MASTER

Present and future electricity generation : possibilities and restraints of large and small scale hydro power plants : case of the State of Kerala, India

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Preface

Due to back ground and interest it was my explicit wish to conduct M.Sc. research in India. The department of Technology and Development Studies (TDS) of the faculty of Technology Management (TM) of the Eindhoven University of Technology (TUE), eventually provided the opportunity through their collaboration project with the Cochin University of Science and Technology (CUSAT) in Cochin in the state of Kerala.

The original subject of my research was 'energy and its use in poor rural and urban households in Kerala'. In view of my technical discipline - physics - and the fact that I am also enrolled as a student in the first degree physics teachers course, part of the planned research had a strong technical focus. Circumstances beyond my control, however, made it impossible to execute the research as planned once I arrived in Kerala. In consultation with my first supervisor at TUE, and after having lost some months of valuable time, it was decided to shift the focus of the research to the energy situation in Kerala in general and the role of hydro power in electricity generation in particular. On my return to Eindhoven, I was requested to add an additional literature study in the field of small scale hydro power to my research.

Eventually, I spent seven months in Kerala. The first three months at the CUSAT campus in the Aiswarya Ladies Hostel: an interesting but tiresome and frustrating experience. After this period I moved to the Jyoti Hostel at the campus of the Rajagiri College of Social Sciences. Here I was well received and could focus on my work.

I am grateful for the assistance I received from many people. Some of them I want to thank in particular. Remy Bakker, who helped me trough hard times, for his love, support and the sharing of ideas in the process of writing. Dr.ir. P.E. Lapperre, dr.ir. W. van Helden and drs H. Gaillard of TUE - my supervisors during the preparation and execution of the research and the compilation of the report - for their assistance and patience. I particularly thank Paul Lapperre for his great help, inexhaustible motivation, support and sharing of ideas.

Thanks are also due to prof.dr. K.P. Vijaykumar of CUSAT - my supervisor in Kerala - and his wife Sudachechi. Marleen W. John and Shuby K. Joseph were my friends in the Jyoti Hostel. I thank them for their great company and their efforts to overcome some of the problems that arose. To the Principal, father J. Alex, and the warden, Ciziliy, both of Rajagiri College of Social Sciences, I am endebted for permitting me to stay at the Jyoti Hostel and to make me feel comfortable. Viji Varghese and Ramkumar Shyama I thank for their help, patience and frienship and this also applies to Beena G.K., Bindu R., Lakshmi M., Sindhu S. and Maya Pillai. Father Martien van Ooy and father Adriaan v.d. Wilk, priests of the Sacred Heart, and the boys of their seminar were very pleasant company indeed.

Last but not least I thank all my friends in the Netherlands who have helped me through my lonesome days by writing letters. Their interest and support have supported me in Kerala and the period that followed.

Mohini Keunen
April, 1998

Executive summary

1
PROBLEM SETTING

Officially India is a developing country (judged by its GNP/cap.) and in some aspects it is an industrialized one (judged by its industrial ranking). With respect to energy consumption, it is a real developing country. Although the total energy production is high, in comparison with the rest of the world, the energy consumption per head is very low due to the large population. The energy consumption is about 400 kg coal equivalent per inhabitant per year, compared to 6,000 kg coal equivalent for industrialized countries. The energy situation in general is not optimal and this also applies to the state of Kerala. Energy supply doesn't meet demand. Biomass, with almost 90%, is the main energy source used in Kerala. The biomass mix consists of fuelwood and a small part of crop residue. Electricity provides about 10% of the total power used in Kerala. Almost the only source of electricity generation is hydro power. At present there is a power shortage: the demand is higher than the supply. Due to the growing population and development, the electricity demand will only increase in the future. If no measures are taken the electricity shortages will become unmanageable. In addition, many more isolated parts of Kerala are likely to remain without connections to the power grid, thus depriving parts of the rural population from the benefits of this versatile energy source.

2
RESEARCH QUESTIONS

From the problem setting, four research questions were derived.

1. *What is the present energy situation in Kerala with respect to electricity?*
2. *What is the nature and size of expected electricity shortages in future and what possible role can hydro power play?*
3. *What is the present state of art with respect to small scale hydro power technology in the world?*
4. *Which designs of small scale hydro power plants would be most suitable in the Kerala context?*

The first question focuses on the available energy sources in Kerala and intends to investigate the present energy mix and distribution in Kerala. The second question intends to map the energy situation in the future and to determine the power shortage problem in more detail. The third question investigates the technical possibilities with respect to small scale hydro power. The fourth question intends to assess, on basis of the earlier results, which technology of small scale hydro power is the most adequate one to be used in future on suitable sites in Kerala.

3
EXECUTION OF RESEARCH WITH RESPECT TO THE RESEARCH QUESTIONS

Research questions 1 and 2.
Data were gathered by means of a literature study at CUSAT by visiting KSEB and ANERT. Furthermore, interviews with key persons were held. Data have been collected from different sources and a detailed analysis was needed to get a clear idea about the energy situation in Kerala now and in the future.

Research question 3.
The third research question was mainly answered by a literature study. The "wood stove methodology" of Prasad[1] was used to inventorise and analyse the different turbines. Furthermore, interviews were held with experts who have developed small scale hydro turbines.

Research question 4.
Data were gathered by means of a literature study and an analysis of the data followed. On basis of earlier results, a selection was made which technology of small scale hydro power is the most adequate to be used in future on suitable sites in Kerala.

4
FINDINGS WITH RESPECT TO THE RESEARCH QUESTIONS

4.1
Research question 1

The accuracy and consistency of the collected information, including a great variety of statistics, was erratic. Therefore, considerable efforts and time went into making tables and graphs as coherent as possible.

It is found that population growth (average annual growth rate 1.6%) is closely linked to the energy consumption. The population with its labour force is divided in 'small farmers', 'agricultural labourers', 'cottage industry' and 'other workers'. The sector 'other workers' (including medium and large scale industry, households, commerce and services) contains the main part of the working force in rural and urban areas.

The most common source of energy is biomass (88%), existing of fuelwood (78%) and crop residues (10%). Electricity is an important commercial source with about 10% of the consumption and LPG forms a small part with around 2%. Many villages in Kerala are already electrified and the necessary infrastructure is largely in place.

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[1] *Prasad, K. and Lepeleire, G. de (and others), A woodstove compendium, Woodburning stove group TUE, Eindhoven June 1981.*

The electricity generation depends mainly on hydro power plants, governed by the KSEBs. In total there are 11 major hydro stations, with 41 units and an installed capacity of 1492 MW (1995).

Until 1985, the electricity generation covered the electricity consumption. From 1985 onwards, electricity imports exceeded exports. The electricity supply depended on imports too, increasing to around 25% in 1995. The large gap between the generation and consumption is due to losses which vary between 20-50%. The growth of consumption can mainly be attributed to the domestic and industry sectors. The domestic sector had an annual growth rate of 6% and industry, which is relative large, had a growth rate of 2% in the period 1980-1995.

