining the user's needs, from a domestic use point of view- consumption and use conditions.

- the required autonomy in the absence of sun-which determines the battery pack capacity
- the required “ Loss-of-Load probability”(P LOL) and the planned system voltage

These parameters lead to the determination of the array nominal power (i.e. the installed STC power according to the manufacturer specifications), and the battery pack capacity. Graph shows the potentially available solar energy, along with the user's needs, the average state of charge of the battery (low values could lead to a quicker deterioration of the batteries), and PLOL monthly distribution. The table holds all monthly values, including then needed back-up energy, an approximate economic evaluation and energy price.

6) When sizing a PV stand-alone system, the basic constraints are the availability of solar energy during the year, and the satisfaction of the user's needs. The problem to be solved is the optimisation of the size of the photovoltaic generator and the storage capacity, subjected to criteria which may take on different weights depending on the use:

- Reliability of the supply**:** in a domestic installation, this may be overcome with a small back-up generator i.e. measured as the "Loss of Load" Probability ("P LOL").
- Investment and maintenance costs: should take into consideration the cost of the PV generator, the initial cost of the batteries, as well as that of their maintenance and replacement. The high price of the kWh used necessitates a highly detailed study of

the real user's needs, and the use of specific appliances that are highly economical regarding to energy consumption.

- Durability: the cost of the batteries is closely related to the quality of the batteries chosen, as well as their longevity, which is itself dependent on the conditions of use (average state of charge, cycling, depth of discharge, temperature).

7) Battery Voltage Choice: In a stand-alone PV system with direct coupling to the user the battery voltage determines the distribution voltage. Three days autonomy for battery is used in this study, assuming that the voltage regulation is 30%

Table 6.1 Battery voltage with appliances

	12V: little systems for lighting and TV	24V: medium size fridge and appliances	48V: special industrial/ agricultural use
Max power	< 300 W	< 1000 W	< 3 kW
current	25 A	42 A	62 A
Inverter	< 1 kW	< 5 kW	< 15 kW

6.4 Demography of India

Fig. 6.2 Map of India

Fig. 6.3 Map of Karnataka

The population of India was about 1.027 billion in 2001 as per Census 2001.The average number of members per household is 5.15 in rural areas and 4.47 in urban areas. Out of 10 households, seven in India are in the rural areas. Of the every 100 households in the rural areas, 36 are pucca houses, 43 are semi-pucca houses, and the rest are kuchcha houses. Plinth level of the house, that is, the height of ground floor of the house from the land on which the building is constructed is zero for 36% of the rural and 32% of the urban households.

On an average, a rural household occupies 38 square meter of floor area and an urban household occupies 37 sq. meters. The poorest segment, that is, households in the lowest monthly per capita consumption expenditure class of less than 225 rupees in rural areas, occupy 31 sq. meters of floor area and those in urban slums, 29 sq. meters. About 30% of the dwelling units in rural and 4% in urban areas do not have basic facilities like drinking water, electricity for lighting, and a toilet. (Source: National Energy Map for India: Technology Vision 2030.TERI)

6.4.1 **Preliminary design** (Ref. Fig 5.8 to fig.5.13)

Table 6.2 latitude and longitudes

	India	Karnataka	Dharwad
Latitude North Equator	6^0 44’ and 35^0 30’	11^0 30’ and 18^0 30’	15^0 27’
Longitude East	68^0 7’ and 97^0 25’	74^0 and 78^0 30’	75^0 05’

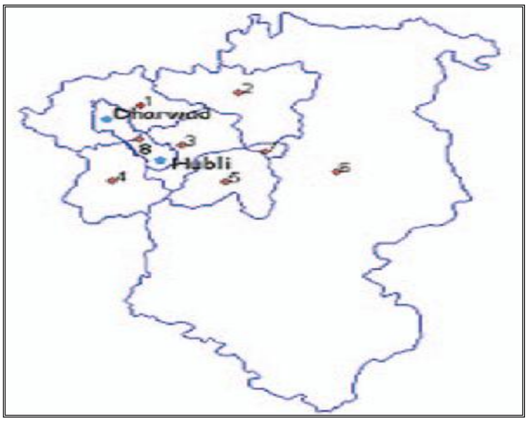


Fig. 6.4 Map of Dharwad

Fig. 6.5 Map of Dharwad

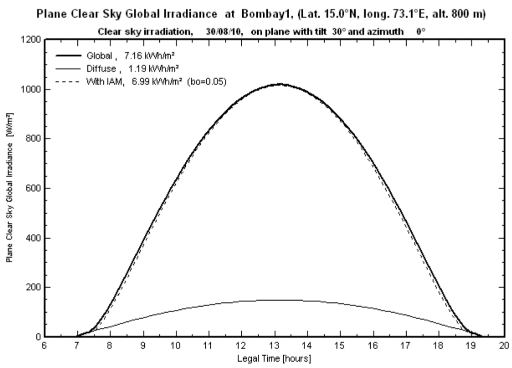


Fig. 6.6 plane clear sky global radiation

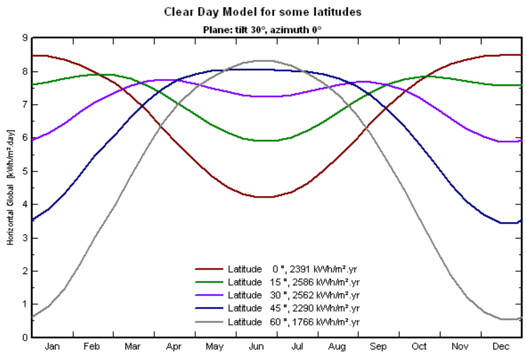
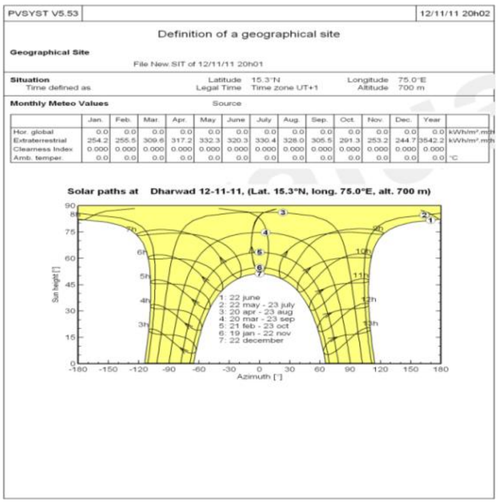


Fig. 6.7 clear day model for latitude



PVSYST V5.53	12/11/11 20h02

Definition of a geographical site

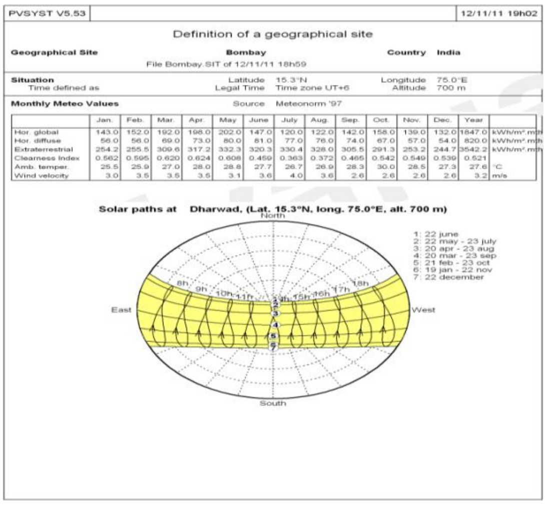
Geographical Site

File New.SIT of 12/11/11 20h01

Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+1 Altitude 700 m

Monthly Meteo Values Source

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh/m².mth
Extraterrestrial	254.2	255.5	309.6	317.2	332.3	320.3	330.4	328.0	305.5	291.3	253.2	244.7	3542.2	kWh/m².mth
Clearness Index	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Amb. temper.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	°C



PVSYST V5.53	12/11/11 19h02

Definition of a geographical site

Geographical Site **Bombay** **Country** **India**

File Bombay.SIT of 12/11/11 18h59

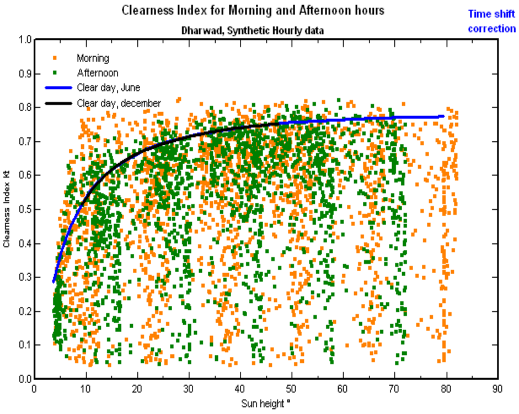
Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+6 Altitude 700 m

Monthly Meteo Values Source Meteonorm '97

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	143.0	152.0	192.0	198.0	202.0	147.0	120.0	122.0	142.0	158.0	139.0	132.0	1847.0	kWh/m².mth
Hor. diffuse	56.0	56.0	69.0	73.0	80.0	81.0	77.0	76.0	74.0	67.0	57.0	54.0	820.0	kWh/m².mth
Extraterrestrial	254.2	255.5	309.6	317.2	332.3	320.3	330.4	328.0	305.5	291.3	253.2	244.7	3542.2	kWh/m².mth
Clearness Index	0.562	0.595	0.620	0.624	0.608	0.459	0.363	0.372	0.465	0.542	0.549	0.539	0.521	
Amb. temper.	25.5	25.9	27.0	28.0	28.8	27.7	26.7	26.9	28.3	30.0	28.5	27.3	27.6	°C
Wind velocity	3.0	3.5	3.5	3.5	3.1	3.6	4.0	3.6	2.6	2.6	2.6	2.6	3.2	m/s

Fig. 6.8 solar path horizontal

Fig. 6.9 solar path polar



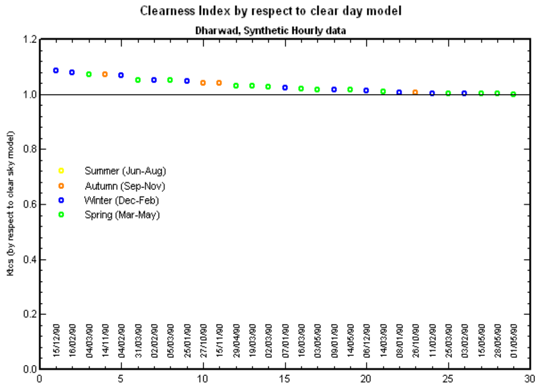
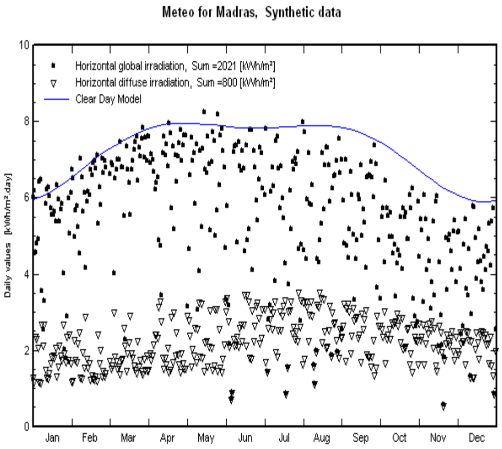


Fig. 6.10 Clearness Index

Fig. 6.11 Clearness index clear day model



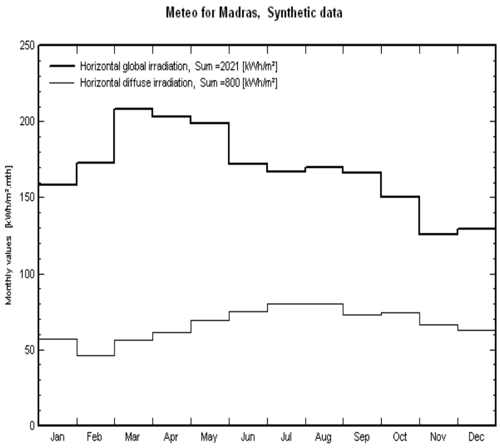
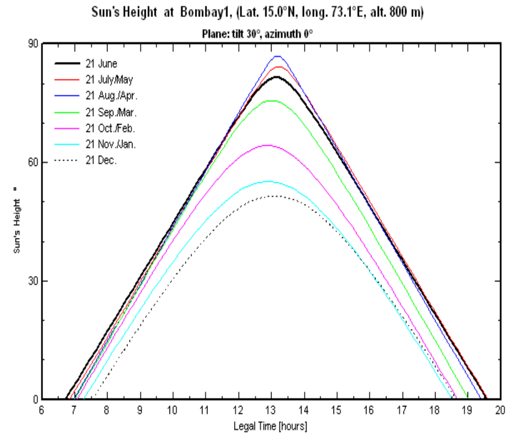


Fig. 6.12 Yearly Global radiations

Fig. 6.13 Yearly Global radiations



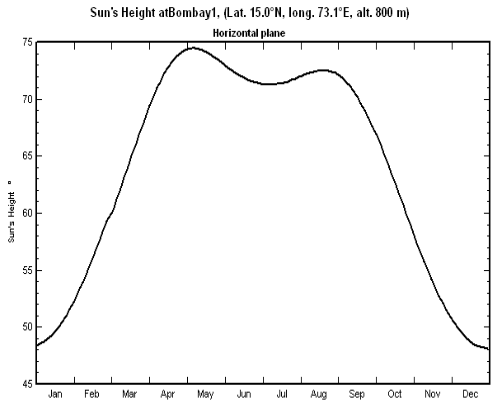
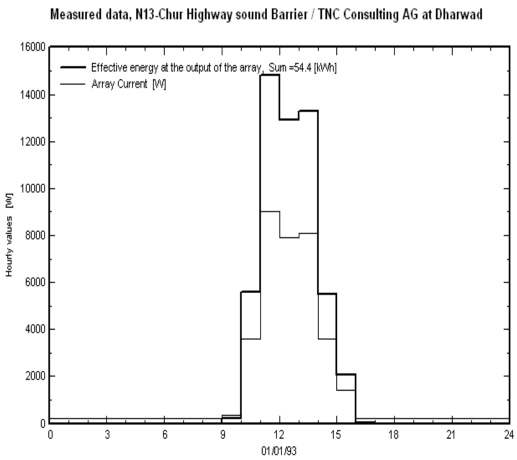


Fig. 6.14 Sun's height with time

Fig. 6.15 Sun's height with month



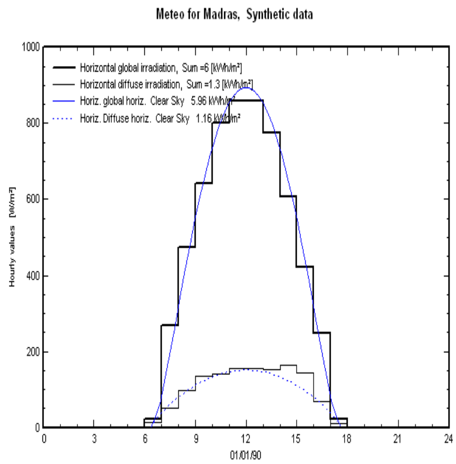


Fig. 6.15 solar energy generation

Fig. 6.16 solar energy generation

Preliminary design is an approximate estimation of the energy yield based on few parameters like location etc. (Fig 6.2 to Fig. 6.16)

6.4.2 Number of panels for a rural home

A SHS consists of PV module that charges a battery bank, charge controller and an inverter (Fig.6.18). The charge controller which is an integral part of the SHS controls the energy inflow and outflow into and from the battery bank. SHS are ideally suited for domestic lighting and small power applications.

A Rural house comprises of mainly lighting load, TV, Tape recorder, radio. Electricity consumption has been estimated for electrified areas, with use varying from 0.33 kWh per household per day for landless households to 0.84 kWh per household per day in larger landholdings for lighting purposes (Census 2001). Thus we take kWh per day as 0.58. (Table 6.3)

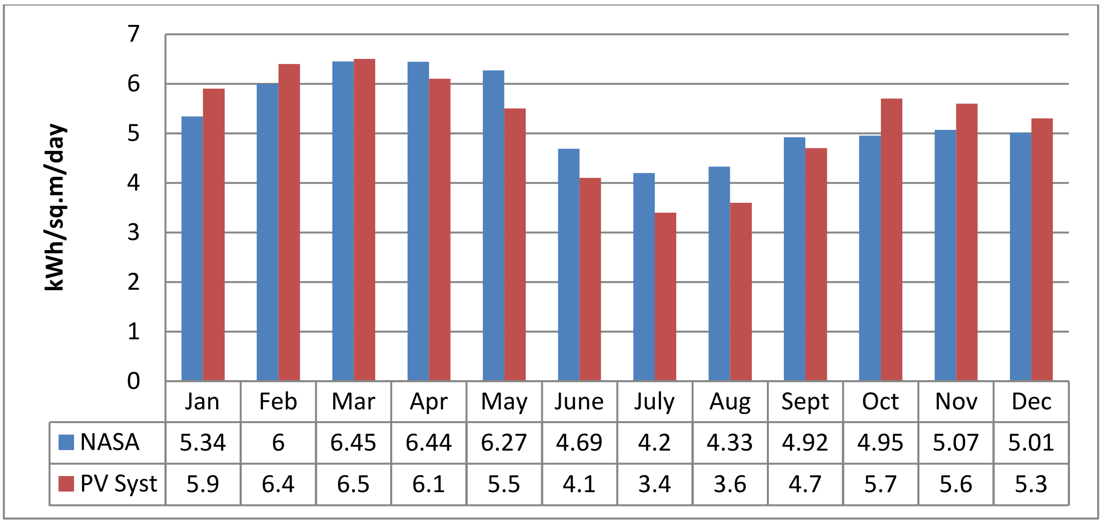


Fig. 6.17 Monthly Averaged Insolation Incident on a Horizontal Surface at Dharwad (kWh/sq.m/day) 22-year Ave: 5.30. kWh /sq.m/day
(Ref: NASA-SSE, Atmospheric Science Data Centre and PVSYST)

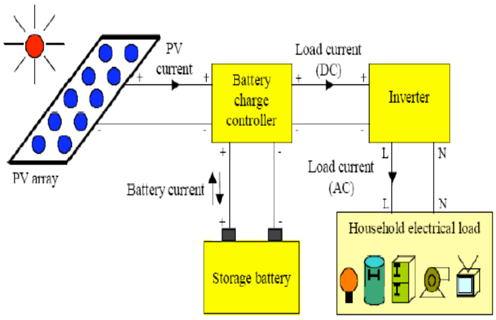


Fig. 6.18 The stand-alone PV system

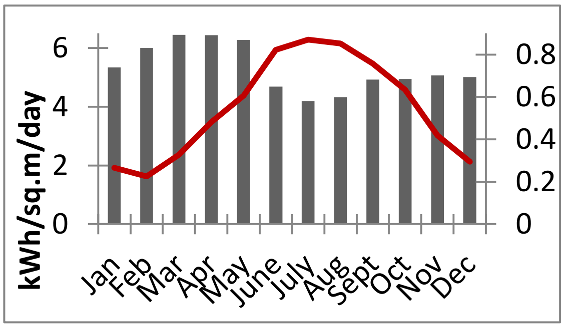


Fig. 6.19 Average insolation and cloud area

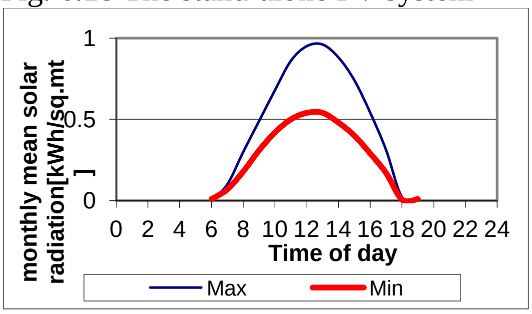


Fig. 6.20 max. and min.solar radiation

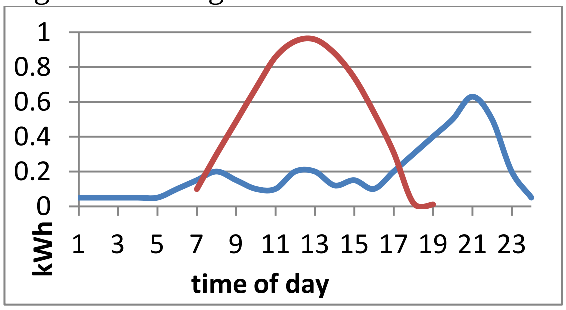


Fig. 6.21 load pattern and solar generation

Table 6.3 Average load of a household (without irrigation pump set) (Ramachandra et al. 2000)

Utility	watt	hour	Total [Whr]
Lamps (three)	40	2.5	300
Tape/Radio	20	3	60
TV	80	3	240

Accounting for system losses due to dust 10% and voltage drop of 0.5%, Wattage required = 580X 10.5% =609 Whr

Ampere= 609/ (6 Hrs X12V) =8.45 [4.5+1.5=6 effective charging hours]

Battery size required for 3 days autonomy =580 X 3/ (0.8X12volt) =181.5,-i, e. 3

Thus, 75 W_p, 4.4 Amp**,** 12 volt, 2 panels in parallel, and three batteries of 60Ahr are required.

PV panels generate kWh per day=6 hrs X 2 panels X 75 W_p=0.9 kWh

PV panels generate 297 kWh per year [207.9kg coal reduction] in 330 days and 7425 kWh in 25 years [5717.25kg coal reduction].

(Specific fuel consumption of Indian coal is 0.7kg per kWh)

Electricity generated in 25 years is (150W_p X 300days X 25 yrs) 1.125 MW.

I=4.4Amp, V=17 Volt, P=75W_p

6.4.3 Cost

A) Panels=75 W_p x 2 panels X 125 Rs. per W_p = Rs.18750

Batteries 60 Ampere-hour=3XRs 5500 per battery=Rs.16500

Charge controller=Rs.500, Wiring=Rs.3000, Inverter=Rs.7000

Total cost=Rs.52800, Maintenance cost=Rs.100 per year

In 25 years of life cycle battery changing cost=3 times X 3 batteries X 5500 Rs. per battery = Rs.49500

Life cycle cost=Rs. 27750+25 X 100+49500=Rs.79750

B) Subsidy given by MNRE= (Rs.81 per W_p) X 150=Rs.12150

Hence cost borne by consumer= Rs.79750 – Rs.12150=Rs. 67600

Cost per kWh=67600/7425=Rs. 9.1 (for 25 years)

Cost Rs. 9.93 with 50% subsidy reduced and Rs. 10.74 without subsidy.

Cost of Grid supply

Cost per unit paid for grid electricity (Chakrabarti et al. 2002) = Rs. 5.00

Annual power required=0.840X 365=306 units (0.840 kWh maximum)

Total annual amount to be paid for grid electricity=5x306= Rs. 1530

Cost of conventional grid for 25 years=1530 X 25=Rs. 38250

Cost of UPS with battery backup is included=7000+3X5500 =Rs. 23500

(To increase the reliability and to improve the power quality)

Hence total cost of the grid=23500+38250=Rs. 61750

Cost per kWh=61750/ 25X306 = Rs. 8.07 (Rs.9.29 for 0.6kWh)

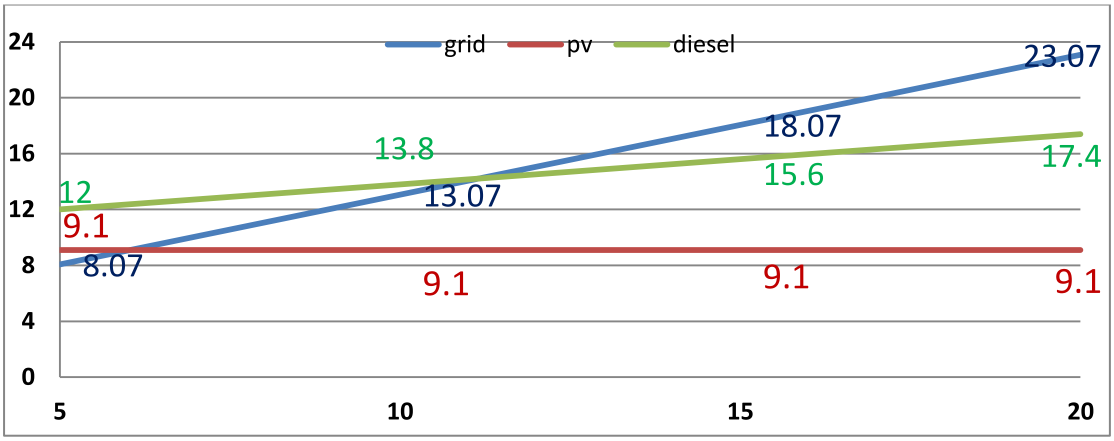


Fig. 6.22 Comparison of unit Cost (Rs.) with distance (km) (Diesel cost: Rs. 37/L)

- SHS cost is economically viable alternative to grid cost after a distance of 5.9375 km away from the grid.

Assumptions (Ref.5.4.3)

- Solar panels are fixed with no sun tracking facility.
- The charge controllers are simple ON/OFF type without maximum power tracking facility .Battery charge controllers and inverters are built in modules of PVSYST.
- The system has 3 days autonomy and panel has 25 year life span.
- The percentage increase of unit in grid cost per year about to 15 percent is not considered.

6.5 Technical feasibility

6.5.1 Project design

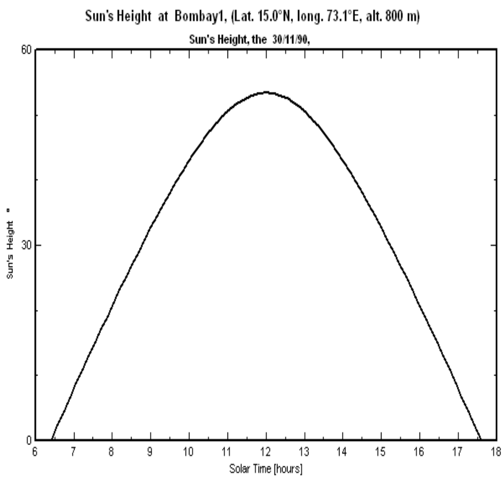


Fig. 6.23 Sun's height

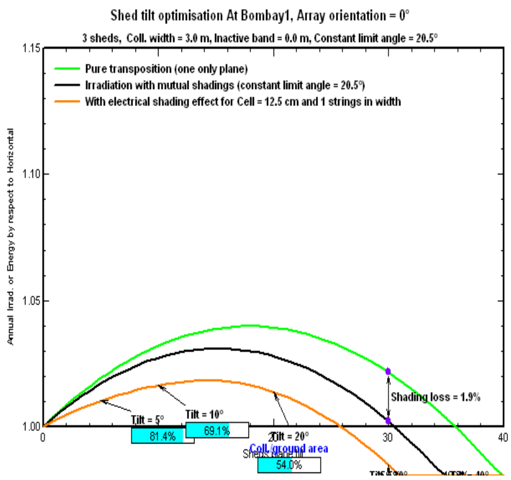


Fig. 6.24 Shed tilt optimisation

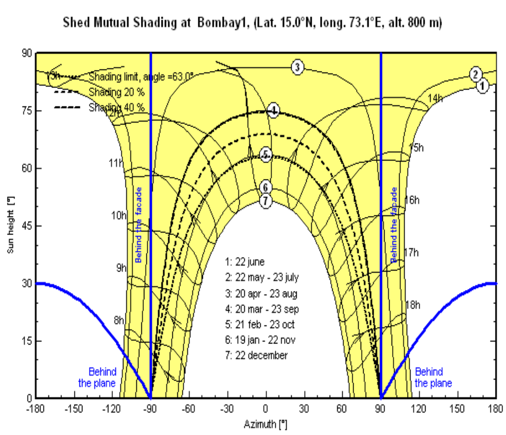


Fig. 6.25 shed mutual shading

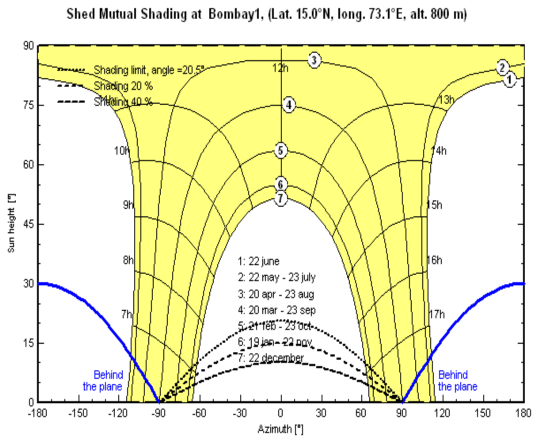


Fig. 6.26 Shed tilt optimisation shading

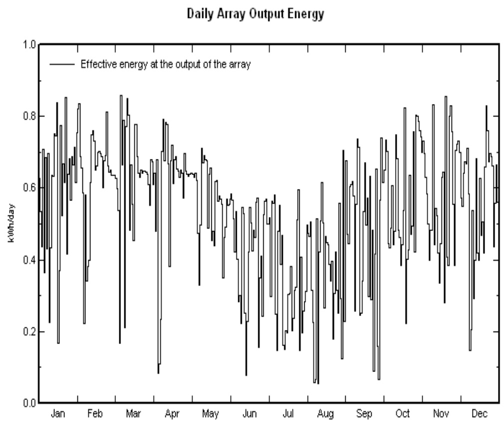


Fig. 6.27 Daily array output

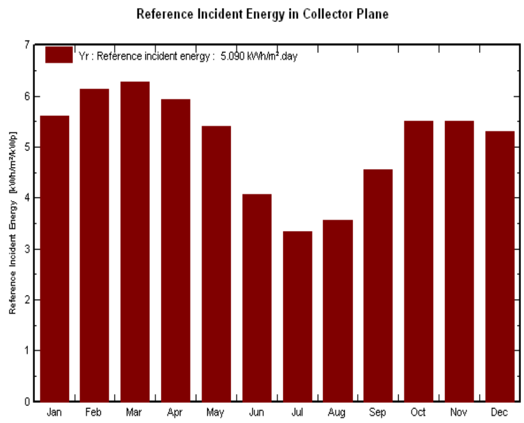
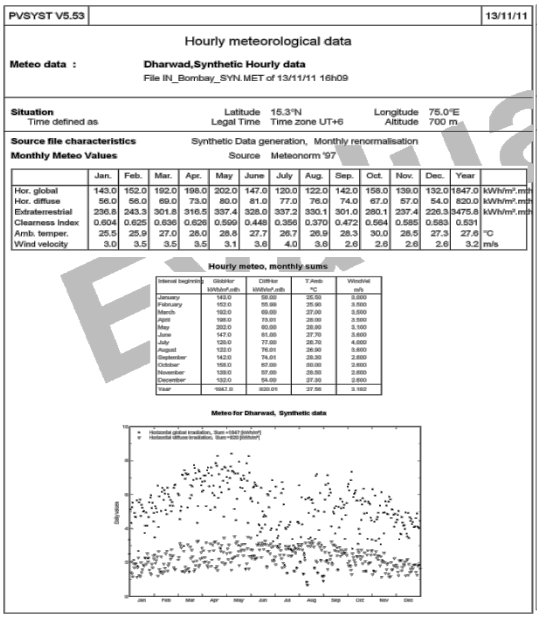


Fig. 6.28 Ref. incident energy in collector plane


PVSYST V5.53 13/11/11

Hourly meteorological data

Meteo data : **Dharwad,Synthetic Hourly data**
File IN_Bombay_SYN.MET of 13/11/11 16h09

Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+6 Altitude 700 m

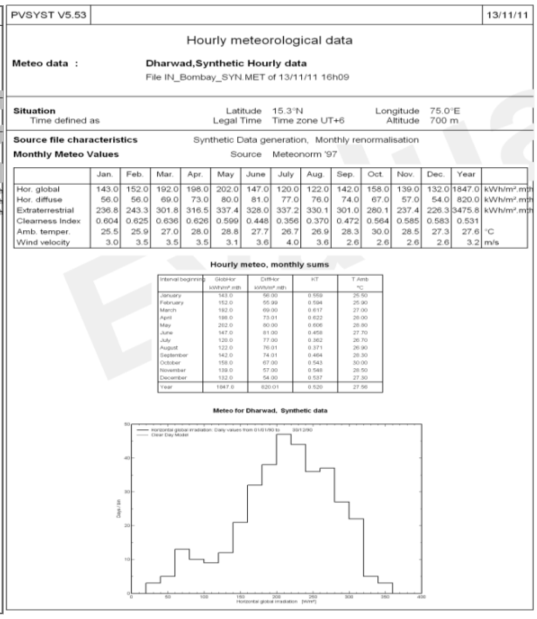
Source file characteristics Synthetic Data generation, Monthly renormalisation
Monthly Meteo Values Source Meteonorm '97

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	143.0	152.0	192.0	198.0	202.0	147.0	120.0	122.0	142.0	158.0	139.0	132.0	1847.0	kWh/m².mth
Hor. diffuse	56.0	56.0	69.0	73.0	80.0	81.0	77.0	76.0	74.0	67.0	57.0	54.0	820.0	kWh/m².mth
Extraterrestrial	236.8	243.3	301.8	316.5	337.4	328.0	337.2	330.1	301.0	280.1	237.4	226.3	3475.8	kWh/m².mth
Clearness Index	0.604	0.625	0.636	0.626	0.599	0.448	0.356	0.370	0.472	0.564	0.585	0.583	0.531	
Amb. temper.	25.5	25.9	27.0	28.0	28.8	27.7	26.7	26.9	28.3	30.0	28.5	27.3	27.6	°C
Wind velocity	3.0	3.5	3.5	3.5	3.1	3.6	4.0	3.6	2.6	2.6	2.6	2.6	3.2	m/s

Hourly meteo, monthly sums

Meteo for Dharwad, Synthetic data

Fig. 6.29 Synthetic data generated


PVSYST V5.53 13/11/11

Hourly meteorological data

Meteo data : **Dharwad,Synthetic Hourly data**
File IN_Bombay_SYN.MET of 13/11/11 16h09