The electricity consumption per capita increased more than 3 times in the period 1980-1995. The total number of connections increased with a factor 3. The domestic sector is the largest one (72%) and has increased 3.5 times. In spite of the increasing connected load, the number of consumers increases even more rapidly. The domestic and industry sectors take most of the load (32% and 41% respectively in 1980). The domestic connected load increases twice as rapidly as the industry connected load in period 1980-1995.

The installed capacity increased in a number of steps. The available generated electricity is, however, much lower than the installed capacity. This is mainly due to the fact that stations run below installed capacity, peak demands and station losses due to break downs and maintenance. Furthermore, there are transmission and distribution losses, which decrease the available generated electricity too. The already projected demand for Kerala is estimated higher than the real consumed electricity until now. But even with the present consumption growth, the installed capacity will not meet the demand in the near future. Already now (1995) the supply depends for 25% on imports.

As we have seen, the domestic and industry sectors make up the main part of the connected load. However, the electricity consumption is relatively low for both sectors, compared with the connected load. The same occurs in the agriculture and commercial sectors, but the difference of connected load and electricity consumption in these sectors is smaller. The sector 'others' has the smallest difference between consumption and load.

4.2
Research question 2

The population projection for 2005 is 34.83 million people. The domestic sector covers 76% of the connections and the commercial sector 16%. The needed capacity (2005) will be 4500 MW to cover the power consumption of 3000 MW, due to station losses. While the estimated electricity generation will be around 2359 MW, due to transmission and distribution losses.

There are different estimates with respect to the total hydro power potential in Kerala and the plans to increase the installed capacity in the future. The hydro power potential can be placed between 2500 MW[2] and 6000 MW [3]. There is one plan to increase the installed capacity with 342 MW of hydro power and 220 MW of two thermal plants, contracted by the private sector, up to 1998. Then the power shortage will be 746 MW in year 2000 and even 2446 MW in year 2005 (see chapter 4). Other sources project no shortages at all since thermal power is expected to catch up with the growing demand. These plans for hydro and thermal power contrast with the plans to increase the capacity with a nuclear plant of 1000 MW. From the above, and chapter 4, it is clear that various plans to install various types of electricity generating technology contradict each other. In addition, or maybe even as a consequence of this, also projections contradict.

However, of one thing we can be certain: power shortages can vary between 2000-3000 MW in the year 2005. These shortages cannot be covered by hydro power only because of the limited available hydro power potential in Kerala.

4.3
Research question 3

In early days hydro power water-wheels were used to generate mechanical energy. Later to generate electricity. Due to the severe restrictions of water-wheels, water turbines were invented in the nineteenth century. With these it is possible to extract more energy from the same quantity of water compared to water- wheels. This is mainly due to the use of higher heads. An additional hydro power device is the hydram. A hydram is an automatic pumping device which utilizes a small fall of water to lift a fraction of the supply flow to a much greater height. Hydrams are mostly intended for water supply duties.

Theoretically, the power potential depends on the head and the flow rate. The real power output, however, depends also on the efficiency of the turbine.

There are two types of turbines: impulse and reaction turbines. In addition there are reverse working pumps which can act as turbines. Turbines can be classified according to the flow of water through the turbine. This flow can have an axial or a radial direction. Turbines also relate to the working head. The table shows a summary of the various types of turbines presently available world wide.

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[2] *CMIE, Economic Intelligence Service, India's energy sector, September 1996.*

[3] *Western Ghats co-ordinated Research Programme Committee, Feasibility survey of micro and mini hydel potential in Kerala, Thiruvanathapuram May 1985.*

	Impulse turbines		Reaction turbines	
Head	Radial flow	Axial flow	Radial flow	Axial flow
High	Pelton Multi-jet pelton			
Medium	Crossflow Turgo Multi-jet Pelton		Francis Volute-cased	
Low	Crossflow		Francis Open-flume Propeller Vertical-shaft Kaplan	Propeller Tube Propeller Geared-bulb Propeller Ungeared-bulb

For the reverse pump turbines, there are two pumps, both with a radial water flow: the Turbine Centrifugal pump and the Mixed-flow pump. A completely new invention is the 'Firefly' turbine, a small scale hydro turbine, which is still rather unknown.

The main components of a hydro power installations are a river, weir, intake, canal, forebay, penstock, power house with the turbine and a tailrace back into the river. Other components are used to improve and suit the hydro power plant to the wishes of the users.

The principles of the various types of turbines were worked out in such a way that one can compare the turbines to choose the most suitable one for a specific location and specific other conditions such as ease of manufacturing and operating complexity.

The auxiliary components of a turbine are the governor, the drive and the generator. Civil works have to be carried out before one can implement a hydro installation.

4.4
Research question 4

According to the findings when answering the earlier research questions, the power shortage in Kerala cannot be solved by hydro power only. Other possibilities are the installation of thermal plants, nuclear plants or wind plants. The problem of these plants is that there is almost no experience with this technology in Kerala.

To meet the power shortage as much as possible in the near future, and with a focus on the more remote rural areas, small scale hydro power is a solution. The big advantage is the short building time and the relatively low costs, compared with large scale hydro power plants. Already 44 suitable sites for mini and micro hydro plants have been located, with a total capacity of 150 MW.

Suitable turbines are chosen via general characteristics for small scale hydro power. For example, the part flow efficiency has to be good because small water flow variations are immediately noticeable. Furthermore, the suitable sites have general similarities, like the head. The sites are distributed according to the available head.

5
CONCLUSIONS AND RECOMMENDATIONS

5.1
Research questions 1 and 2

The collection, storage and particularly processing of information is in a deplorable state. For example, different units of measure are used, data series do not match and a lot of 'writing errors' exist. It is recommended to improve collecting and processing of statistics at all relevant levels (production, organisations, districts and state). This will greatly increase the reliability of the policy instruments to be designed.

The existing power shortages will increase in the future, with domestic and industry as main sectors. In the future, these sectors have to compete because the growth rate of consumption is higher than the growth rate of connected load. Therefore, the domestic sector can only grow at the expense of the industry, which reduces its consumption share. Domestic and agriculture sectors are highly subsidised and this influences the consumption pattern considerably. By changing the price mechanism to a more realistic one, one controls and affects the consumption. The consumption growth of the domestic sector will slow down as a consequence of higher electricity prices.

The electricity generated is much lower than the installed capacity, mainly due to maintenance and break down losses. But even if all power stations work at 100 per cent, the installed capacity will not be sufficient in the near future. Furthermore, there is a limited possibility to cover higher peak demands and generate more electricity in the future.

Increasing the total installed capacity, in order to solve the power shortages, by large scale hydro power plants, is not possible. Mainly due to the limited available potential and disadvantages of large scale hydro power plants. Although it is not possible to solve the shortages it is, however, possible to bring further development to remote rural areas via small scale hydro power .

5.2
Research question 3

At present there are 12 types of hydro power installations operational in the world, which are classified on basis of turbine type, water flow and head. Apart form the 'Firefly', very little development has taken place with respect to small scale hydro power in the past 15 years. The 'Firefly' in principle is a Crossflow turbine and its advantages are that it is small and not heavy, easy to produce and cheap because it can be made of locally available material. The 'Firefly' is recommended for further investigation, because it is still an unproven technology.