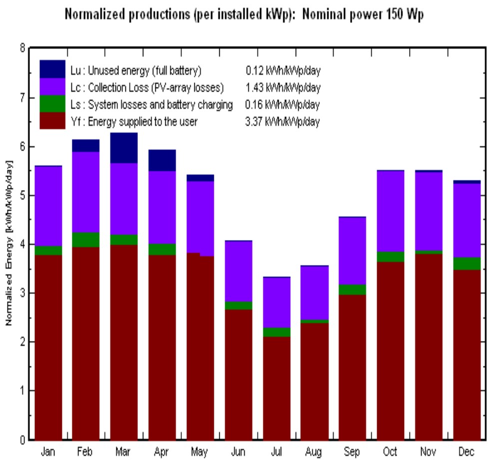
Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+6 Altitude 700 m

Source file characteristics Synthetic Data generation, Monthly renormalisation
Monthly Meteo Values Source Meteonorm '97

Hourly meteo, monthly sums

Meteo for Dharwad, Synthetic data

Fig. 6.30 Hourly meteorological data



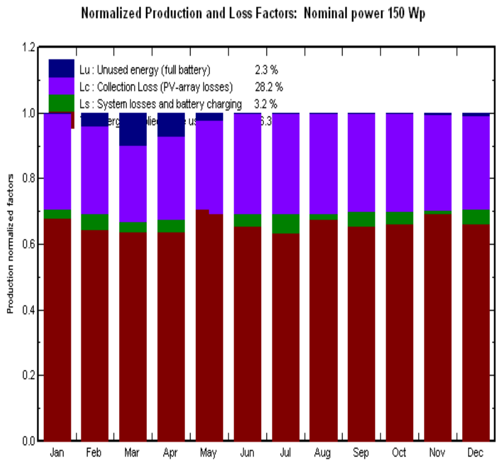
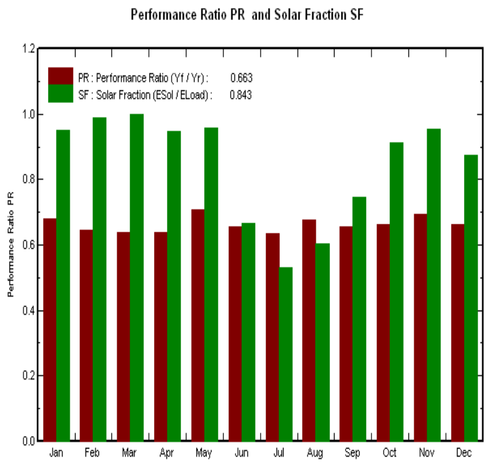


Fig. 6.31 Normalised production Fig. 6.32 Normalised production and loss factors



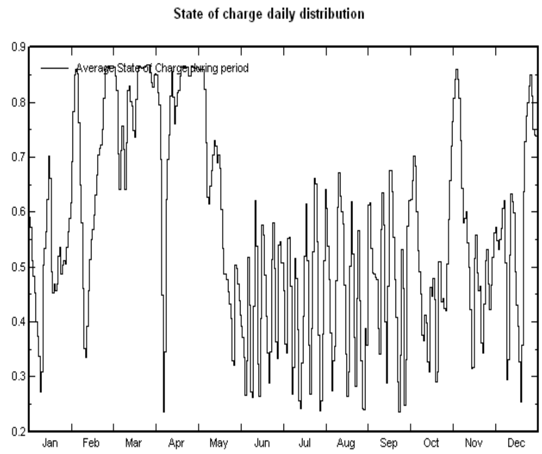
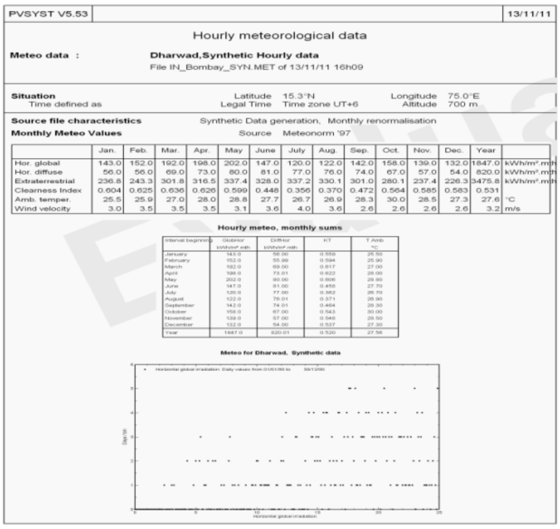


Fig. 6.33 Performance ratio and solar fraction Fig. 6.34 state of charge daily



PVSYST V5.53 13/11/11

Hourly meteorological data

Meteo data : **Dharwad,Synthetic Hourly data**
File IN_Bombay_SYN.MET of 13/11/11 16h09

Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+6 Altitude 700 m

Source file characteristics Synthetic Data generation, Monthly renormalisation
Monthly Meteo Values Source Meteonorm '97

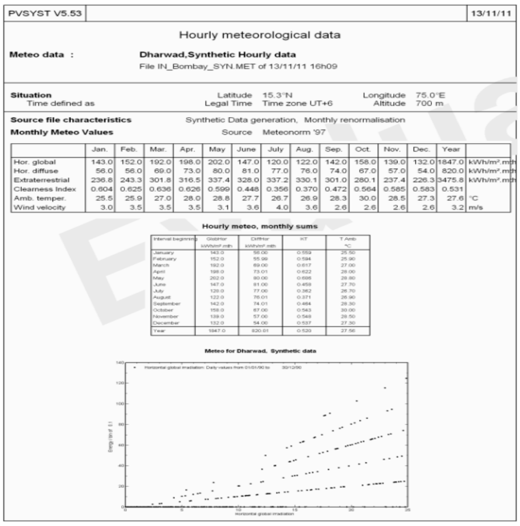
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	143.0	152.0	192.0	198.0	202.0	147.0	120.0	122.0	142.0	158.0	139.0	132.0	1847.0	kWh/m².mth
Hor. diffuse	56.0	56.0	69.0	73.0	80.0	81.0	77.0	76.0	74.0	67.0	57.0	54.0	820.0	kWh/m².mth
Extraterrestrial	236.8	243.3	301.8	316.5	337.4	328.0	337.2	330.1	301.0	280.1	237.4	226.3	3475.8	kWh/m².mth
Clearness Index	0.604	0.625	0.636	0.626	0.599	0.448	0.356	0.370	0.472	0.564	0.585	0.583	0.531	
Amb. temper.	25.5	25.9	27.0	28.0	28.8	27.7	26.7	26.9	28.3	30.0	28.5	27.3	27.6	°C
Wind velocity	3.0	3.5	3.5	3.5	3.1	3.6	4.0	3.6	2.6	2.6	2.6	2.6	3.2	m/s

Hourly meteo, monthly sums

Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	KT	T Amb °C
January	143.0	56.00	0.559	25.50
February	152.0	55.99	0.594	25.90
March	192.0	69.00	0.617	27.00
April	198.0	73.01	0.622	28.00
May	202.0	80.00	0.606	28.80
June	147.0	81.00	0.456	27.70
July	120.0	77.00	0.362	26.70
August	122.0	76.01	0.371	26.90
September	142.0	74.01	0.464	28.30
October	158.0	67.00	0.543	30.00
November	139.0	57.00	0.548	28.50
December	132.0	54.00	0.537	27.30
Year	1847.0	820.01	0.520	27.56

Meteo for Dharwad, Synthetic data

Fig. 6.35 Clearness index



PVSYST V5.53 13/11/11

Hourly meteorological data

Meteo data : Dharwad,Synthetic Hourly data
File IN_Bombay_SYN.MET of 13/11/11 16h09

Situation Latitude 15.3°N Longitude 75.0°E
Time defined as Legal Time Time zone UT+6 Altitude 700 m

Source file characteristics Synthetic Data generation, Monthly renormalisation
Monthly Meteo Values Source Meteonorm '97

Hourly meteo, monthly sums

Meteo for Dharwad, Synthetic data

Fig. 6.36 Energy data

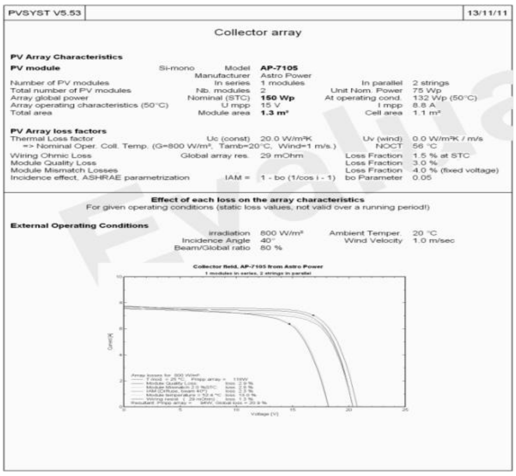


Fig. 6.37 PV array characteristics

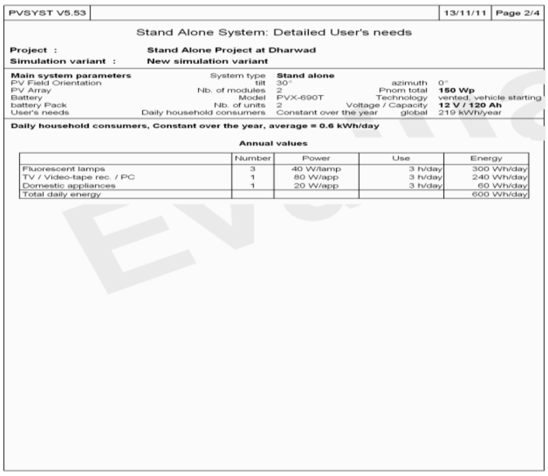


Fig. 6.38 stand alone project load detail

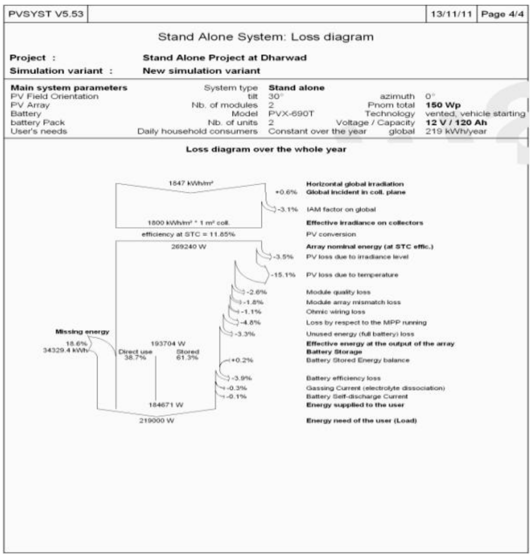


Fig.6.39 Project report

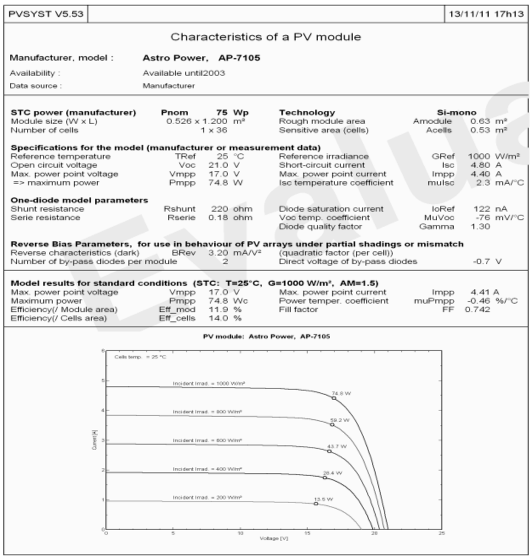


Fig.6.40 Characteristics of PV module

New simulation variant
Normalized Performance Coefficients

	Yr	Lu	Yu	Lc	Ya	Ls	Yf	PR
	kWh/m².day		kWh/kWp/d		kWh/kWp/d		kWh/kWp/d	
January	173.57	0.000	5.82	1.628	37.33	0.171	3.80	0.679
February	171.53	0.116	6.29	1.877	40.84	0.288	3.96	0.647
March	194.64	0.268	6.43	2.073	41.86	0.206	4.00	0.637
April	178.02	0.188	6.07	1.918	39.56	0.233	3.78	0.638
May	167.60	0.037	5.61	1.649	36.04	-0.069	3.83	0.708
June	122.23	0.001	4.29	1.241	27.16	0.164	2.67	0.655
July	103.49	0.001	3.53	1.019	22.26	0.195	2.12	0.636
August	110.28	0.002	3.76	1.085	23.72	0.061	2.41	0.678
September	136.68	0.003	4.74	1.359	30.37	0.214	2.98	0.655
October	170.72	0.001	5.69	1.640	36.71	0.216	3.65	0.663
November	165.04	0.011	5.67	1.626	36.68	0.060	3.81	0.693
December	164.19	0.022	5.48	1.543	35.31	0.253	3.50	0.661
Year	1857.99	0.054	5.27	1.552	33.94	0.165	3.37	0.663

Table 6.4 Normalised performance coefficients

New simulation variant
Losses in the PV system

	ModQual	MisLoss	OhmLoss	EArrMPP	MPPLoss	EArUfix	EUnused	EArray
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
January	0.554	0.369	0.248	19.51	1.039	18.47	0.002	18.46
February	0.535	0.357	0.239	19.04	0.706	18.33	0.993	17.85
March	0.587	0.391	0.256	21.49	0.688	20.80	2.866	19.56
April	0.542	0.361	0.230	19.51	0.596	18.92	1.884	18.07
May	0.524	0.349	0.202	18.58	0.935	17.65	0.500	17.47
June	0.383	0.255	0.123	13.74	0.986	12.75	0.004	12.75
July	0.324	0.216	0.090	11.70	0.911	10.79	0.005	10.78
August	0.345	0.230	0.107	12.43	0.923	11.51	0.012	11.50
September	0.432	0.288	0.165	15.23	0.827	14.40	0.012	14.39
October	0.539	0.360	0.232	18.82	0.835	17.98	0.006	17.98
November	0.523	0.349	0.226	18.26	0.771	17.49	0.069	17.44
December	0.524	0.349	0.222	18.41	0.853	17.56	0.184	17.45
Year	5.811	3.874	2.340	206.72	10.068	196.65	6.538	193.70

Table 6.5 Losses in PV system

New simulation variant

Battery operation and performances

	U Batt	SOCmean	SOC End	WeCycle	WeState	MGass	EffBatI	EffBatE
	V			%	%	liter	%	%
January	12.3	0.503	0.665	0.69	98.3	0.000	93.1	92.9
February	12.5	0.668	0.876	0.64	96.8	0.002	95.8	89.1
March	12.7	0.805	0.859	0.73	95.1	0.005	95.3	92.3
April	12.6	0.770	0.871	0.69	93.4	0.005	94.4	90.9
May	12.4	0.601	0.412	0.66	91.7	0.001	97.1	103.2
June	12.2	0.421	0.491	0.49	90.1	0.000	94.5	90.5
July	12.2	0.432	0.652	0.40	88.4	0.000	93.1	86.7
August	12.2	0.438	0.523	0.46	86.7	0.000	94.7	95.9
September	12.3	0.481	0.628	0.53	85.0	0.000	93.8	89.3
October	12.3	0.495	0.791	0.66	83.3	0.000	96.1	90.9
November	12.3	0.550	0.593	0.68	81.7	0.001	96.6	97.5
December	12.4	0.586	0.799	0.62	80.0	0.001	95.3	89.2
Year	12.4	0.562	0.799	7.23	80.0	0.016	95.0	92.4

Table 6.6 Battery operation and performance

New simulation variant

Meteo and incident energy

	GlobHor	DiffHor	T Amb	WindVel	GlobInc	DifSInc	Alb Inc	DifS/GI
	kWh/m²	kWh/m²	°C	m/s	kWh/m²	kWh/m²	kWh/m²	
January	143.0	56.00	25.50	3.0	173.6	58.47	1.916	0.337
February	152.0	56.00	25.90	3.5	171.5	56.80	2.036	0.331
March	192.0	69.00	27.00	3.5	194.6	66.47	2.572	0.342
April	198.0	73.00	28.00	3.5	178.0	66.32	2.653	0.373
May	202.0	79.99	28.80	3.1	167.6	70.38	2.706	0.420
June	147.0	81.00	27.70	3.6	122.2	72.17	1.969	0.590
July	120.0	77.00	26.70	4.0	103.5	69.89	1.608	0.675
August	122.0	76.01	26.90	3.6	110.3	69.88	1.635	0.634
September	142.0	74.01	28.30	2.6	136.7	69.47	1.902	0.508
October	158.0	67.00	30.00	2.6	170.7	65.81	2.117	0.385
November	139.0	57.00	28.50	2.6	165.0	58.50	1.862	0.354
December	132.0	54.00	27.30	2.6	164.2	56.84	1.768	0.346
Year	1847.0	820.01	27.56	3.2	1858.0	781.00	24.745	0.420

Table 6.7 Meteo and incident energy

6.5.2 Economic considerations

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Stand Alone System: Economic evaluation

Project : **Stand Alone Project at Dharwad**
Simulation variant : **New simulation variant**

Main system parameters System type **Stand alone**
PV Field Orientation tilt 30° azimuth 0°
PV Array Nb. of modules 2 Pnom total **150 Wp**
Battery Model PVX-690T Technology vented, vehicle starting
battery Pack Nb. of units 2 Voltage / Capacity **12 V / 120 Ah**
User's needs Daily household consumers Constant over the year global 219 kWh/year