Furthermore, Mixed-flow pumps and Centrifugal pumps can be used as turbines in reverse operation, however, little literature could be found on this type of turbines. In view of the cheapness of the pumps, it is recommended that these aspects are further investigated.

5.3
Research question 4

Although small scale hydro power cannot solve the power shortages, it has an application field in rural areas. Mainly because of its short building time, low investment costs, the fact that no foreign exchange is required, damage to environment is kept minimal and access to remote and rural areas is easy. Furthermore, there is no need for long transmission lines, so transmission and distribution losses are lower, operation of the stations is simple and little maintenance is required.

A survey revealed that there are already 44 suitable sites for small scale hydro power identified, with a total generation capacity of 150 MW. The suitable sites are for 20 sites situated in mountainous areas and for 24 sites in low land areas. For the mountainous areas, the 6-jet Pelton, the Turgo, the Crossflow, the Propeller Tube and the Propeller Geared-bulb are recommended. In the low land areas, the Crossflow, the Francis Open-flume and the Propeller Tube designs are most suitable.

These recommendations apply to the design of installations with respect to parameters as head, water quantity and regularly of flow. Detailed feasibility studies are necessary for the accurate size of installations, infrastructural works and auxiliary equipment.

Review of contents

List of tables, figures and maps

1
TABLES

2
FIGURES WITH ACCOMPANYING TABLES IN APPENDIX E

3

FIGURES ONLY

4

MAPS

List of abbreviations and glossary

1
ABBREVIATIONS

AC	: Alternating Current
ANERT	: Government Agency for Non-conventional Energy and Rural Technology, Trivandrum, Kerala
CICA	: Centre for International Co-operation Activities
CMIE	: Centre for Monitoring Indian Economy
CUSAT	: Cochin University of Science and Technology
DC	: Direct Current
ECN	: Netherland's Energy-research Centre
EHT industry	: Extra High Tension industry
GDP	: Gross Domestic Product
GNP	: Gross National Product
HT industry	: High Tension industry
IREDA	: Indian Renewable Energy Development Agency
IREP	: Integrated Rural Energy Planning Programme
KSEB	: Kerala State Electricity Board
KIT	: Royal Institute of the Tropics
LT industry	: Low Tension industry
NEPC-MICON-limited	: Non-governmental Organisation for Wind energy
Novib	: Netherland's Organisation for International Developing Co-operation
PLF	: Plant Load Factor
RPM	: Revolutions per minute
SHP	: Small Hydro Power
SKAT	: Schweizerische Kontaktstelle für Angepaste Technik, St. Gallen, Switzerland
TDS	: Technology and Development Studies
TERI	: TATA Energy Research Institute
THT	: Twente College of Technology
TM	: faculty of Technology Management
TUE	: Eindhoven University of Technology

2
GLOSSARY

Current Equivalent
Indian Rupees 35 = 35 Rs = US $ 1.0 (as of October 1996).
Indian Paise 100 = 100 Ps = Indian Rupee 1

Unit of measurements

Crore	: 10,000,000 units
GJ	: Giga joule = 10^9 joule
GW	: Giga watt = 1,000,000 kilo watt
HP	: Horse power = 746 watt
Hz	: hertz = cycle per second
kVA	: kilo volt ampere, equivalent to kW at a power factor of 1
kWh	: kilo watt hour
Lakh	: 100,000 units
MkWh	: Mega kilo watt hour = 1,000 kilo watt hour = 0.0036 PJ
MTOE	: Million Tonnes of Oil Equivalent = 42.5 PJ
MW	: Mega watt = 1,000 kilo watt = 0.0315 PJ
P	: Peta = 10^{15} units
Ton	: 1,000 Kg
Watt	: joule per second
Micro	: installed capacity up to 100 kW
Mini	: installed capacity of 101 - 2,000 kW
Small	: installed capacity of 2,001 - 15,000 kW
Large	: installed capacity of more than 15,001 kW

Chapter 0
Theoretical Framework

0.1
PROBLEM SETTING

General

In some aspects, India is still a developing country, whilst in others it is an industrialized nation. Industrialized, for example, in view of its extensive industry and advanced technology in the fields of space travel and nuclear research. Furthermore, India ranks high among the nations of the world in her endowments of technical and scientific personnel.

Developing if one looks at, for example, population growth, literacy, BNP per capita, energy consumption and electricity use. The average population growth is high with 2.1% per annum in 1994. The illiteracy rate is about 48% and the BNP per capita was $300 in 1993, compared with $20,950 for the Netherlands. The total energy production (like electricity generation, coal production and petroleum production) is very high in India, compared world wide. But the energy consumption per head is very low, due to the large population of India. The energy consumption is about 400 kg coal equivalent per inhabitant per year for India, with an average of 6,000 kg coal equivalent for industrialized countries. The electricity consumption per head is 327 kW per year, whilst the average available electricity per head in the world is 2,234 kW per year (1994).

The energy situation is not optimal in India. The energy supply doesn't meet the demand. More than fifty per cent of the population has to provide their own energy. There is little money to buy energy and there are not always energy sources available to buy. Furthermore, the population grows faster than the direct available energy sources. Due to the fast growing population, the energy demand will only increase in the future. The main source of energy is biomass, which covers more than 50% of the energy consumption. The electricity provision has problems too, because the electricity demand exceeds the electricity supply. The electricity demand will only increase in the future by, among others, the fast growth of the population. The main sources for electricity generation are thermal plants and hydro plants, with a distribution of respectively about 70% and 25%. Hydro power is a sustainable energy source, contrary to thermal power of which the supply can run out. Hydro plants generate about 21 GW. This is a small part of the total hydro potential -83 GW- in India. Consequently there are possibilities to extend the hydro power generation capacity.

Kerala

Kerala is a relative small state of India. The research has been conducted in the state of Kerala. Mainly due to contacts of the TUE with the Cochin University of Science and Technology (CUSAT) in Kerala.

In a few aspects, Kerala is an exception compared with India or other states within India. Kerala is the most developed state, due to the followed policy. It has a communist government. The high development level can be seen by looking at different aspects, like the highest literacy rate of India, the low unemployment rate, the lowest infant mortality, low birth rate and death rate. Kerala has a literacy rate of around 90%. Furthermore it's the most densely populated state of India (747 persons per km^2) and the relatively equitable distribution of land and income is found rarely to the same degree elsewhere in India. The population growth rate of 1.5% per year, is significantly lower then in the rest of India.

The energy situation is not optimal in Kerala, like in India the supply doesn't meet the demand. Furthermore, the population depends for almost 90% on biomass. Electricity provides the remaining 10%. Other used energy sources contain only a relatively small part of the total energy mix. Hydro-electric generation is the main source for electricity and thermal plants generate a small part. Officially it is even only hydro power which supplies the power. At present there is a power shortage, that is the demand is higher than the supply, whilst supply already depends on imports. This shortage will increase by the growing electricity demand in the future, due to, for example, the growing population. To solve the gap between the demand and supply, the supply has to be enlarged. There are different ways to do this, for example with additional capacity, reducing losses or building new plants. Something has to be done to face the power gap.

0.2
RESEARCH QUESTIONS

From the problem setting, a number of research questions were derived. The focus of the research was not only determined by the problems outlined in the previous paragraph but also by the nature of my study programma and my technical discipline. The study 'Technology and Development Studies' combined with Physics, is an unique integration of Physics and social aspects. The target of the study is to be able to deal with development problems in developing countries. Because of the Physics background, the facing development problems have technical aspects. Often the optimal solution is to take into account both the technical possibilities and the social and cultural possibilities. Energy problems are situated in the Physics area, if you look at the efficiency of energy conversions or for understanding the principles and working of energy conversion plants.

The research questions are:

1 *What is the present energy situation in Kerala with respect to electricity?*
1.1 What are the major sources of energy in Kerala?
1.2 What information is available on energy supply and demand and what is the accuracy of this information?
1.3 What infrastructure is available for electricity production and consumption?
1.4 How many electricity consumers and electricity connections are there now and are expected in the future?
1.5 What is the installed, generated and utilized electricity capacity?
1.6 What are the major pricing mechanisms?

2 *What is the nature and size of expected electricity shortages in future and what possible role can hydro power play?*
2.1 Which role does hydro power at present play in the electricity generation?
2.2 How are connections and population distributed?
2.3 What is the expected growth of the consumers and how does this influence the electricity demand in the future?
2.4 What is the expected needed generated electricity in the future?
2.5 What is the expected needed extension of the installed capacity?
2.6 What is the policy of extending the installed capacity?
2.7 What are the possible ways to cover shortages?

3 *What is the present state of art with respect to small scale hydro power technology in the world?*
3.1 What is the historical background of hydro power?
3.2 What is small scale hydro power?
3.3 What are the turbines used at present in the world?
3.4 What are the major principles of hydro power plants?
3.5 What are the auxiliary components of hydro power plants?

4 *Which designs of small scale hydro power plants would be most suitable in the Kerala context?*
4.1 What are the advantages and disadvantages of small scale hydro power compared with large scale hydro power?
4.2 What is the small hydro power potential and are there suitable sites?
4.3 What are the most suitable turbines with respect to head on the sites?
4.4 What are the most suitable turbines with respect to water flow on the sites?

0.3
METHODOLOGY

The research questions were approached in the following ways:

Research questions 1 and 2.
The first question deals with the available energy sources in Kerala and the present energy mix and distribution in Kerala. The second research question looks at the energy situation in the future and to determine the power shortage problem in more detail. Data were gathered by means of literature study and interviews with key persons. Data were not centrally available and had to be collected from a great variety of sources. Key persons had to be located and interviewed and organisations had to be visited. All these different data and information (see Appendix A) had to be analysed to get a clear idea about the energy situation in Kerala.

Research question 3.
The third research question was answered mainly by a literature study to establish the technical possibilities with respect to small scale hydro power. The "wood stove methodology" of Prasad[4] has been used. Furthermore, experts were interviewed in the field of small scale hydro power.

Research question 4.
This research question was aimed to assess, on basis of the earlier results, which technology of small scale hydro power is the most adequate to be used in future on the suitable sites in Kerala. Data were gathered by means of a literature study. Data were analysed and conclusions were drawn.

0.4
REVIEW OF CHAPTER CONTENT

Chapter 0 contains the theoretical framework of this report, with the problem setting, the research questions and the methodology.

Chapters 1 and 2 contain general information about the country India and the state Kerala. They provide the opportunity to see the similarities between India and Kerala and the differences. For easy reference, occasionally the Netherlands are used for comparison.

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[4] *Prasad, K. and Lepeleire, G. de (and others), A woodstove compendium, Woodburning stove group TUE, Eindhoven June 1981.*

Chapter 3 explores the energy situation in Kerala and explains the situation of the energy sources and the role of electricity. The chapter is based on the physical infrastructure - availability and accuracy of information - electricity generation and consumption - consumers and connections in numbers - installed capacity, generated capacity and utilized capacity - review of pricing mechanism. The chapter ends with an analysis of the situation.

Chapter 4 presents a brief overview of the electricity shortages in the future and highlights how desperate the situation is.

Chapter 5 is a technical overview of all presently available small hydro power technology. The turbines have been ranged schematically in such a way that it is possible to compare turbines and their specific characteristics. The chapter gives a historical review of hydro power, types of turbines, working principles of the various types of turbines and auxiliary components of turbines.

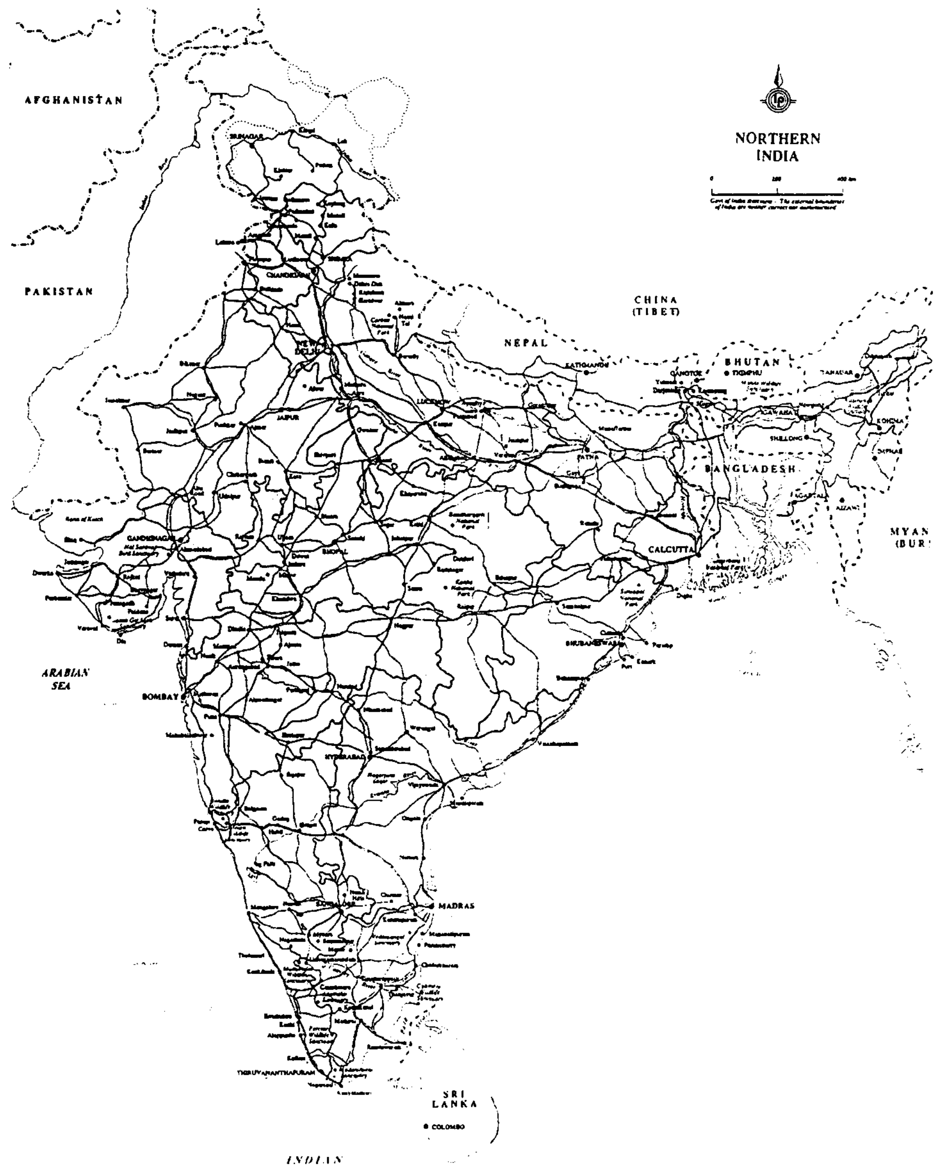
Chapter 6 deals with the hydro power possibilities in Kerala. The chapter is based on the electricity supply and demand (present and future), supply shortages, possible ways to cover shortages, small scale hydro power, small hydro power in different locations, suitability for different locations and feasibility. The chapter contains a map of suitable sites for small hydro power.