Investment
PV modules (Pnom = 75 Wp) 2 units 6250 INR / unit 12500 INR
Supports / Integration 3500 INR / module 7000 INR
Batteries (12 V / 60 Ah) 2 units 5500 INR / unit 11000 INR
regulator / converter 800 INR
Settings, wiring, ... 3000 INR
Substitution underworth -0 INR
Gross investment (without taxes) **34300 INR**

Financing
Gross investment (without taxes) 34300 INR
Taxes on investment (VAT) Rate 0.0 % 0 INR
Gross investment (including VAT) 34300 INR
Subsidies -46000 INR
Net investment (all taxes included) **-11700 INR**
Annuities (Loan 5.0 % over 20 years) -939 INR/year
Maintenance 100 INR/year
insurance, annual taxes 0 INR/year
Provision for battery replacement (lifetime 5.0 years) 2200 INR/year
Total yearly cost **1361 INR/year**

Energy cost
Used solar energy 185 kWh / year
Excess energy (battery full) 6.5 kWh / year
Used energy cost 7.37 INR / kWh

Table 6.8 with interest 5%, 100 % subsidy

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Stand Alone System: Detailed User's needsEconomic evaluation

Project : **Stand Alone Project at Dharwad**
Simulation variant : **New simulation variant**

Main system parameters System type **Stand alone**
PV Field Orientation tilt 30° azimuth 0°
PV Array Nb. of modules 2 Pnom total **150 Wp**
Battery Model PVX-690T Technology vented, vehicle starting
battery Pack Nb. of units 2 Voltage / Capacity **12 V / 120 Ah**
User's needs Daily household consumers Constant over the year global 219 kWh/year

Daily household consumers, Constant over the year, average = 0.6 kWh/day

Annual values

	Number	Power	Use	Energy
Fluorescent lamps	3	40 W/lamp	3 h/day	300 Wh/day
TV / Video-tape rec. / PC	1	80 W/app	3 h/day	240 Wh/day
Domestic appliances	1	20 W/app	3 h/day	60 Wh/day
Total daily energy				600 Wh/day

Investment
PV modules (Pnom = 75 Wp) 2 units 6250 INR / unit 12500 INR
Supports / Integration 3500 INR / module 7000 INR
Batteries (12 V / 60 Ah) 2 units 5500 INR / unit 11000 INR
regulator / converter 800 INR
Settings, wiring, ... 3000 INR
Substitution underworth -0 INR
Gross investment (without taxes) **34300 INR**

Financing
Gross investment (without taxes) 34300 INR
Taxes on investment (VAT) Rate 0.0 % 0 INR
Gross investment (including VAT) 34300 INR
Subsidies -46000 INR
Net investment (all taxes included) **-11700 INR**
Annuities (Loan 5.0 % over 20 years) -939 INR/year
Maintenance 100 INR/year
insurance, annual taxes 0 INR/year
Provision for battery replacement (lifetime 5.0 years) 2200 INR/year
Total yearly cost **1361 INR/year**

Energy cost
Used solar energy 185 kWh / year
Excess energy (battery full) 6.5 kWh / year
Used energy cost 7.37 INR / kWh

Table 6.9 with 5% loan, 100 % subsidy

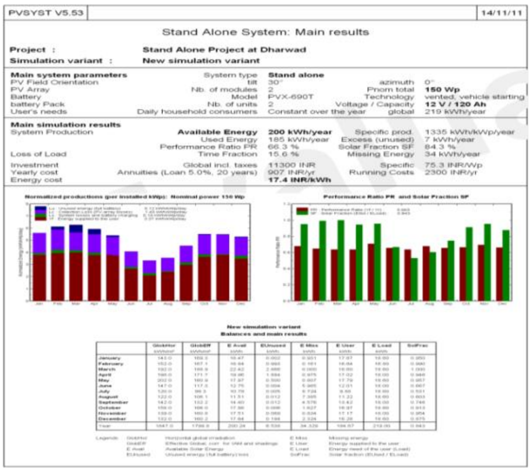

Fig. 6.41 with 50% subsidy, 5% loan

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Stand Alone System: Economic evaluation

Project : **Stand Alone Project at Dharwad**
Simulation variant : **New simulation variant**

Main system parameters System type **Stand alone**
PV Field Orientation tilt 30° azimuth 0°
PV Array Nb. of modules 2 Pnom total **150 Wp**
Battery Model PVX-690T Technology vented, vehicle starting
battery Pack Nb. of units 2 Voltage / Capacity **12 V / 120 Ah**
User's needs Daily household consumers Constant over the year global 219 kWh/year

Investment
PV modules (Pnom = 75 Wp) 2 units 6250 INR / unit 12500 INR
Supports / Integration 3500 INR / module 7000 INR
Batteries (12 V / 60 Ah) 2 units 5500 INR / unit 11000 INR
regulator / converter 800 INR
Settings, wiring, ... 3000 INR
Substitution underworth -0 INR
Gross investment (without taxes) **34300 INR**

Financing
Gross investment (without taxes) 34300 INR
Taxes on investment (VAT) Rate 0.0 % 0 INR
Gross investment (including VAT) 34300 INR
Subsidies -23000 INR
Net investment (all taxes included) **11300 INR**
Annuities (Loan 0.0 % over 20 years) 565 INR/year
Maintenance 100 INR/year
insurance, annual taxes 0 INR/year
Provision for battery replacement (lifetime 5.0 years) 2200 INR/year
Total yearly cost **2865 INR/year**

Energy cost
Used solar energy 185 kWh / year
Excess energy (battery full) 6.5 kWh / year
Used energy cost 15.5 INR / kWh

Table 6.10 with 50% subsidy

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Stand Alone System: Economic evaluation

Project : Stand Alone Project at Dharwad
Simulation variant : New simulation variant

Main system parameters — System type: Stand alone; PV Field Orientation: tilt 30°, azimuth 0°; PV Array: Nb. of modules 2, Pnom total 150 Wp; Battery: Model PVX-690T, Technology vented, vehicle starting; battery Pack: Nb. of units 2, Voltage / Capacity 12 V / 120 Ah; User's needs: Daily household consumers, Constant over the year, global 219 kWh/year

Investment

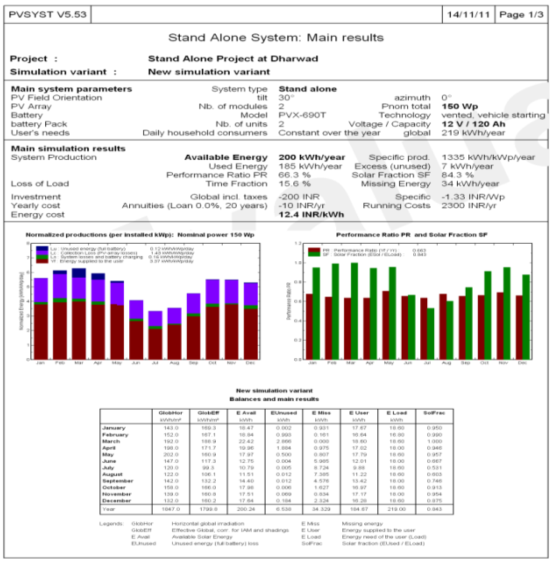
PV modules (Pnom = 75 Wp)	2 units	6250 INR / unit	12500 INR
Supports / Integration		3500 INR / module	7000 INR
Batteries (12 V / 60 Ah)	2 units	5500 INR / unit	11000 INR
regulator / converter			800 INR
Settings, wiring, ...			3000 INR
Substitution underworth			-0 INR
Gross investment (without taxes)			34300 INR

Financing

Gross investment (without taxes)		34300 INR
Taxes on investment (VAT)	Rate 0.0 %	0 INR
Gross investment (including VAT)		34300 INR
Subsidies		-0 INR
Net investment (all taxes included)		34300 INR
Annuities	(Loan 0.0 % over 20 years)	1715 INR/year
Maintenance		100 INR/year
Insurance, annual taxes		0 INR/year
Provision for battery replacement	(lifetime 5.0 years)	2200 INR/year
Total yearly cost		4015 INR/year

Energy cost

Used solar energy	185 kWh / year
Excess energy (battery full)	6.5 kWh / year
Used energy cost	21.7 INR / kWh



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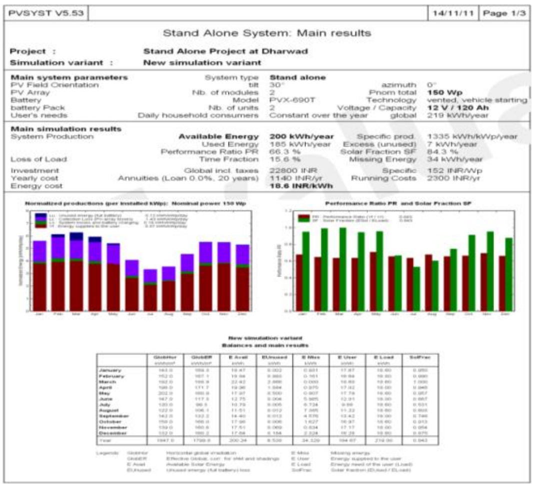
Stand Alone System: Main results

Project : Stand Alone Project at Dharwad
Simulation variant : New simulation variant

Main system parameters — System type: Stand alone; PV Field Orientation: tilt 30°, azimuth 0°; PV Array: Nb. of modules 2, Pnom total 150 Wp; Battery: Model PVX-690T, Technology vented, vehicle starting; battery Pack: Nb. of units 2, Voltage / Capacity 12 V / 120 Ah; User's needs: Daily household consumers, Constant over the year, global 219 kWh/year

Main simulation results — System Production: Available Energy 200 kWh/year, Specific prod. 1335 kWh/kWp/year; Used Energy 185 kWh/year, Excess (unused) 7 kWh/year; Performance Ratio PR 66.3 %, Solar Fraction SF 84.3 %; Loss of Load: Time Fraction 15.6 %, Missing Energy 34 kWh/year; Investment: Global incl. taxes -200 INR, Specific -1.33 INR/Wp; Yearly cost: Annuities (Loan 0.0%, 20 years) -10 INR/yr, Running Costs 2300 INR/yr; Energy cost 12.4 INR/kWh

Table 6.11 without subsidy, loan, and taxes Fig. 6.42 with 75% subsidy, without loan



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Stand Alone System: Main results

Project : Stand Alone Project at Dharwad
Simulation variant : New simulation variant

Main system parameters — System type: Stand alone; PV Field Orientation: tilt 30°, azimuth 0°; PV Array: Nb. of modules 2, Pnom total 150 Wp; Battery: Model PVX-690T, Technology vented, vehicle starting; battery Pack: Nb. of units 2, Voltage / Capacity 12 V / 120 Ah; User's needs: Daily household consumers, Constant over the year, global 219 kWh/year

Main simulation results — System Production: Available Energy 200 kWh/year, Specific prod. 1335 kWh/kWp/year; Used Energy 185 kWh/year, Excess (unused) 7 kWh/year; Performance Ratio PR 66.3 %, Solar Fraction SF 84.3 %; Loss of Load: Time Fraction 15.6 %, Missing Energy 34 kWh/year; Investment: Global incl. taxes 22800 INR, Specific 152 INR/Wp; Yearly cost: Annuities (Loan 0.0%, 20 years) 1140 INR/yr, Running Costs 2300 INR/yr; Energy cost 18.6 INR/kWh

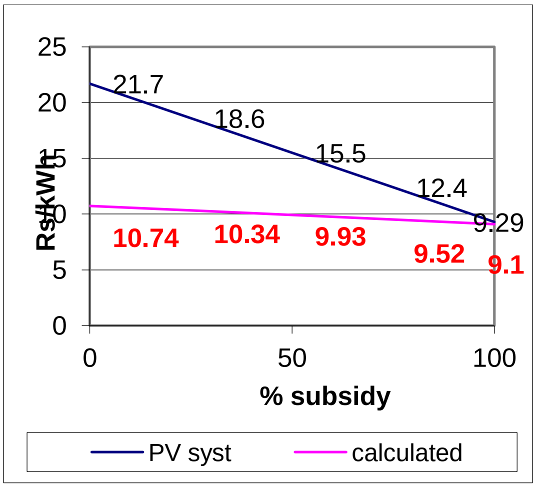


Fig.6.43 with 25% subsidy, no loan Fig. 6.44 comparison of PVSYST with calculated

Project design gives detailed hourly simulations, performances of PV module, inverter and battery, and optimised economic aspects according to user needs.

6.5.3 Savings from PV System-away from Grid

Actual unit consumed=0.840 kWh/day X 30 days=25.2 kWh/month

Actual Cost of grid supply=0.840 kWh/day X 365 X 5Rs/kWh =Rs 126 /month and Rs. 1533 /year.

For Solar panel=150 W_p X 6 hour X 0 .8 X 30 days=21.6 kWh/month

(Assuming 20% reduction due to cloud, shading and others)

Sharing of solar with respect to grid (21.6/25.2) is 85.71%

Thus, it saves (0.8571 X 126 X 12) Rs 1295.93 per year.

Assuming 4% inflation rate and for 25 years, total Cumulative saving is Rs 40142.02.(Table 6.12)

Table 6.12 Grid cost saving due to PV away from grid in 25 years

Year	Inflation (%)	Saving (Rs.)	Year	Inflation (%)	Saving (Rs)	Year	Inflation (%)	Saving (Rs.)
1	1.04	1347.84	10	1.4	1814.4	19	1.76	2280.96
2	1.08	139968	11	1.44	1866.2	21	1.8	2332.8
3	1.12	1451.5	12	1.48	1918	22	1.84	2384.6
4	1.16	1503.3	13	1.52	1969.9	23	1.88	2436.48
5	1.20	1555.2	14	1.56	2021.76	24	1.92	2488.32
6	1.24	1607.04	15	1.6	2073.6	25	1.96	2540.16
7	1.28	1658.88	16	1.64	2125.4			
8	1.32	1710.72	17	1.68	2177.2			
9	1.36	1762.56	18	1.72	2229.1			

Projected escalating cost of grid Electricity for 25 years, 15% per year for Rs. 1530/year base is Rs. 1061785. (Table 6.13) Also it provides non-pollutant, reliable electric energy without customer hour loss. Thus for villages far away from grid, SHS is the technically feasible economically viable, aesthetically acceptable, environment friendly options.

Conclusions

1) With continuous advancements in the research of materials, production processes and techniques, the environmental implications of the life cycle of PV systems are likely to improve.

Table 6.13 Projected grid cost for 25 years

Yr	Inflation (%)	Approximate Grid Cost (Rs.)	Yr	Inflation (%)	Approximate Grid Cost (Rs.)	Yr	Inflation (%)	Approximate Grid Cost (Rs.)
1	1.15	1795.5	10	2.5	3825	19	3.85	5890.5
2	1.30	1989	11	2.65	4054.5	21	4	6732
3	1.45	2218.5	12	2.8	4284	22	4.15	6349.5
4	1.60	2448	13	2.95	4513.5	23	4.3	6579
5	1.75	2677.5	14	3.1	4743	24	4.45	6808.5
6	1.90	2907	15	3.25	4972.5	25	4.6	7038
7	2.05	3136.5	16	3.4	5202			
8	2.2	3366	17	3.55	5431.5			
9	2.35	3595.5	18	3.7	5661			

2) SHS are being promoted and disseminated by government to meet lighting needs of villages. These SHS can contribute directly to reduction in carbon emissions in India in two ways - first by replacing kerosene-based lighting in around 67 million households and secondly by avoiding the carbon-intensive grid extension to less inhabited villages.

3) Emerging trends in decentralized PV systems for rural electrification continue to hold relevance at local levels on account of the key challenges of ensuring energy security to all communities such as-

- Improving household electrification level in electrified villages where households are scattered and grid extension is not very feasible.
- Pre-electrifying villages which are likely to be electrified in near future for introducing basic electricity services initially and subsequently facilitating load growth for making grid extension viable in future.
- Augmenting the electricity supply in electrified villages for achieving better healthcare, education and community services by providing dedicated PV systems.
- Managing the periods of low demand such as street lights, compound lighting in the night in institutions/campuses where large diesel generator sets run for daytime peak loads.
- In addition to the above market drivers, there are a few emerging trends in related technologies which are expected to fuel the growth of decentralized PV systems. India ranks 7th in the worldwide for PV cell production. GoI provides all the facilities to 9 manufacturers of solar cells, 21 of PV modules, 60 companies engaged in assembly and 43.6% of their products are exported.(Fig.6.45)

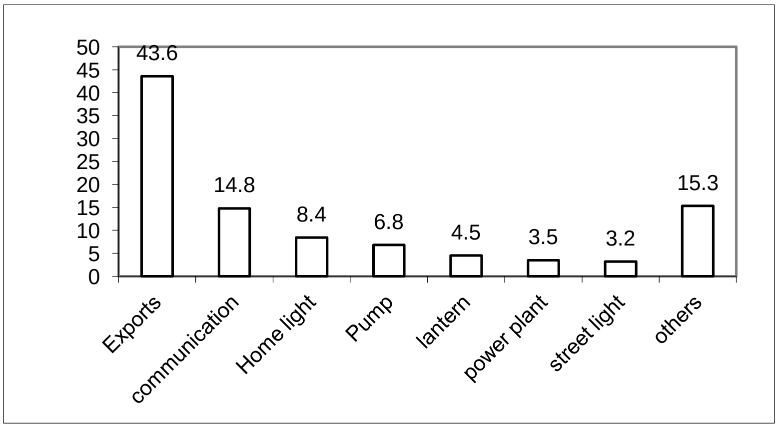


Fig.6.45 Share of PV market in India during 2009
(Source;Indian Semiconductor Association Report 2010)

Concessional duty import of raw materials, components, solar cells, PV modules and systems is permitted. Most of the PV products are exempted from excise duty and 80% accelerated depreciation can be availed during the first year. Of several distributed generation technologies, small-scale (kW_p range) roof-top PV systems are feasible and most suitable. In Indian context, PV based distributed generation;

including roof-top PV systems has tremendous potential in rural and peri-urban areas where availability of roof-space in houses is not a constraint. Hence it is necessary to make policy approach towards addressing the challenges of rural electrification.

A generalized approach to assess suitability of standalone and grid connected systems at a given location, based on techno-economic-financial-environmental feasibility does not find adequate coverage. If data pertaining to system costs, operation, maintenance and other relevant cost details are made available along with the learning from the case studies, the economic-financial assessment objective could be easily accomplished. It is found that the techno-economic assessment of grid-connected systems and stand-alone systems is restricted to annualized life cycle costing methods. Successful implementation of standalone projects under CDM requires devising suitable policy measures after taking cognizance of local support, institutional barriers and other social factors. This necessitates combined efforts from policy makers and modeling experts to study the systems collectively with other allied interdisciplinary sciences, for a clear representation of the energy problem and effective implementation of the solutions.

CHAPTER 7

ECONOMIC ASPECTS

Solar systems are characterised by high initial cost and low operational costs as compared with the relatively low initial cost and high operating costs of conventional systems. The comparison between these systems is based only on direct monetary outlay of the user ignoring non-economic factors like social, environmental, status value, freedom from utility grid etc. Following are the three main approaches used for comparing the relative costs of the solar and conventional systems-

a) Energy payback Time(EPBT)
b) Net Present Value(NPV)
c) Life Cycle Cost(LCC)

7.1 Energy Pay Back Time (EPBT)

Most solar cells and modules used today are crystalline silicon. Both single-crystal and multicrystalline silicon are used in large wafers of purified silicon. Purifying and crystallizing the silicon are the most energy-intensive parts of the solar-cell manufacturing process. Other aspects of silicon-cell and module processing that add to the energy input include: cutting the silicon into wafers, processing the wafers into cells, assembling the cells into modules (including encapsulation), and overhead energy use for the manufacturing facilities.

Today's PV industry generally recrystallizes any of several types of off-grade silicon from the microelectronics industry and estimates for the energy used to purify and crystallize silicon vary widely. Hence energy payback calculations are not straight-forward. Until the PV industry begins to make its own silicon, which it could do in the near future, calculating payback for crystalline PV requires certain assumptions.

To calculate payback, Dutch researcher Alsema reviewed previous energy analyses and did not include the energy that originally went into crystallizing microelectronics scrap. His best estimates of electricity used to make frameless PV were-600 kWh/m^2 for single crystal silicon modules and 420 kWh/m^2 for multicrystalline silicon.

Assuming 12% conversion efficiency (standard conditions) and 1700 kWh/m^2 per year of available sunlight energy (the U.S. average is 1800); Alsema calculated a payback of about 4 years for current multicrystalline-silicon PV systems. Projecting 10 years into the future, he assumes a solar-grade silicon feedstock and 14% efficiency, dropping energy payback to about 2 years. (Fig. 7.1)

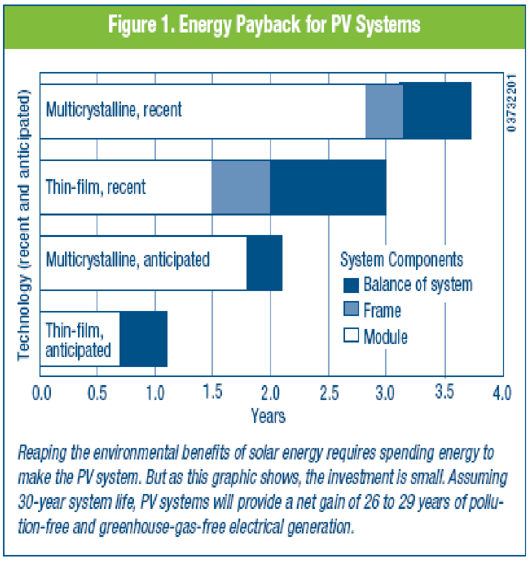
Other recent calculations support Alsema's figures. Based on a solar-grade feedstock, Japanese researchers Kato et al. calculated a multi-crystalline payback of about 2 years (adjusted for the U.S. solar resource). Palz and Zibetta also calculated an energy payback of about 2 years for current multicrystalline-silicon PV. For single-crystal silicon, which Alsema did not calculate, Kato calculated a payback of 3 years when he did not charge for off-grade feedstock. Knapp and Jester studied an actual manufacturing facility and found that, for single-crystal-silicon modules, the actual energy payback time is 3.3 years. This includes the energy to make the aluminum frame and the energy to purify and crystallize the silicon.

Energy payback time (Karl E. Knapp 2010**)** is one method adopted by several analysts in characterizing the energy sustainability of various technologies. It is the energy analog to financial payback, defined as the time necessary for a photovoltaic panel to generate the energy equivalent to that used to produce it. This investigation focuses on the energy payback time for both single-crystalline silicon ("sc-Si") and thin film copper indium diselenide ("CIS") photovoltaic modules as manufactured by Siemens Solar Industries ("SSI"). Two parameters determine the EPBT are (1) Production and (2) Implementation. The energy needed to produce a product (specific energy) includes both the energy consumed directly by the manufacturer during processing and the energy embodied in the incoming raw. (Source; NREL)

Implementation refers primarily to location, which determines the solar insolation and therefore the electrical output of the PV panel but could extend to installation details (fixed tilt or tracking, grid-connected or stand-alone, etc.) or balance of system (BOS) requirements such as mounting structure, inverter, or batteries. Figure 7.2 shows lines of constant payback times with the vertical axis being specific energy and the horizontal axis is energy generation rate for 1700 $kWh/m^2/year$. The energy payback time is computed from-

EPBT= (Specific Energy) / (Energy Generation Rate)

The payback time for today's production photovoltaic technology is substantially less than its expected lifetime. With a module lifetime of 25 years, the panels analysed here will produce nine to seventeen times the energy used in its production. The effects of the other components of a photovoltaic system can be significant relative to the module payoff itself, most notably in systems requiring batteries. Including life-cycle energy balances in both module production and BOS design are necessary to claim sustainability. (Table 7.1)



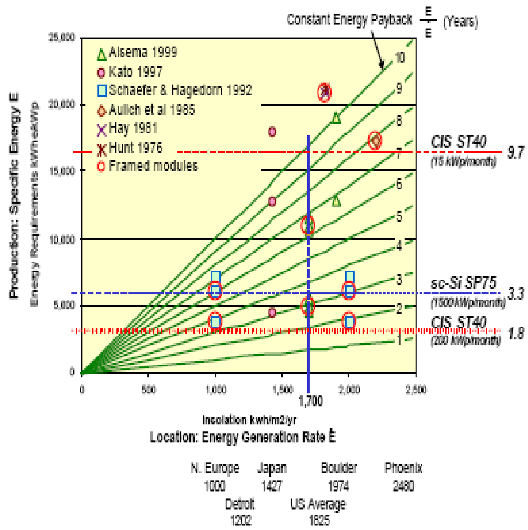


Fig.7.1 Energy Pay back Fig. 7.2 Specific Energy and Energy Generation Rate

Table 7.1 Energy Pay Back Time

1.Single crystalline-Si production 2MW$_p$/month kWh$_e$/kW$_p$	Ingot	Cell	Module	Total	EPBT
Process	1382	850	510	2742	1.6
Indirect Mat' 1	36	412	--	448	0.3
Direct mat'1	1884	1	523	2408	1.4
Total	3302	1264	1032	5598	3.3
EPBT (years)	1.9	0.7	0.6	3.3	
2.CIS(copper indium (di)selenide) Pre-Pilot15kW$_p$/month kWh$_e$/kW$_p$	Cell	Module	Other	Total	EPBT
Process	6949	1966	6192	15107	8.9
Indirect Mat' 1	111	-	-	111	0.1
Direct Mat'1	369	940	-	1308	0.8
Total	7429	2906	6192	16527	9.7

EPBT (years)	4.4	1.7	3.6	9.7	
3.CIS production $200kW_p$/month kWh_e/kW_p	Cell	Module	Other	Total	EPBT
Process	958	147	619	1725	1
Indirect Mat' 1	36	-	-	36	0.02
Direct Mat'1	369	940	-	1308	0.8
Total	1363	1087	619	3070	1.8
EPBT (years)	0.8	0.64	0.36	1.8	

Some determinants of the energy payback for alternative energy technologies are controllable by the manufacturers and some are not. There is a long-term sustainability ideal that say is to be done, to reduce the energy burden imposed by new technologies.

Energy payback time is a time in which the energy input during the PV system life-cycle is compensated by electricity generated by the PV system excluding life time of PV system.

$$EPBT = I_{nput} / (O_{utput} /year)$$

Example for a CdTe PV module (Table 7.2 and Fig 7.3)

Table 7.2 Energy payback Time

E_{input}= Cumulative Energy LCA	$12236MJ_{prim}/kWp$
Irradiation	$1700kWh/m^2$.year
Performance ratio (IEC 61724)	0.75
Generated electricity	1275kWh/kWp
Efficiency electricity supply	$11.4MJ_{prim}$/ kWp. Year
Avoided Energy	1275 X 11.4=14535MJ_{prim}/ kWp. Yr
Energy Payback Time	12236/14535=0.84 years

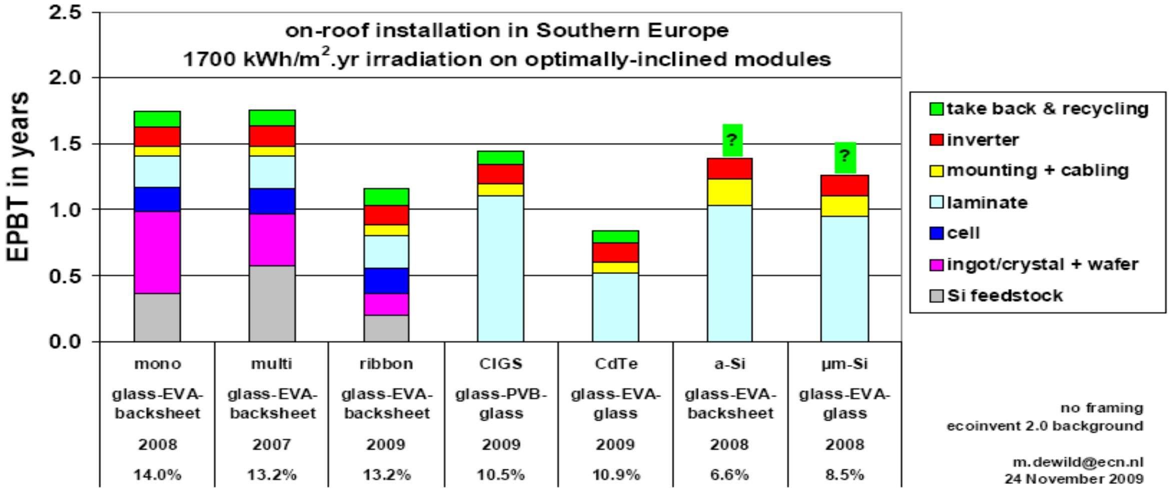


Fig.7.3 Roof top generation EPBT

7.2 Net Present Value (NPV)

To determine about the fuel savings over life time of the system and comparing it with the time value of the investment- with money from hand and with money on loan are the two approaches. This is more complex than payback, but provides better information. It may be unclear what payback period is acceptable, but NPV provides the actual cost value of completing a project.

NPV also recognizes the time value of money. While this fact is obvious to most people, explicitly accounting for it in calculations is foreign to many homeowners. This analysis includes the calculation of NPV for sample solar systems. But the result is highly dependent on the discount rate used. (Fig 7.4)

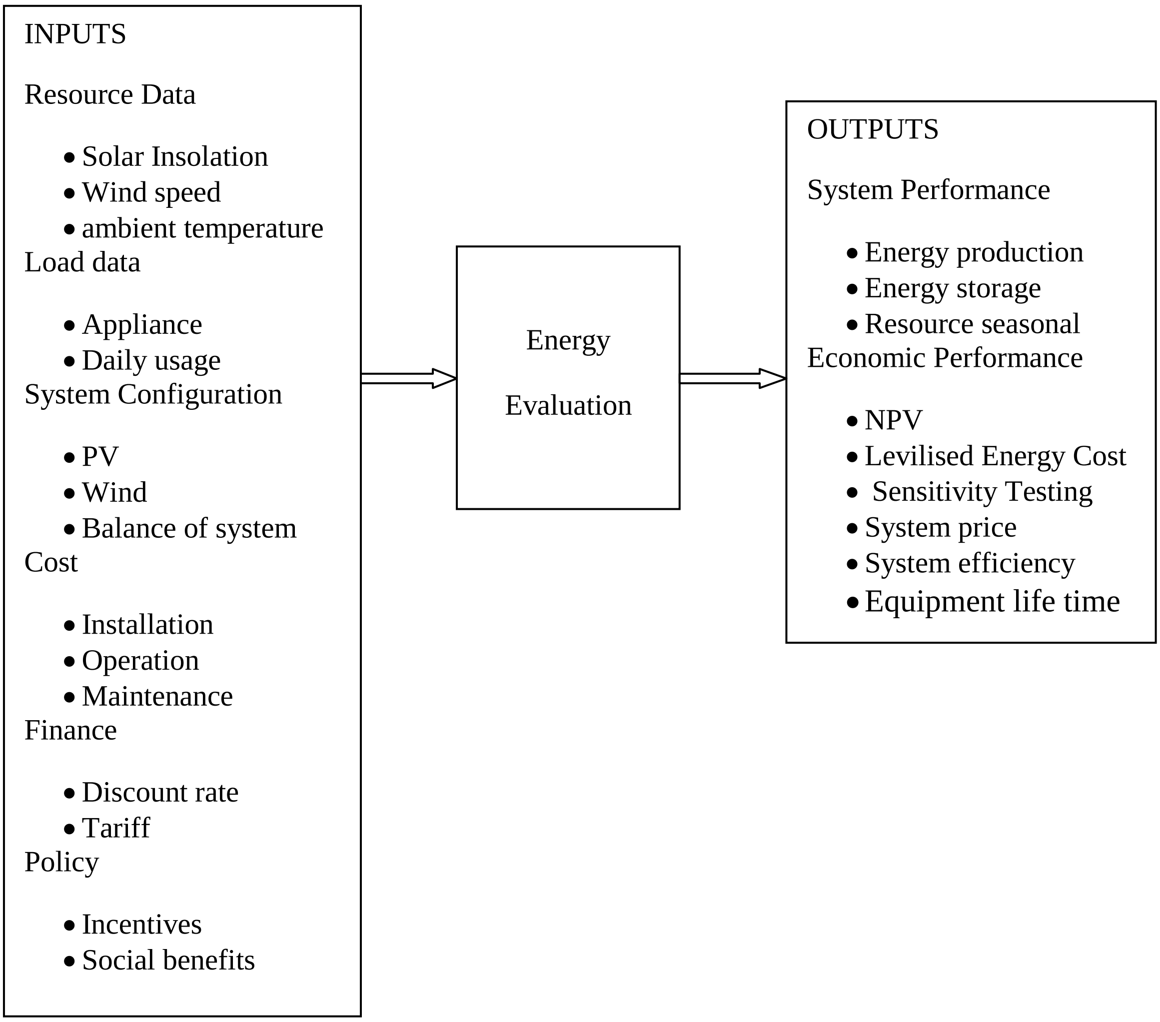


Fig 7.4 Rural Renewable Energy Analysis and Design model

7.3 Life Cycle Cost (LCC) (Ref. 6.5.2)

Solar life time cost includes capital costs, interest on the capital, fuel costs, operating and maintenance costs, replacement cost of components, etc. over the useful life of the system.LCC per kWh of the different technologies depends very much on the number of kWh generated (number of households that consume electricity and the amount of electricity that an individual household consumes).

If there is a main electric grid close by and there is sufficient energy demand, extension of the electric grid is the most cost effective option, when compared to other electrification options.SHS become competitive with grid extension, even a few kilometers from the main electric grid with the cost of connection to the grid being the most important parameter that determines the break-even point.

PV-minigrids are cost effective compared to SHS for systems that are larger than approximately 10kWp if connections costs are low (less than P2000 average connection cost), that are when the household density is high. The break-even point depends very much on the average connection cost.