Chapter 7 is a conclusion of the energy situation in Kerala. Furthermore, it contains recommendations with respect to the energy problems and how to face them the best way possible in future.

Chapter 1
India

1.1
General

Presently, the Indian Republic - Bharat Juktarashtra (Indian Union) - comprises 25 states and 9 centrally governed territories. It is a central Asian state, bordered on the northwest by Pakistan, on the northeast by China, Nepal and Bhutan and in the east by Burma. The north eastern part of India encloses Bangladesh completely. Map 1.1 shows how India is situated in the region.



Map 1.1
India in the Asian region.

Source: Crowther, G. and A Raj, P.., India - a travel survival kit, 5th edition, Lonely Planet Publications, London July 1993.

The capital city is New Delhi, with 10.1 million people. Other big cities are Bombay[5], Calcutta, Madras, Hyderabad, Bangalore, Ahmedabad, Pune and Kanpur. All these have several millions inhabitants.

There does not exist an 'Indian' language. The official languages spoken in India are English and Hindi. Hindi is the most spoken national language. Furthermore, there are a great number of local languages. In total there are 18 languages officially recognised by the constitution, and these fall into two major groups: Indic or Indo-Aryan (like Hindi and Bengali) and Dravidian (for example Tamil and Telegu). Almost three quarters of the population speaks an Indo-Aryan language and the other part a Dravidian language. There were over 1600 minor languages and dialects listed in 1991. Thirtyfour per cent of the total population speaks Hindi, 8% speaks Marathi and 9% speaks Bengali.

1.2
POPULATION

India has a total surface area of 3,287,263 km^2, by which it is the 7th largest country in the world. India has the second largest population, exceeded only by that of China. The population of India was approx. 879.5 million people in 1994[6]. For 1995 it's estimated that the population will be 930 million[7]. The average population growth rate is around 2.1% per annum. In 1994, 27% of the people lived in urban and 73% in rural areas. By the year 2000 the population is expected to exceed 1 billion and about 350 million people will live in cities. Many parts of the country are overpopulated. This is not surprising, because the country covers only 2.4% of the whole land area in the world, whilst almost 15% of the total world population lives in India. More than half of the population lives on 23.2% of the total land area. This overpopulation obstructs (economic) development seriously.

1.3
RELIGION

There is a great variety of religions. India is the cradle of Hinduism (practised by 83% of the total population) and Buddhism (1%). It has to be noted that Hinduism brought, via the caste system, a basic social inequality. Besides these two religions, numerous other religions are present: Islam (11%), Sikhism (2%), Christianity (2%), Jainism, Zoroastrianism/Mazdeism and Judaism (together about 1%).
Tensions initiated by religion are present, especially between Sikhs and Hindu and Muslim and Hindu. These religious frictions escalated in the past. At the moment,

[5] *The names of cities have been changed. For example Bombay is named Mumbai. See appendix B for other names.*

[6] *Kindersley, D., World Reference Atlas, 1994, pp. 270-274.*

[7] *Finley, H. and Wheeler, T. (and others), India - a travel survival kit, 6th edition, Lonely Planet Publications, London January 1996, p. 47.*

widespread, religious agitation is not present.

1.4
POLITICS

India gained its independence in 1947 and British rule left an economy which had been stagnant for more than 70 years. The political structure was based on the English one. The political structure of India is one of central and state parliaments and cabinets. The central political structure consists of the Lok Sabha (lower house), which is directly elected and the Rajya Sabha (council of states), which is indirectly elected by the state assemblies. Elections for the Lok Sabha are to be held every five years, or on government's call. The Prime Minister is the leader of the country.
The 25 states and 9 union territories have a state government with legislative assemblies, the Vidhan Sabha. State government activities are restricted to the areas of education, agriculture, police force and industry. Other areas are jointly administered. The central government always has the right of 'President's Rule': taking over power in a state that is deemed to be unmanageable.

The economic crisis which occurred around 1990, resulted in fundamental policy changes. The most important of these are the improved possibilities for foreign investment, the privatization (although at a slow pace) of parastatal enterprises and the reduction of subsidies in order to reduce the government's budgetary deficit. The implementation of these new policies, however, proceeds slowly.

Also the government of India has introduced several structural reforms in the infrastructural sectors. In the power sector, a package of incentives to attract and involve the private sector in investing into power generation, has been announced. This package includes the reduction of import duties on power equipment to 20%, a 5-year tax holiday for new power projects, a guaranteed 16% rate of return on paid up and subscribed capital and the provision of guarantees by the Central Government.

1.5
ECONOMY

Today, the economic performance of India in volume places it on the 12th position worldwide. However, this does not mean that India is a well developed and leading economic power, able to provide sufficient wealth and well-being for its inhabitants. In 1994, the GNP and the GNP per capita were respectively US$ 285 billion and US$ 324. India, therefore, finds itself among the lower income countries such as Pakistan, Nigeria and Kenya. Over the last decade, the average growth of GDP per annum was 5%.

The Indian economy is a mixed one, governed by 5-year plans, since 1951. In this mixed economy, state owned and private enterprises operate simultaneously. The parastatals are, among others, found in energy supply, banking and railways and have the primary function of providing favourable conditions for the private enterprises. The size and profitability of the private sector exceeds that of the parastatal one.

In the period before the 5-year plans (before 1951), the Indian economy was not fixed on economical growth, but it was a typical self supplying economy. The goal of the 5-year plans is to control the development at the long term and to achieve fixed growth in the economy of the agriculture sector, industry and the energy supply. In the sixth 5-year plan (1980-1985), the attention was focused on the transport sector, the energy supply and the heavy industry. For example, with nearly 85% of India's population living in 579,000 villages in the country, electrification is one of the main infrastructural needs of the rural people. The 8th 5-year plan ends March 1997. Target of the 8th plan is to install new capacity of 30,500 MW, but the expected achievement is around 17,700 MW. During almost all the 5-year plans, the deviations vary between 20-50%. Thus power shortage is likely to continue well into the next century.