A Vigneswaran et al. (2008) carried out the cost comparison between amorphous silicon (a-Si) and cadmium telluride (CdTe) technology for a stand-alone photovoltaic system by applying LCC method of analysis. A simulation tool; RETScreen is used to perform the financial analysis in setting up the stand-alone photovoltaic system for a typical house with an occupancy of four persons. The analysis consists of the photovoltaic cells cost per watt, efficiency and all factors contributing to the output power generated from these cells include the balance of the system, the battery storage, charge controller and inverter. From this investigation, although stand alone photovoltaic system provides several advantages from the environmental viewpoint, the major drawback is the fact that it costs ten times more than the cost of conservative energy. The price of energy for a standalone photovoltaic system ranges from RM (Ringgit Malaysia, 1RM=30Rs) 5.20/kWh for cadmium telluride to RM 5.32/kWh for amorphous silicon with an average of RM 5.26/kWh.

Sheeraz Kirmani et al. (2010) studied on a stand-alone PV system to provide the required electricity for a single residential household in India. The complete design of the suggested system is carried out, such that the site radiation data and the electrical load data of a typical household in the considered site are taken into account during the design steps. Also, the LCC analysis is conducted to assess the economic viability of the system. The results of the study encouraged the use of the PV systems to electrify the rural sites of India.

In remote sites that are too far from the Indian power grid, the PV installers are encouraged to sell the electricity of their PV systems at a price not lower than \$0.74/kWh to earn a profit. It is to be noted, here, that although this price is very high compared to the current unit cost of electricity in India (\$0.1/kWh), this price will drop to \$0.49/kWh if the future initial cost of the PV modules drops to \$0.1/W_P. At the same time, if the future unit cost of electricity in India becomes five times its current value, due to the rapid increase in the conventional fuel prices, therefore PV energy generation will be promising in the future household electrification in India, due to its expected future lower unit electricity cost, efficiency increase, and clean energy generation compared to the conventional utility grid.

The economic viability of a stand-alone solar photovoltaic PV system with the most likely conventional alternative system, i.e. a diesel-powered system, has been analysed for energy demand through sensitivity analysis using a life-cycle cost computation by Mohanlal Kolhea et al. (2002). The sensitivity analysis allows estimation of the comparative viability of PV against a conventional alternative system based on particular country-specific parameters. The overall PV best and worst case viability, as compared with a conventional diesel-powered system, have been obtained from sensitivity analysis of the energy demand.

A life-cycle cost comparison of PV powered systems and diesel-powered system has been carried out to give a first-order indication of when a PV system should be considered for application. Sensitivity analysis has been given to explore the system comparisons with base-case assumptions. The analysis has been carried out for the energy demand for different key parameters, such as discount rate, diesel fuel cost, diesel system lifetime, fuel escalation rate, solar insolation, PV array cost, reliability, etc.

- Sensitivity to discount rate

It has been found that a PV system is economical compared to a diesel-powered system up to an energy demand of 58 kWh/day with a 10% discount rate as base. At discount rates of 15% and 20%, PV-powered systems are economically advantageous up to an energy demand of 40 and 30 kWh per day respectively. This shift in the crossover occurs because of the nature of the PV and diesel cash flows, in terms of recurring vs. capital costs. The base-case PV cash flow, on the other hand, is less affected by cost escalation. The PV system also has recurring costs due to battery replacements, so the LCC is sensitive to the discount rate.

- Sensitivity to diesel fuel cost

It has been observed that a PV system is economical up to an energy demand of 53 kWh per day for a diesel cost of Rs. 30 per litre. At a diesel cost of Rs. 20/litre, the crossover occurs at energy demand of 38 kWh per day and at Rs. 10/litre, the PV is cost-effective only up to 28 kWh per day. In India, the cost of diesel is highly subsidised; if the Indian government were to remove the subsidy at the consumer end, the cost of diesel would increase and the PV system would become more attractive. In remote areas, the transportation cost of fuel doubles or even triples the cost of diesel.

- Sensitivity to diesel system lifetime

The lifetime of diesel-powered systems varies widely with the quality and frequency of maintenance. The effect of diesel system lifetime on energy costs shows that the PV system is economical up to an energy demand of 48 kWh per day for a diesel system lifetime of 6 years. For a diesel system life of 3 years, the PV is economical up to 60 kWh/day, and for 9 years, up to 42 kWh/day.

- Sensitivity to fuel escalation rate

It has been found that if the fuel escalation rate is 3% and above, the PV is more favourable for the base-case assumptions. Fuel escalation mainly depends on the international price of diesel, reserved foreign exchange of the country, etc.

- Sensitivity to solar insolation

The comparison of life-cycle costs of PV and diesel-powered systems over a range of energy demands for different solar insolation shows that for solar insolation of 4 kWh/m^2/day, the PV system remains cost-effective up to an energy demand of 53kWh/day. For solar insolation of 6 kWh/m^2 /day, the PV is competitive up to 77kWh/day. If the solar insolation increases by 66%, the LCC of PV decreases by 30%. In India, solar insolation varies between 4 and 7 kWh/m^2 and day.

- Sensitivity to PV array cost

The life-cycle costs of PV and diesel-powered systems have been compared over a range of energy demands and it has been found that for a PV array cost of Rs.150/W_p, the PV is economical up to an energy demand of 50kWh/day, and for Rs. 300W_p, up to 35kWh/day.

- Sensitivity to reliability of PV system

The reliability of a PV system mainly depends on its application. A comparison of life-cycle costs of PV and diesel-powered systems over a range of energy demands for different reliability levels has been carried out and showed that PV is economical up to 43kWh/day for 99.5% reliability of the PV system; for 95% reliability it is economical up to 72kWh/day. The LCC of a PV system is highly sensitive to its reliability.

For the best-case PV viability, a low discount rate of 10%, a high fuel diesel cost of Rs. 30/litre, a short diesel system lifetime of 3 years and solar extremes of the ranges, i.e. a discount rate of 20%, diesel cost of Rs. 10/litre, a diesel system lifetime of 9 years and solar insolation of 4kWh/m^2/day. The economic viability of a stand-alone PV system in comparison to the most likely conventional alternative system, i.e. a diesel-powered system, has been analysed for energy demand through sensitivity analysis. The analysis shows that PV powered systems are the lowest cost option at a daily energy demand of up to 15 kWh even under unfavourable economic conditions. When the economic parameters are more favourable, PV powered systems are competitive up to 68 kWh/day. These comparisons are intended to give a first-order indication of when a stand-alone PV system should be considered for application. As the cost of PV systems decreases and diesel costs increase, the break-even points occur at higher energy demand.

7.4 Recycling of PV Systems

1) Recycling of Crystalline Silicon PV Modules: It is conceivable that fully functioning modules will be replaced with newer and better ones, and the replaced ones will have to be recycled also. Considering these facts, by 2015/2020 economic and efficient recycling methods for solar modules must be in place. (Table 7.3)

2) Recycling of Amorphous Silicon PV Modules: Schematic survey of thermal process for solar module recycling is shown in Fig 7.6.

Table 7.3 Materials contained in solar modules

Components	Used materials	Appr. mass % age without frames
Glass(2-10mm)	SiO_2,Al_2O_3,Fe_2O_3,CaO, MgO,Na_2O,K_2O,SO_3	30-65
Transparent adhesive (1-2mm)	EVA, acryl ate (PVB)	5-10
Solar cell (200-400µm)	silicon	5-10
Connection material (0.04X 2-0.2 X5)	Cu(Sn, Pb,Ag),Al(Mg,Si)	1
Metallisation	Ag,SiO_2,Cu,Ni,Al, Ti, Pd, Sn	< 0.1
Antireflection Layer	TiOx, SixNy	>0.1
Doping	B or Al, Ga, In, P or As, Sb	
Cable 1.5-2.5mm^2	Cu, PVC, rubber, Silicon, PTFE	1
Connection Box	PVC,PC,PET,ABS, Cu, Brass, Steel, rubber	0-5
Sealing, gum	Silicon, butyl, polysulfide, cy	0-10
Back side material	Chlorofluorocarbon, Polyester	0-10

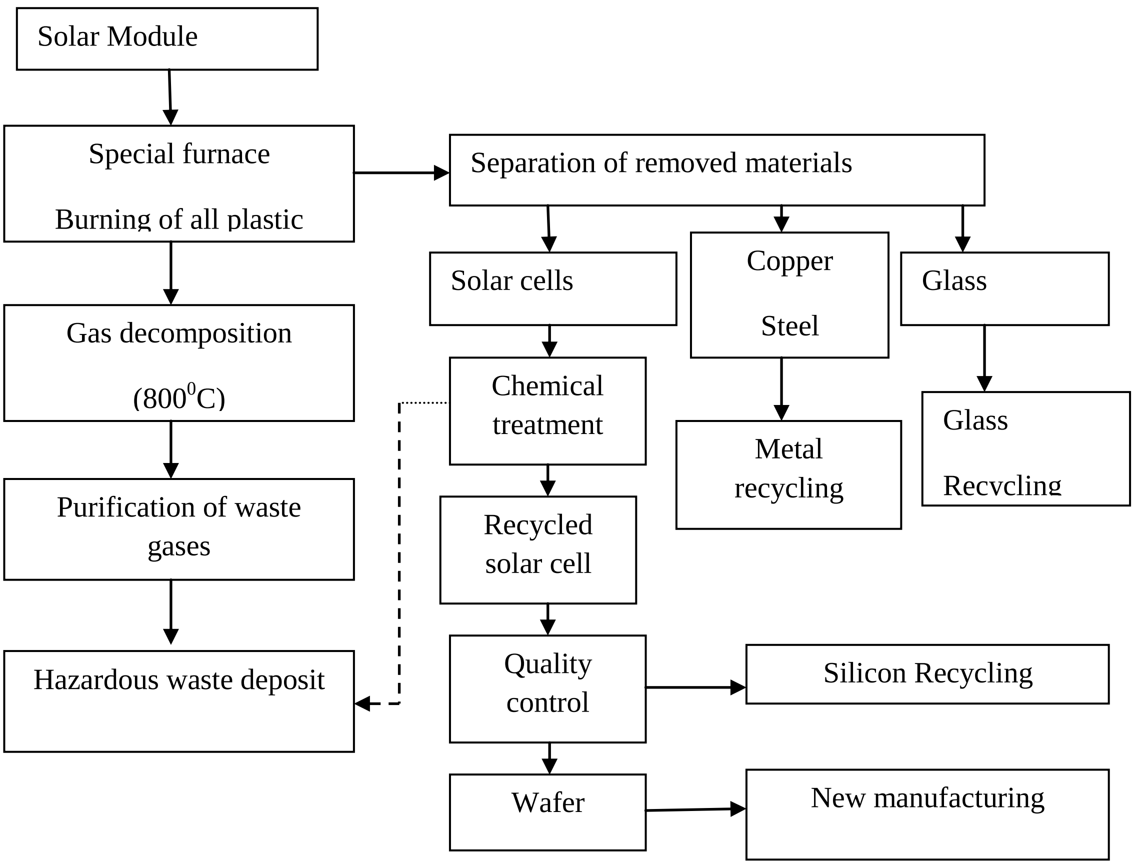


Fig 7.6.Schematic thermal process for solar module recycling

Conclusions

- Cost analysis of PV system module manufacturing involves energy in extraction of silicon from raw material, preparing silicon wafers, making cell and PV module. Energy required in this process is not included in the present study.
- Some feel that there should not even be cross subsidies and indeed no subsidies at all to any category of consumers. The thinking is that, in an ideal world with perfect markets, efficient use of an input like electricity requires that its price covers the cost of production. However, the price of electricity must not be set on the basis of the average cost of cheap plants constructed in the past. Demands for extra electricity may require new plants. Thus, the price should cover the cost of a unit of electricity from the next power plant, i.e., the long-run marginal cost of production, that tends to be much higher.
- A crucial strategy in this context is to exploit the fact that consumers are more concerned about their total expenditure on an input like electricity than its unit price. So, if their expenditure stays the same, they will not mind paying more per unit consumed. A higher tariff for the same expenditure means a lower consumption. But this lower consumption must not lead to a decrease in the energy service that they obtain. To achieve the same energy service with a lower consumption requires efficiency improvements so that energy is used more efficiently. Thus, efficiency improvements must be used to ensure that the resulting reduction of electricity consumption offsets tariff increases so that there are no increases of consumers' expenditures on electricity. Thus, the second guideline is that reduction of subsidies and tariff increases must come after implementation of efficiency improvements so as to offset expenditure increases.
- Since SHS are inaccessible to the rural poor, it is tempting to dismiss them as elite energy sources. If, however, the purpose of SHS is, not merely to improve the quality of life of the households, but to illuminate after-sundown activities that augment income (example, weaving baskets), then the elitist characterisation may not be applicable. Suppose that a one-light SHS permits a tribal household to weave two extra baskets per evening to earn Rs.5 per basket and therefore (after paying for materials) about Rs.250 per month. Then the income generated by the SHS more than pays for the investment on the light. A similar case is that of a mobile vegetable

vendor who can have two extra hours of sales. Thus, there are non-elitist niche markets for SHS. This is because the income generated under illumination by the SHS more than pays for the investment on the light.

- Another reason for cautioning against hasty judgments about the elitist or egalitarian character of sources and devices derives from the well-known fact that technological advances and organisational learning can bring about major cost reductions in the case of emerging not-yet-mature technologies. The point is well illustrated by the declining trend in the cost of PV modules. This means that decisions must be made on the basis of future costs, rather than present costs that are bound to decline. The implication is that declining costs can erode the elitist character of sources and end-use devices and strengthen their egalitarian character.
- Grassroots rural development workers are preoccupied with the immediate problems of the people with whom they work directly. As a result, they tend to choose technological options that are available straightaway off-the-shelf. They use a very high discount rate for their technological decisions being totally preoccupied with the present. In contrast, technical experts are excited by technological possibilities.

CHAPTER 8

CONCLUSIONS AND FUTURE DIRECTION

8.1 Observations

The cost of energy in the fossil fuel-based centralised power stations consists of the generation, transmission and distribution costs, whereas in the decentralised power generating system energy cost is primarily the generation cost. Conventional centrally-managed approaches to electricity distribution have been expensive and unsustainable and the financial analysis presented in this thesis makes the case for a distributed approach in remote, rural areas using stand alone solar home system.

Experiences with rural electrification through renewable energies so far have shown many positive aspects, as well challenges that need to be considered to avoid them in future projects.

- It is found that after SHSs are installed, the electricity demand of the users usually does not increase. They stick to the usual three to four lights, radio and a TV. In general they do not have any purchasing power to buy more sophisticated appliances and their lifestyle does not require them.
- Also it is expected that operation and maintenance worked best in indigenous communities, where original social structures are still in place as opposed to villages that have lost their traditional practices and institutional structures.
- Government subsidies are needed to electrify the poorest in the country, who cannot afford to pay for the systems themselves.

Based on the studies of SHS rural electrification through solar energy provided the following observations:

- Lack of awareness of solar energy technology necessitates demonstration of it to rural people; this approach generates demand from nearby communities. In supporting solar power generation in rural areas,
- Appropriate financial arrangements, which may include payment in installments, fee for services and other suitable modes, are necessary for rural people to afford the system.

- Technical training can enable users to do trouble shooting for minor problems such as replacing fuses, adding distilled water, and replacing bulbs. This may avoid technician calls and increase system reliability.
- Technician training is essential for developing local technical support, which can also help make the project sustainable. Building local skills for the system's operation and maintenance, and ensuring locally produced and accessible components are also important in developing support for this technology.
- Solar systems with different options should be available to consumers so they can choose themselves according to their needs and financial capacity.
- For the electrification of rural markets through solar energy, local collective management yields better results by reducing the risk of theft and nonpayment.
- Solar systems help in generating income, by extending working hours and creating a convenient environment for business.
- Components/accessories of solar systems should be available locally so that the users can buy them easily when required. This can increase acceptability of the technology by users.
- Solar PV can integrated with wind, diesel, micro turbine for reliable operation, with increase in the cost.

These impacts can mean that a developing country can more rapidly achieve the millennium development goals.

8.2 Policy Initiatives and National Solar Mission

In recent times, India has been under the radar of western countries for its high and increasing greenhouse gas emissions. Thanks to increasing pressure from the West, the Indian Government is looking to explore opportunities in alternative energy to reduce greenhouse gases. While countries such as China and United States have ambitious targets to reduce greenhouse gases, India has just started laying foundation for reducing emissions. Due to increasing demand for electricity and widening gap between demand and supply, India has targeted 20GW of Solar Power by 2022 in its Jawaharlal Nehru National Solar Mission (JNNSM).

Since solar power is at the introductory stage of its life cycle, Government initiatives are expected to drive it until 2012. The Government of India realizing the need for alternate sources of energy other than coal and oil has introduced many schemes and incentives to support the growth of the Solar Energy Sector. Some remarkable policies and targets are:

- 11th five year plan targets 50 MW of grid interactive solar power by 2012, however, this target has been revised to 1000 MW by 2013
- 20 GW of Solar Power by 2022 (JNNSM)
- Increasing domestic photovoltaic module production to 4-5 GW by 2020
- Achieving grid parity for solar power in 2020(JNNSM)
- Funding of 20-25 percent of capital expenditure under the semiconductor policy.
- Generation based incentive at a tariff rate of approximately Rs 15 per kWh.
- Fund allocation for R&D activities and rural electrification programs.

Apart from the above, state level targets and schemes are also expected to benefit the solar power sector**.** MNRE has already started many initiatives like Automatic Solar Radiation Monitoring Systems (ASRMS) in different parts of India.