Although India is a predominantly agricultural country - 70 per cent of its inhabitants depend on agriculture - it also has a large manufacturing base. Whilst the manufacturing sector modernizes, the agricultural sector appears to be rather stagnant. In a way this is a pity, since investments in agriculture result in 3 to 3½ times more production and 8 times more jobs than investments in industry[8].

1.6 EDUCATION

The British system is still prominently present in today's educational system. Although differences between the states exist, the most common advanced path is (8+2)+2+3 years of education.

The average illiteracy rate is about 48%. One of the reasons for the high illiteracy rate is, for example, that the primary education, although compulsory (8 years), is not capable to provide the basic education promised, due to, for example, lack of facilities and teachers. Furthermore, the quality of the state run schools is low, the drop-out rate in primary education is more than 60%. The economic dependence of households on children, low quality of primary education and the low priority given to education by the Indian government until 1986 and the budgetary constraints afterwards, are reasons of this high drop-out rate. The average ratio teacher/student is about 1:40 for primary education and 1:34 for upper primary education.

[8] *Novib, Landelijke India Werkgroep, India, Den Haag 1982.*

In secondary education, 2 years after the primary, the vocational streams are underdeveloped. Many secondary education students are unemployed, since the labour market is not prepared to absorb large numbers of generally educated students.
The general education of 10 years, can be continued by 2 years of senior secondary education, preparing pupils for undergraduate college. This is followed by 3 years of undergraduate college. These contain the beginning of scientific education. That can be completed in 2 years of higher scientific education.

It is strange that most attention is focused on higher education and that there is almost no attention for lower and medium education. Whilst around 48% of the population is illiterate. Note the criteria: somebody who can write his own name is a literated person.

1.7
ENERGY

The actual situation in India with respect to the energy supply and demand is far from optimal. The energy demand is higher than the energy supply and more than 50 per cent of the population has to provide its own fuel to get energy. Many people can hardly afford to buy fuel, because they have little money. So an important part of energy use are the non-commercial energy sources like wood, dung and agricultural waste. This type of energy is used mainly by households.

Table 1.a shows the total available energy sources in India and the targets of power generation in the 8th 5-year plan (1992-1997) by the government, including the private sector, 1995.

Table 1.a
Available energy sources and targets of power generation in 8th 5-year plan in India (1995).

Source	Power potential	8th plan targets, power generation
Coal reserve	30,900 MTOE (6% of world's reserves)	
Oil reserve	8,298 MTOE (0.59% of world's reserves)	
Natural gas reserve	7,698 MTOE (10% of world's reserves)	
Total solar output over the land mass solar photovoltaic solar thermal power	$5*10^{15}$ kWh/year	 25 MW 30 MW
Draught animal power	30,000 MW	
Biomass/bioenergy	17,000 MW	500 MW
Cogeneration	8,000 MW	300 MW
Wind power	20,000 MW	500 MW
Ocean thermal power	50,000 MW	
Tidal power	10,000 MW	
Sea wave power	20,000 MW	
Hydro power	84,000 MW	
Small hydro power (mini-micro)	10,000 MW	600 MW

For the decades to come, coal, oil and gas resources are sufficient. For example with a consumption growth of 4 per cent per year, the coal resources will last for 130 years.

If 1% of all solar energy, that is available to India, is utilised and converted into electricity with an efficiency of 10%, this covers 35 times the present energy demand of India. There is an attempt to harness this as-yet untapped source through the solar-thermal route and through solar photovoltaics. It's input, however, will remain small.

Furthermore it is clear that animal power is still an important source of energy.

The present total energy consumption relies for about 57% on biomass use in the whole of India. There is a potential availability of 12 million biogas plants and 120 million improved chulhas (cooking stoves). Every year, biomass plants store 10 times the present annual consumption of energy. However, most of this energy is used inefficiently due to technological and economic constraints. The target is to generate 500 MW power via biomass.

Co-generation is aimed at optimizing surplus power generation through upgrading boiler pressures and improving efficiencies. It saves an interesting part of power. It is used for the power generation in the 8th 5-year plan.

Wind energy is available in limited areas. These areas cover only 5 per cent of the total area of India. The target is to harness 500 MW wind power, in the 8th 5-year plan.

Ocean thermal energy (use of temperature differences of nearly 20 degrades Celsius between warm surface and deep cold water, at depths of 1 to 2 km) constitutes an important part of the available sources. The Indian ocean has a vast potential of 50,000 MW and there is an enormous opportunity to tap this renewable source of energy. However, worldwide, this technology is still in its infancy.

Tidal power covers a small but important part too. The possibility to harness tidal power is unknown at present. Here also, further development will only take place in the medium to long term future.

Harnessing of sea wave energy is explored by Sea Power AB of Sweden. A demonstration Oscillating Water Column plant of 150 kW has been installed by KSEB, and in technical collaboration with another organisation in Madras, in 1993 at Vizhinjam (Kovalam Beach) near Trivandrum, Kerala[9]. No information is available about potentials. This technology is still in its infancy.

Hydro electric power has a large power potential. Small hydro power covers a small part, but still an interesting part. The target is to generate 600 MW by small hydro power in the 8th 5-year plan. At present, the power generation depends on hydro power for about 25 per cent.

The present distribution of generating capacity -1996- consists of only hydro, thermal and nuclear plants. The hydro plants generate 20,976 MW, 60,087 MW is generated by thermal plants and 2,225 MW by nuclear plants (situated in Tarapur, Kota, Kalpakkam and Norara). The thermal plants generate the main part (71 per cent), hydro power about 25 per cent and nuclear plants only a small part (3 per cent). The owners of the total generating capacity are for 65 per cent the States, 31 per cent the Central Government and only 4 per cent the private sector.