Table 8.1 Automatic Solar Radiation Monitoring Systems (ASRMS) by MNRE

Sl. No	States	ASRMS	Sl. No	States	ASRMS
1	Rajasthan	12	8	Madhya Pradesh	3
2	Gujarat	11	9	Jammu & Kashmir	1
3	Tamilnadu	7	10	Chhattisgarh	1
4	Andhra Pradesh	6	11	Pondichery	1
5	Karnataka	5	12	Haryana	1
7	Maharashtra	3	Total		51

Each ASRMS consists of two towers of 1.5 m and 6 m tall each. The 1.5 m tall tower houses a Solar Tracker equipped with Pyranometer, Pyranometer with Shaded Ring and Pyrheliometer to measure solar parameters, such as, global, diffused and direct radiation. The 6 m tall tower houses instruments measuring rainfall, ambient temperature, atmospheric pressure, relative humidity, wind speed and direction. Each ASRMS is totally powered by 160 Watt SPV Panels and consists of 13 equipments/instruments and records 37 parameters inclusive of both measured and derived. The data from each ASRMS averaged to 10 minutes will be transmitted to a Central Receiving Station established at C-WET, Chennai through GPRS mode. The implementation of the project has started from February 2011 and all stations have already been installed, completed and commissioned. The monthly average (daily) wise data received from each ASRMS is available on C-WET website as test run. The quality checking process of the data is on.

8.3 Conclusions

1. At the beginning of the twenty first century, human society faces two great challenges: the transition towards a sustainable development, and the eradication of poverty. Renewable energy sources can play an important role in overcoming both challenges. The use of renewable energy sources for rural electrification in developing countries is a paradigmatic example of this role. While the extension of the electricity grid to those areas can be very costly, the use of off-grid, small-scale renewable energy systems can provide electricity to remote rural areas at a reasonable price. New electricity supplies will promote rural development in both the short-term -by facilitating the development of new economic activities-and the long term-by improving health and education services.
2. Government programs for rural electrification should coordinate their efforts with other rural development initiatives so the new electricity supply creates opportunities for the development of new economic activities. In addition, the goals of these programs should be based not only on the number of rural households with access to electricity but also on the quality of the electricity service provided to them.
3. There is no standard solution for rural electrification projects. Each project needs to be tailored to the local characteristics of the rural community in which the project will be implemented. The assessment of available renewable energy resources (solar radiation, wind speed, water flow rate, etc) will be key factors in the selection of the technology to be used.
4. Apart from the availability of renewable resources, other important factors to consider in the design of any rural electrification project are the high-priority end-uses for the electricity, the income level of the community, the availability of financial services, etc.
5. If rural electrification brings rural economic development as intended, the electricity demand of the rural community may increase significantly after the execution of the project. Consequently, the design of any rural electrification project should include some degree of flexibility and modularity that allows the

expansion of the system along with the growth of the demand at a minimum cost. The project design should also include standards for the use of efficient equipment by final consumers.

6. A solid management model is key factor for the long-term viability of rural electrification projects. The management model must clearly define operation and maintenance tasks and responsibilities. The participation of the local community in these tasks, as well as the design of a tariff system that at least covers the costs associated to them, are basic pillars of any sound management model.
7. To assure an efficient use of electricity and the involvement of the users in the project, final users should always pay some tariff for the electricity service they receive. In some cases, rural customers may be willing to pay a higher tariff than expected due to the valuable benefits obtained from the new electricity service. This is especially true when the electricity supply facilitates the development of new economic activities, thus generating a new source of income for the community.
8. A major obstacle to the widespread use of RES for rural electrification is their comparatively high capital and installation costs. Nonetheless, owing to the simplicity and reliability of these systems, operating and maintenance costs are relatively low. This means that RES may appear as an attractive option under a life-cycle cost analysis.
9. Typically, only the wealthiest residents of rural villages can afford to pay for the RES with cash. The demand associated to this delivery model is therefore very limited, but credit and rental options can expand the market significantly. The fee-for-service arrangement tends to be strongly preferred by end users because it eliminates the need to undertake a large capital investment. In addition, it eliminates the risk to the end user of technical failure of the system, since it is in the best interest of the company to ensure an appropriate maintenance of the equipment.
10. Implementation of the project requires base line study, assessment of user needs, standards in project, engineering design and optimisation of systems, regulatory procedures, and construction of infrastructures, execution, evaluation and monitoring.

8.4 Power generation projections

In the blue map scenario of India, total power capacity would amount to 748 GW (Giga watt). The full potential of biomass, geothermal, wind and tidal energy would be used. For hydro, 51% of the potential would be developed. Total coal-fired capacity would be roughly at the current level, but almost all this capacity would be equipped with carbon capture sequestration (CCS). For solar a significant expansion is assumed, from near zero now to 191 GW.

By contrast, CEA/Verma (2008) projects capacity needs of 1335-1854 GW by 2050. However, this assumes a much higher electricity demand (6698-8679 TWh, vs. 4069 TWh). The difference is accounted for by a combination of much higher economic growth rates (two-thirds of the gap) and lower efficiency gains (one-third) compared to the ETP 2010 scenarios.

On a regional level, the blue map scenario projects the need for large capacity additions in the regions of Delhi, Calcutta and Patna (Fig. 8.1). These are also those regions with large installations of gas capacity. In the regions of Ahmadabad, Mumbai, Trivandrum and Chennai, coal plants equipped with CCS should be located close to CO_2 storage sites. Most of the nuclear plants are built to exploit the available cooling water resources along the coastline. Major installations of solar power plants are projected for the regions of Bhopal, Calcutta and Delhi.

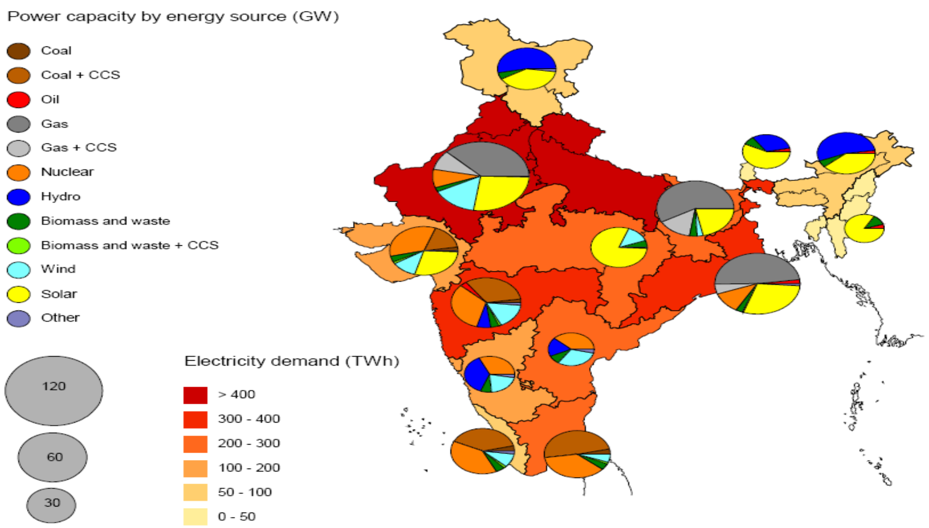


Fig. 8.1 Power capacities by region in the blue map scenario, 2050

In the baseline scenario, India's total CO_2 emissions grow almost fivefold, from 1.34 Giga ton (Gt) in 2007 to 6.45 Gt in 2050. The drastic growth in electricity demand combined with the reliance on coal for power generation leads to an increase of CO_2 emissions in the power sector from 0.75 Gt in 2007 to 2.87 Gt in 2050. However, efficiency improvements in new coal power plants reduce the average CO_2 intensity of electricity generation in the baseline scenario from 935 gm CO_2/kWh in 2007 to 707 gm CO_2/kWh in 2050.

In the BLUE Map Scenario, the global carbon price of USD 175/tCO_2, which is required to achieve the 50% reduction in global CO_2 emissions by 2050, reduces the total CO_2 emissions of the Indian energy sector in 2050 by 73% compared to the Baseline Scenario. Relative to 2007, this emission level in 2050 of 1.47 Gt corresponds to a modest emission increase of 10%. India's power sector gets essentially decarbonised in the BLUE Map Scenario. The shift to nuclear, CCS and solar power yields a dramatic decline in the average CO_2 intensity of India's power generation from 935 gm CO_2/kWh in 2007 to 79 gm CO_2/kWh in 2050.

Solar is the feasible option with a large technical potential, and must be included in the decarbonisation strategy for India. However, its use is starting from a very low level of installed capacity and a much more ambitious approach is needed for both PV and CSP. India needs to capitalise on solar investment opportunities in the short and medium term**.**

8.5 Future Directions

Future research and development should account for the following issues:

a) Smart Photovoltaic Systems with Energy Management Systems: Hardware and algorithms will need to be developed that incorporate communication protocols used by EMS (Energy Management System) and utility distribution systems. When hardware is available that can accept input from advanced utility distribution systems and control loads and generation, algorithms can be developed that optimize economic use of energy sources. The physical implementation of the EMS may be incorporated within the PV system or may be a separate device, depending on market forces. Small, limited-feature smart PV systems will likely incorporate a simplified EMS function; larger and more configurable designs may choose to create a separate EMS device.

b) Reliability and Lifetime of Inverter/Controllers: Inverter hardware currently available has an MTBF (Mean Time before Failure) of 5 to 10 years. Since the MTBF of the PV modules that those inverters are connected to is closer to 20 to 30 years, inverters will have to be replaced once or twice during the life of the system. Also, an inverter failure incurs a missed-opportunity cost for energy that was not generated. Thus, increasing the usable life of inverters will most likely lead to lower energy costs.
c) PV system reliability can be enhanced with hybrid systems like PV and wind, PV and diesel, PV and micro turbine. However this increases the cost of system.
d) Additional Voltage Regulation Concepts: Interconnection policies such as IEEE1547 strongly discourage voltage regulation by DG sources in the utility distribution system. However, a cohesive technical and policy approach to allowing voltage regulation by DG will need to be developed to handle projected high-penetration scenarios. Slow regulation and fast regulation will both be needed in high-penetration scenarios. Demonstrations of solid technical approaches for voltage regulating DG will provide support for updated standards that will streamline commercial product development and simplify utility interconnection.
e) Study of voltage profile on rural distribution feeders, allowable voltage drops both at MV and LV lines, voltage drop calculations for unbalanced systems, balancing the load between phases, loading of distribution transformers and correct sizing, transient and steady state analysis of distribution lines connected to irrigation and pump sets and future demand forecasting are the key factors for decision making.
f) Computer-based technological assessment tools in combination with material flow analysis (MFA), substance flow analysis (SFA), life cycle assessment (LCA) finds little reference in the literature. For a realistic estimate it is important to capture uncertainty in systems and hence stochastic modeling and simulation studies have to be encouraged in the field of energy studies. It is also clear from the literature that SA systems do not enjoy the CDM support. It is therefore important to realize the potential of SA systems in GHG emission reduction in developed countries and their role in promoting sustainable rural development in developing countries.
g) Distribution-Level Intentional Islanding (Microgrid): Further development is needed for control strategies to manage microgrids. This area is related to the grid-

connected voltage regulation needs discussed earlier, but it will most likely need to be augmented with communications to coordinate the transition between grid-connected and isolated modes of operation. With smart grid technology the village can become both buyer and supplier of electricity.

h) Optimize sizing of SHS according to requirements, the performance tests as battery usable capacity, functional test, recovery test, system balance point, days of autonomy, battery quality problem, inappropriate setting for controller and controller quality problems, etc on real time basis are to be investigated.

i) Renewable energy laboratory's breakthrough process creates nanoholes that trap sunlight so that more photons can be converted into electricity; the millions of holes create surface plasmons that account for the unusually high transmission in the silver films. Low-cost nano-patterning process makes millions of holes in silver film, boosting light- capturing qualities of organic solar cells manufactured in the research laboratories are expected to make a breakthrough in cell efficiency.

Appendix I

Rural electrification as on 31-8-2011 (Source: Central Electrical Authority)

No.	States and UTs	Total inhabited villages (2001 census)	Village electrified as on 31-03-10		Cumulative achievement as on 31-08-2010	villages electrified as on 31-08-2010 (%)	Un-electrified village as on 31-08-2010
			Numbers	%age			
1	Andhra Pradesh	26613	26613	100.0	26613	100.0	0
2	Arunachal Pradesh	3863	2195	56.8	2195	56.8	1668
3	Assam	25124	51503	85.6	22185	88.3	2939
4	Bihar	39015	23914	61.3	26799	68.7	12216
5	Delhi	158	158	100.0	158	100.0	0
6	Jharkhand	29354	9119	31.1	9119	31.1	20235
7	Goa	347	347	100.0	347	100.0	0
8	Gujarat	18066	18015	99.7	18015	99.7	51
9	Haryana	6764	6764	100.0	6764	100.0	0
10	Himachal Pradesh	17495	17183	98.2	17183	98.2	312
11	Jammu & Kashmir	6417	6304	98.2	6304	98.2	113
12	Karnataka	27481	27458	99.9	27458	99.9	23
13	Kerala	1364	1364	100.0	1364	100.0	0
14	Madhya Pradesh	52117	50231	96.4	50249	96.4	1868
15	Chhattisgarh	19744	19132	96.9	19132	96.9	612
16	Maharashtra	41095	36296	88.3	36296	88.3	4799
17	Manipur	2315	1997	86.3	1997	86.3	318
18	Meghalaya	5782	3428	59.3	3428	59.3	2354
19	Mizoram	707	570	80.6	570	80.6	137
20	Nagaland	1278	823	64.4	823	64.4	455
21	Orissa	47529	29735	62.6	29735	62.6	17794
22	Punjab	12278	12278	100.0	12278	100.0	0
23	Rajasthan	39753	28253	71.1	28525	71.8	11228
24	Sikkim	450	425	94.4	425	94.4	25

25	Tamil Nadu	15400	15400	100.0	15400	100.0	0
26	Tripura	858	491	57.2	491	57.2	367
27	Uttar Pradesh	97942	86450	88.3	86450	88.3	11492
28	Uttaranchal	15761	15309	97.1	15309	97.1	452
29	West Bengal	37945	37756	99.5	37760 (#)	99.5	185
Total (States)		**593015**	**499511**	**84.2**	**503372**	84.9	**89643**
Union Territories							
1	A & N Island	501	336	67.1	336	67.1	165
2	Chandigarh	23	23	100.0	23	100.0	0
3	D &NHaveli	70	70	100.0	70	100.0	0
4	Daman, Diu	23	23	100.0	23	100.0	0
5	Lakshadweep	8	8	100.0	8	100.0	0
6	Pondicherry	92	92	100.0	92	100.0	0
	Total (UTs)	717	552	77.0	552	77.0	165
	Total	**593732**	**500063**	**84.2**	**503924**	**84.9**	**89808**

Appendix II

1. HIGHLIGHTS OF POWER SECTOR

a Installed Generation Capacity (As on 31-10-11)

All India	Thermal				Nuclear	Hydro (Renewable)	RES@ (MNRE)	Grand Total
	Coal	Gas	Diesel	Total				
MW	100098.38	17742.85	1199.75	119040.98	4780.00	38706.40	20162.24	182689.62
%age	54.8	9.7	0.7	65.2	2.6	21.2	11.0	100.0

@ Based on data as on 30.06.2011.

b Capacity Addition Target during 11th Plan

	Hydro	Thermal	Nuclear	Total
MW	15627	59693	3380	78700
%age	19.9	75.8	4.3	100.0

c Generation Capacity Addition Target/Achievement (2011-12)

	Hydro	Thermal	Nuclear	Total
Target (MW)	2080.0	14636.0	1000.0	17716.0
Achievement up to Oct.,11 (MW)	1139.0	6361.5	0.0	7500.5
%age	54.8	43.5	0.0	42.3

d Electricity Generation Target/achievement (2011-12)

	Hydro	Thermal	Nuclear	Bhutan (Imp)	Total
Target MU	112050	712234	25130	5586	855000
Achievement up to Oct.,11 MU	92094.93	393772.97	18729.25	4545.95	509143.1
%age	82.19	55.29	74.53	81.38	59.55

e Status of CEA Concurrence to Hydro Schemes

Period	Project report received	Carry forward from Prev. year	Under Prelim. Exam	Accepted for concur-rence	Concurrence given by CEA	Project reports returned to Developer
2007-08	13	-	-	3	4	10
2008-09	8	3	-	1	4	5
2009-10	19	10	2	9	3	6
2010-11	22	20	3	7	7	20
2011-12	15	23	3	8	4	4

f All India Thermal PLF (%)

2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12 * upto Oct. 11
72.7	74.8	73.6	76.8	78.6	77.2	77.48	75.07	71.14

provisional*

g All India Annual per Capita consumption of Electricity

Year	Per Capita Consumption (kWh) (As per U. N. methodology)	
2003-04	592.0	
2004-05	612.5	
2005-06	631.5	
2006-07	671.9	
2007-08	717.1	
2008-09	734.5	
2009-10	779*	*provisional

h All India Transformation, T&D and AT&C losses :

Year	T&D losses(DMLF CEA)	AT&C Losses(PFC)
2003-04	32.53	34.78
2004-05	31.25	34.33
2005-06	30.42	33.02
2006-07	28.65	30.62
2007-08	27.20	29.45
2008-09	25.47	27.74
2009-10	NA	27.15

i a) All India Village Electrification (as on 30.09. 2011): 540228

b) Pumpsets Energised (as on 30.09. 2011): 17633853

j All India Coal Consumption for Power Generation (Utilities)

YEAR	Coal Cunsumption (Million Tonnes)
2002-03	253
2003-04	263
2004-05	278
2005-06	280
2006-07	302
2007-08	330
2008-09	355

k Average cost of power supply & average realization (paise/kWh)

Year	cost of supply (paise/unit)	realization(paise/unit) Including Agriculture	Only Agriculture
2003-04	239	203	72.39
2004-05	254	209	75.68
2005-06	260	221	76.36
2006-07	276	227	74.23
2007-08	293	239	77.27
2008-09	341	262	85.26
2009-10	354	268	89.05

Source:- PFC Reports on the performance of State Power Utilities

l Power supply Position 2011-12(OCTOBER,11)*

Region	Energy(MU) Requirement	Deficit%	Peak Demand(MW)	Deficit%
Northern	23,383	-12.1	36,981	-14.4
Western	22,338	-7.8	42,042	-14.4
Southern	22,633	-10.9	33,854	-14.0
Eastern	8,067	-4.0	14,121	-4.9
North Eastern	980	-9.4	1,909	-6.7
All India	**77,401**	**-9.6**	**128,907**	**-13.1**

* Provisional

Appendix III

12. GROWTH OF TRANSMISSION SECTOR SINCE 6TH FIVE YEAR PLAN

A. TRANSMISSION LINES (ckm)

At the end of	400 kV Transmission lines				220 kV Transmission lines			
	Central	State	JV/Pvt	**Total**	Central	State	JV/Pvt	**Total**
6th Plan	1831	4198		**6029**	1641	44364		**46005**
7th Plan	13068	6756		**19824**	4560	55071		**59631**
8th Plan	23001	13141		**36142**	6564	73036		**79600**
9th Plan	29345	20033		**49378**	8687	88306		**96993**
10th plan	50992	24730		**75722**	9444	105185		**114629**
11th Plan upto OCTOBER. 11	73107	32038	6403	**111548**	10638	126548	427	**137613**

B. SUB-STATIONS (MVA)

At the end of	400 kV Sub-Stations				220 kV Sub-Stations			
	Central	State	JV/Pvt	**Total**	Central	State	JV/Pvt	**Total**
6th Plan	715	8615		**9330**	500	36791		**37291**
7th Plan	6760	14820		**21580**	1881	51861		**53742**
8th Plan	17340	23525		**40865**	2566	81611		**84177**
9th Plan	23575	36805		**60380**	2866	113497		**116363**
10th plan	40455	52487		**92942**	4276	152221		**156497**
11th Plan upto OCTOBER. 11	69915	68152	630	**138697**	5956	205505	1567	**213028**

GROWTH OF TRANSMISSION SECTOR (As on 31-10-11)

	Central Sector	State Sector	JV/Pvt	**Total**
Transmission Lines (ckm.)				
765 kV	4849	410		**5259**
400 kV	73107	32038	6403	**111548**
220 kV	10638	126548	427	**137613**
+/- 500 kV HVDC Lines (ckm)	5948	1504	1980	**9432**
Sub Stations: (MVA)				
765 kV	4500	0		**4500**
400 kV	69915	68152	630	**138697**
220 kV	5956	205505	1567	**213028**
+/- 500 kV HVDC Converter/ BTB Stn.Converter Terminal (MW)	9500	1700		**11200**

Appendix IV

PV Systems Engineering Simulations

1)RET screen: free of charges
Basic Description: A decision support tool developed with the contribution of numerous experts from the Canadian government, industry, and academia. The software can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs).
Abilities: The software can model a wide variety of projects ranging from large scale multi-array central power plants, to distributed power systems located on commercial buildings and houses, to industrial remote wind-PV-generator-set hybrid power supplies, to stand-alone battery storage systems for lighting. For agriculture and water supply applications the daily and annual electricity use for water pumping can be estimated using a convenient water pumping tool. The software (available in multiple languages) also includes product, project and climate databases, and a detailed user manual.
Outputs; Energy production and savings, costs, emission reductions, financial viability and risk for central-grid, isolated-grid and off-grid photovoltaic (solar electric) projects.
2) NREL Solar Advisor Model (SAM) : Free of Charge/ Open Source
Basic Description;; System energy output, peak and annual system efficiency, Levilised cost of Electricity, SAM allows users to investigate the impact of variations in physical, cost, and financial parameters to better understand their impact on key figures of merit. Runs on TRNSYS engine
Abilities: The Solar Advisor Model evaluates several types of financing (from residential to utility-scale) and a variety of technology-specific cost models for several and, eventually, all Solar Energy Technologies Program (SETP) technologies. The SETP technologies currently represented in SAM include concentrating solar power (CSP) parabolic trough and dish-Sterling systems and photovoltaic (PV) flat plate and concentrating technologies. SAM uses the total installed cost, which is the sum of direct and indirect costs, to calculate the Levilised cost of energy. Because how costs are assigned to each category does not affect the total installed cost, you can either choose to distribute profit, overhead, shipping, and other costs among the component categories (module, inverter, BOS, Installation) or include them as a single value in the indirect category (miscellaneous
Outputs: system capital and operating and maintenance costs, and hourly system production
3) C.SP-r 11.5: Free of Charge/ Open Source
Basic Description: ESP-r is an integrated modeling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at user determined resolution.

Abilities: Building geometry can be defined via CAD tools, in-built CAD facilities or click-on-grid or image. ESP-r supports a building representation of arbitrary complexity (but most users work with models of 10-50 thermal zones. Models can be exported to other assessments tools such as Energy Plus, Radiance (visual simulations) or VRML worlds. As required, component networks can be defined to represent, for example, HVAC systems, distributed fluid flow (for the building-side air or plant-side working fluids) and electrical distribution systems. Alternatively, users can use idealised environmental controls for early design-stage explorations
Outputs: An interactive result analysis module is used to provide many different views of simulation results undertake a variety of performance appraisals and explore the interactions between assessment domains. Tools are provided to enable the construction of an Integrated Performance View which summarises performance over a range of relevant criteria. The ranges of analyses are essentially unrestricted and data can be exported to other analysis and graphing tools (but many users find they rarely need to access spreadsheets.
4)SolarGIS – pvPlanner: 10x10 km region – 60 €; 300x300 km region – 280 €; Europe, Africa
Description: SolarGIS - pvPlanner is professional new generation online simulation tool for site prospecting, prefeasibility and pre – design assessment, yield assessment of photovoltaic roof systems or power plants with horizont editor.
Abilities: The simulation methods implement the latest knowledge and best-practices in solar radiation and pv modelling. The recent (February 2011) IEA SHC Task 36 data inter-comparison activity, has independently confirmed that SolarGIS is the best performing solar radiation database presently available on the market. PvPlanner is based on this data source. Key features: Easy search of a location or roof, • Simulation of various technology options • Fixed-mounted, single-axis and double-axis tracking, • Module technologies - c-Si, a-Si, CIS/CIGS, CdTe, etc. • Simulation of angular reflectivity and nonlinear response of PV modules to irradiance and temperature, • User-selected inverter efficiency, DC and AC losses and availability. • New generation interactive horizon editor. High-performance report-generation engine for fast and standardised documentation of results.
Outputs: Complete PV report (example) in .pdf format. It contains :Site info, PV system info, Geographic position, Global horizontal irradiation and air temperature – climate reference, Global in-plane irradiation, PV electricity production in the start-up, System looses and performance ratio.
5)INSEL: Free learning edition; 1500 Euro for full version; 500 Euro for minimum version; 75 Euro for full version for students
Description: INSEL is a modular simulation environment used to understand, plan, monitor, and visualize energy systems. INSEL is a general-purpose graphical programming language, which can - in principle - solve any problem of computer simulation. The application fields of INSEL cover the topics solar irradiance simulation, photovoltaic and solar thermal applications.
Abilities: Whereas INSEL is the calculation engine to solve the mathematical model, a commercial visualisation tool named HP VEE was chosen to graphically construct the model in the first place. The core component of INSEL is the inselEngine which is a full compiler that cans interpret and executes applications written in the INSEL language or graphical preprocessors like HP VEE, for example. The core component

of INSEL is the inselEngine which is a full compiler that can interpret and execute applications written in the INSEL language or graphical preprocessors like HP VEE, for example user-programmable environment inselUB in which practically all fields of engineering applications can be built in a very structured way. All standard programming languages like Fortran, C++ are supported
Outputs: Includes a variety of graphical and numerical outputs that is either built-in or can be user defined. These can entail different components of a PV system, including but not limited to optimum PV module parameters and recommended models, annual yield energy output, IV curves, cell temperature distribution and the corresponding effect on the performance of the cell, array, and plant, efficiency comparisons of fixed, 1-axis tracking, and 2-axis tracking, as well as efficiency gains or losses for tilted fixed angles.
6) Solar DesignTool : free version, and an expert version with a monthly fee.
Description: SolarDesignTool is an online tool that solar professionals can use to design solar electric grid-tied systems online. It offers two different ways to create a PV system design. One method is for the user to supply a few basic design and site parameters. The tool then generates a list of all possible system configurations for those parameters. The user then selects a few of the generated configurations, compares them, and then saves one or more of them to a project. The other method to create a system is to use its System Builder. With this tool, the user specifies the details of each array configuration. For example, to create a system with multiple inverters, the user would first provide the temperature range, utility voltage, and then add an inverter and array, which involves selecting an inverter, module, and string configuration. The user would then repeat the process for each additional inverter. Users can also define any number of roof faces and require that the system's array fit within those defined areas.
Ability: Generate System Designs, String Sizing, System comparison, Array Layout design.
OUTPUTs: List of all possible system configurations for supplied design parameters. System comparison table, a summary report of the system. The report includes the following data: Record low temperature and average high temperature of installation site, STC DC output of array, PTC DC output of array, CEC output of array, number, model names, and specs for inverters and modules, area of array, maximum AC output current, dimensions of each roof face, and array layout, and distances of each row of modules. It also includes basic schematics of the roof, including length and width dimensions of the roof faces and layouts. The report is available in both HTML and PDF formats.
7) PV F-Chart : $400.00 for single user, $600.00 for educational site
Description: PV F-CHART is a comprehensive photovoltaic system analysis and design program. The program provides monthly-average performance estimates for each hour of the day. The calculations are based upon methods developed at the University of Wisconsin which use solar radiation usability to account for statistical variation of radiation and the load.
Abilities: Can model utility interface systems, battery storage systems, and stand-alone systems. Includes fixed, 1-axis, and 2-axis tracking as well as concentrators tracking options. Comprises of weather data for over 300 locations, ability to include additional weather data, fast execution, and hourly load profiles for each month,

statistical load variation, buy/sell cost differences, time-of-day rates for buy/sell, life-cycle economics with cash flow, and monthly parameter variation. Graphical and numerical outputs come in both English and SI Units.
Outputs: System performance results, efficiency, load, economics summary, life cycle costs, equipment costs, initial investments, solar fraction, etc
8) PVSYST*:* Trial version,~500 Euro for one machine license;~96 Euro for additional machines
Description: PVSYST 4.33 is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. It is suitable for grid-connected, stand-alone, pumping and DC-grid (public transport) systems, and offers an extensive meteorological and PV-components database. This software is oriented towards architects, engineers, and researchers, and holds very helpful tools for education. It includes an extensive contextual Help, which explains in detail the procedures and the models used
Ability: Tools include the meteo database management, with graphical displays or tables of data. PVsyst includes a database of around 330 sites in the world. Since PVsyst version 4.3 you can easily import meteo data from many popular meteorological sources (Meteonorm, Satellite, US TMY2, Helioclim-2, WRDC, NASA-SSE, PVGIS-ESRA, and the complete database of the RETscreen software). Custom meteo files can be easily imported in any ASCII format (as for instance from the NSRDB). The component database holds over 1750 PV modules, 650 inverters, nearly 100 solar pumps and dozens of batteries or regulator models. Custom updates of the database are very easy, on the basis of usual manufacturer data sheets
Output: Extensive output of solar geometry (sun paths, incidence angles, etc.); Clear sky irradiation yields on tilted planes; Quick meteo calculations on tilted planes, with horizon, sheds or sun-shields shadings; Transposition factor plots, for plane orientation optimization; Generation of meteo hourly synthetic files from monthly values; Hourly meteo plots, and calculations of irradiation on tilted planes, also with on-graph comparison with clear day model; Various graphs of the component's behaviour (PV modules, batteries, pumps); Electrical PV-array behaviour under partial shadings, mismatch or double-orientation; Operating voltage optimisation tool.
9) TRNSYS: $2100 for educational use
Description: TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected
Ability: The modular nature of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. TRNSYS has become reference software for researchers and engineers around the world. Main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells
Output: Open-ended.
10) SolarPro
Description: Solar Pro is by Japanese company LaPlace a system that serves to calculate power production of solar arrays subject to different physical and shadow variations.

Ability: Users can determine the influence of shade from buildings or objects, thus allowing for optimal settings and module design. The system calculates the I-V curve of solar cell modules accurately and quickly based on the electric characteristic for each product of each company. The software calculates the amount of electricity generated based on the altitude, longitude, and condition of the atmosphere at the location of the solar cell allowing users to get precise results. Solar Pro quickly finds out the necessary information on financial analysis of the PV system from power calculations and input data of system cost
Output: I-V curve, power generation, life cycle analysis.
11) PV DesignPro-G:$249.00 for Solar Design Studio CD-ROM.
Description: PV Design Pro-G is a suite of Windows 95, 98, NT, and Win2000 compatible software designed to simulate photovoltaic energy system operation on an hourly basis for one year, based on a user selected climate and system design. Three versions of the PV-DesignPro program are included on the Solar Design Studio CD-ROM: "PV-DesignPro-S" for standalone systems with battery storage, "PV-DesignPro-G" for grid-connected systems with no battery storage, and "PV-DesignPro-P" for water pumping systems.
Ability: The purpose of the programs are to aid in photovoltaic system design by providing accurate and in-depth information on likely system power output and load consumption, necessary backup power during the operation of the system, and the financial impacts of installing the proposed system. PV-DesignPro is directed at individuals who consider themselves as professional PV system designers and researchers, but has been completed in such a way as to make it possible novice designers to evaluate system designs.
Output: Solar Fraction charts, by month of the year; Battery states of charge by month (maximum, average, minimum); Annual performance table (energy produced, necessary backup, and states-of-charge); An Annual Energy Cost Analysis that includes prospective cash-flows based on costs of purchased energy, and any sold PV energy; A Lifecycle Cost Analysis that is a comprehensive pro-forma analysis of the system design based on system cost, costs of backup energy, prices of sold energy, maintenance and replacement costs, and the estimated life of the system. A rate of return is calculated, as is an overall price per kWh of the system, and pay back years; Charts can be viewed that cover every hour of the year and include battery SOC, battery voltage, solar radiation on a horizontal surface, solar radiation on the array, load and backup watts, panels efficiency, panel cell temperature, angles of incidence, slope angle, and the azimuth angle.
12) PV*SOL basic: $398.00 for single user.
Description: PV*SOL basic was created to keep things fast and easy by being an easy-to-use and intuitive user interface. The program is backed by Valentine Software's 20+ years of experience developing industry solar sales, design and simulation tools.
Ability: Design systems containing up to 1,000 modules (up to 300kWp, depending on the PV module size). Photo Plan allows you to put the PV array on a digital photo of the customer's house, while determining the roof size and pitch from digital photo. Size systems based on installation area, digital photos of the home, customer loads or desired kWp. Automatic inverter selection and string sizing, according to NEC temperature requirements. Automatic calculation of cable sizes and losses. Select

climate data via a map or ZIP code. Comprehensive financial analysis .Utility rates and incentives for all major US solar markets, pre-selected by the project location. Integrated database containing over 1,000 US climate locations, over 6,000 PV modules and 1,200 inverters. Automatic internet updates keep the database up-to-date.
Output: Customer reports containing system information, production details, system financials and photo realistic arrays. • System production data • Reformatted reports with user definable fields, tables and graphs • Financial analysis • Array layout • A digital image of the building with the array if using Photo plan
13) PV*SOL Expert:$1480
Description: The Dynamic Simulation Program with 3D Visualization and Detailed Shade Analysis for PV Systems
Ability: PV*SOL Expert makes it possible to carry out a 3D visualization of PV systems with shade calculation based on 3D objects. The program calculates the frequency distribution of the shade onto the roof area caused by the objects entered in the program. The results are shown in a graph. This makes it possible to reach a preliminary decision about the roof area to be covered. The visualization in 3D mode provides the user with vital information on the course of shade over a period of a day or a year.
Output: Simulation of shading in 10 minute intervals, Yield simulation takes account of the precise shading ratio for each module. Easy to use configuration of modules with inverters, Automatic and manual PV module roof coverage, taking account of restricted areas, Animated visualization of the course of shade for any point in time, Visualization of annual irradiation reduction for each point of the PV area, Optimization of PV module coverage and configuration corresponding to the shading situation.

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