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[9] *KSEB, Annual plan '96-'97 proposals, Trivandrum December 1995.*

Chapter 2
Kerala

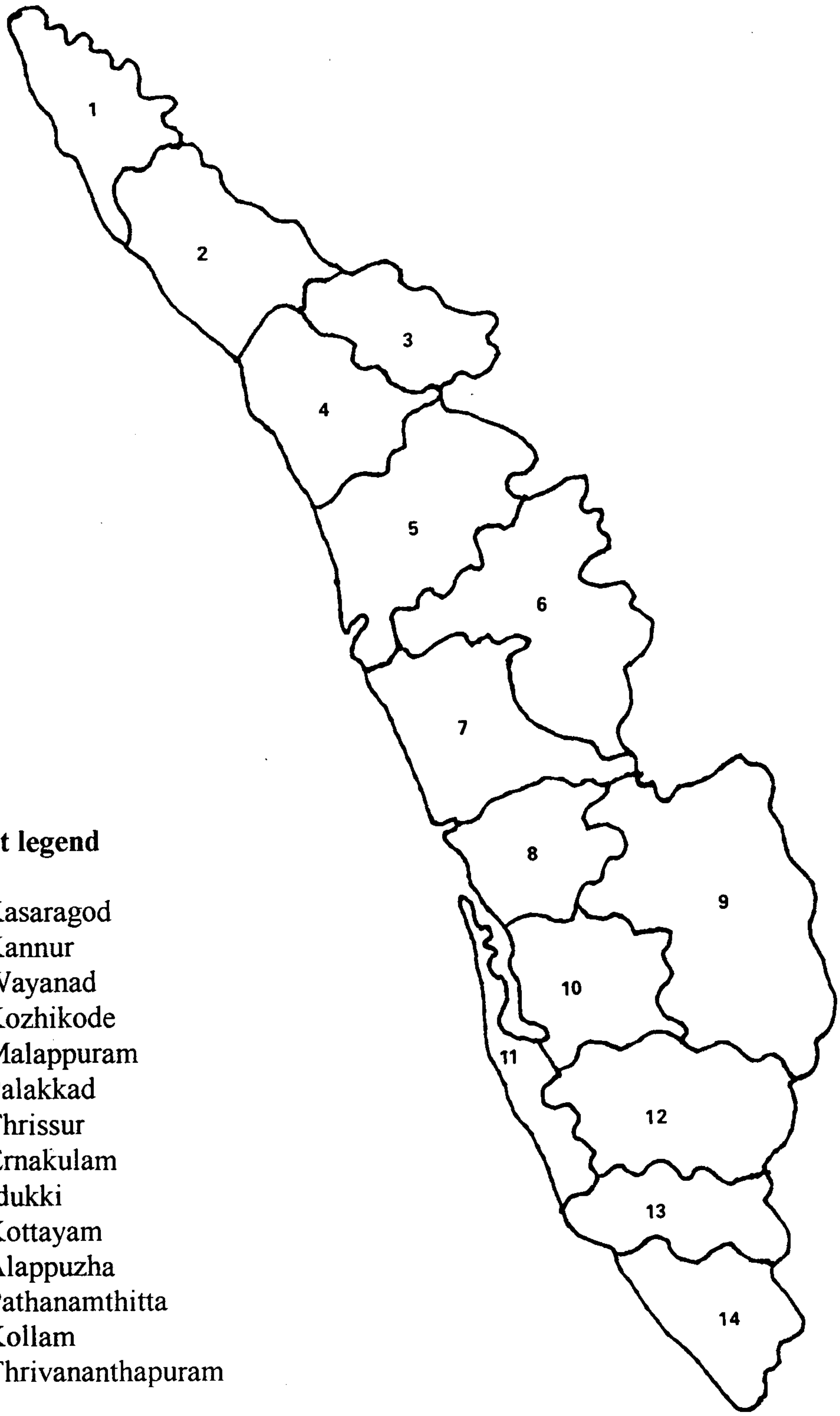
2.1
GENERAL

The state Kerala is situated on the south-west coast of India. In the west is the Lakshadweep Sea and in the east the Western Ghats (mountains). The neighbour states are Tamil Nadu in the east and Karnataka in the north. The Western Ghats have sheltered Kerala from invaders from the rest of India and at the same time have encouraged Keralans to welcome maritime contacts with the outside world. Furthermore, Kerala is famous for its backwaters and lakes. The road density, compared with other states, is highest in Kerala.

Kerala has, divided over 14 districts, a total surface area of 38,864 km^2. The capital city is Thiruvananthapuram. In table 2.a the overall, urban and rural population and the density per district is presented. Map 2.1 shows Kerala and the distribution of the districts.

Table 2.a
Statistics about overall, urban and rural population and the density per district in 1991.

No.	District	Total population	% urban pop.	% rural pop.	Density, pers./km^2
1	Kasaragod	1,070,629	16	84	537
2	Kannur	2,244,819	51	49	757
3	Wayanad	671,195	3	97	315
4	Kozhikode	2,612,897	38	62	1115
5	Malappuram	3,093,190	9	91	871
6	Palakkad	2,376,160	16	84	530
7	Thrissur	2,734,333	26	74	902
8	Ernakulam	2,797,779	49	51	1162
9	Idukki	1,076,555	5	95	214
10	Kottayam	1,819,581	18	82	826
11	Alappuzha	1,990,603	31	69	1408
12	Pathanamthitta	1,186,628	13	87	449
13	Kollam	2,398,285	19	81	962
14	Thiruvananthapuram	2,938,583	34	66	1341



District legend

1 Kasaragod
2 Kannur
3 Wayanad
4 Kozhikode
5 Malappuram
6 Palakkad
7 Thrissur
8 Ernakulam
9 Idukki
10 Kottayam
11 Alappuzha
12 Pathanamthitta
13 Kollam
14 Thrivananthapuram

Map 2.1
Kerala and the distribution of the districts, 1990.

Source: KIT, Personal Atlas of India, 1985.

The most important language is Malayalam, spoken by the majority of the population (around 95%). A small minority speaks Tamil (1%), the language of the neighbouring state Tamil Nadu.

2.2 POPULATION

In 1991, the total population in Kerala was 29 million, of which 26 per cent was urban and 74 per cent rural, with an average growth rate of 1.3% annually. Kerala is the most densely populated state of India, with 747 people per km^2. It has the lowest infant mortality and a low birth and death rate. It is also the only Indian state in which females outnumber males (sex ratio is 1040 females/1000 males), though the main reason for this is the number of males who have gone to work in the Gulf oil fields before returning home to settle down.

2.3 RELIGION

The population of Kerala is about 60% Hindu, 20% Muslim and 20% Christian. There is a minority of Jewish people. Kerala's main Christian area is in the central part of the state, around Cochin and Kottayam. Hindus are mainly concentrated in southern Kerala, around Thiruvananthapuram, though Muslims are also a prominent and vocal component of the population in this area. The main Muslim area is in the northern part of the state, particularly around Kozhikode. The Christian people mostly work in the education and health care sectors.

2.4 POLITICS

Kerala was the first place in the world to freely elect a communist government (1957), which remained in power until now. The relatively equitable distribution of land and income, found rarely to the same degree elsewhere in India, is the direct result of successive communist governments.

The government works with 5-year plans. At present, the 8th 5-year plan (1992-1997) is in effect. The policy in the power sector is to attract private investment via a package of incentives, ordered by the Central government.
Incentives from the Central Government to the States for wind energy include a 5-year tax holiday on wind projects, 100% accelerated depreciation and exemption of concessional duties on wind electric generators.
The ministry provides a subsidy of up to 50% of the cost on electrical, mechanical and civil works.

2.5
ECONOMY

The economy is predominantly based on agriculture. The most important products are cane-sugar, rice, pepper, cacao, tea, coffee, ginger and cashew nuts. The forests yield teak, sandal and ebony wood. The fishery sector is important for the economy too.

As the state's income grows, the infrastructure (in all sectors) increases. Infrastructure is for example services from public utilities (power, telecommunication, piped water supply, sanitation and sewage, solid waste collection and disposal, and piped gas), public works (roads and major dam and canal works for irrigation and drainage) and other transport sectors (urban and interurban railways, transport, ports and water ways and airports). Despite all this, Kerala has the highest unemployment rate in India. Unfortunately little information is available about the origin of the high unemployment. One reason was presented in paragraph 1.6 on education.

2.6
EDUCATION

The literacy rate of the population is 91% - counting all people above 7 years old - and is the highest in India (males 94 per cent and females 87 per cent). These results have been achieved without spending a higher proportion of income on health or education than other states. This is a result of the sort of policy in the State of Kerala: the communist government policy.

2.7
ENERGY

Kerala mainly depends on hydroelectric power plants and to a small extent on thermal plants. Kerala has a large hydro potential.

The only other source which is available in plenty is sunlight. The potential production of biomass is very high because there is a combination of sunlight and water.

There are no nuclear plants in Kerala at present. The sand of Kerala contains 83% of the world reserve of Thorium. So there is a possible perspective in the future, when the nuclear power generation is developed further. With the present technology, Uranium is used as fuel.

Furthermore, the human resources of Kerala are considerable, because it is a very densely populated state.

To tap wind energy, the wind speed, land availability and the existence of a grid to tap the generated power, have to be sufficient. The land area required for a 1 MW wind energy project is around 10 hectares potential site with wind speeds of over 5 m/s. There are 7 potential sites for wind mills in Kerala, with a wind speed varying between 5-8 m/s. A wind farm demonstration project of 2 MW is already operative.

At present, there are fixed power cuts twice a day, since January 1996. The power cuts are distributed in different areas in Kerala each cut at a different time. Besides the power cuts, the power supply fails often, varying from a few minutes to hours a day, which is very disruptive for industry and services.

Chapter 3
Kerala Energy Situation

3.1
General

Rural and urban population growth, population density, the geographical distribution of the population and the distribution of the working population over the various sectors of economic activity, all affect, in one way or another, various aspects of energy generation, consumption and distribution. Therefore this aspect is covered here prior to further details on energy. Figure 3.1 presents the overall, rural and urban population growth in Kerala in the period between 1971 and 2005. The growth figures from 1994 onwards are projections based on an annual growth percentage of 2.6 and 0.7 per cent for respectively the rural and urban populations.

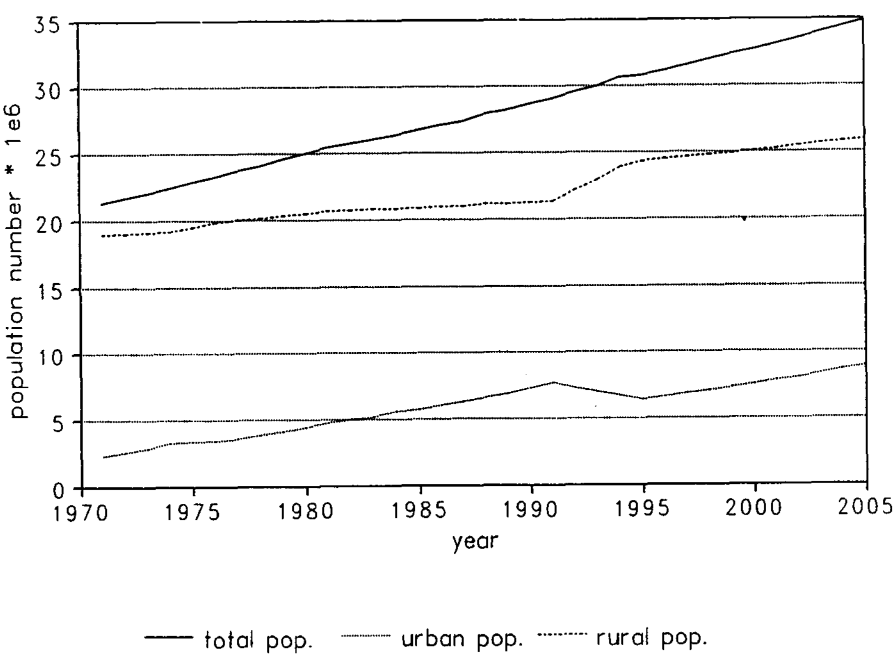


Figure 3.1
Overall, rural and urban population growth in Kerala in the period 1971-2005.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

From figure 3.1, it can be seen that between 1971 and 1994 the overall population increased by 43 per cent, of which 23 per cent can be attributed to rural and 20 per cent to urban population growth. In the period between 1994 and 2005 the population will grow again by 14 per cent, of which 7 per cent can be attributed to rural and 7 per cent to urban population growth. Overall, between 1971 and 2005 the rural population grows faster than the urban population. However, from 1994 onwards, urban population growth catches up. The increase in population density follows the increase in total population. Overall population densities rise from 549 per km^2 in 1974, to an estimated 896 per km^2 in 2005. Information on the geographical distribution of the population is presented in table 2.a. Although this table does not show the population densities in detail, it is apparent that large differences exist between districts.

In 1991, the only year of which detailed data are available, the total population amounted to 29 million, of which 21.4 million lived in rural and 7.6 million in urban settings (73.6 and 26.4 per cent respectively). The working force - people involved in main and marginal economic activities - was 32 per cent of the total population (9.3 million people). Table 3.a presents the division of this working force over the categories 'small farmers', 'agricultural labourers', 'cottage industry workers' and 'other workers' and also shows the division of categories in respectively rural and urban settings.

Table 3.a
Working force in Kerala (1991) in various categories and in rural and urban settings (percentages of working population).

Categories	Total workers (%)	Rural workers (%)	Urban workers (%)
Small farmers	12.38	15.29	4.00
Agricultural labourers	25.66	30.77	10.95
Cottage industry workers	3.92	3.76	4.39
Other workers	58.04	50.18	80.66

From table 3.a, it can be seen that, both in rural and urban settings, the majority of the working force falls in non-agricultural categories ('cottage industry workers' and 'other workers'). Unfortunately, no further specification of the category 'other workers' was available but one must assume that this category includes workers in medium and large scale industry, households, commerce and services. Even in rural settings, one can conclude, a majority of the working force is involved in economic activities not directly related to, often traditional, agriculture. Whether this is reflected in energy consumption patterns we will see later.

3.2
SOURCES OF ENERGY

From a consumers' point of view, energy has to conform to certain requirements:

- it has to be of the right type;
- it has to be delivered at the place where it is needed;
- it has to be delivered when it is needed.

Different consumers, of course, have different requirements. Industry, for example, might require energy as electricity for the operation of machines, while households might require energy in the form of heat for cooking and as electricity for the operation of ceiling fans. Industry might require electricity 24 hours a day, while household might require heat only during cooking hours and electricity only during certain hours and/or seasons. The requirements of all consumers together determine the energy mix in Kerala. The energy sources presently used are fuel wood, crop residue, electricity, cooking gas, dung cakes, kerosene, different types of coal, biogas and diesel. Figure 3.2 shows the energy mix, compiled from different sources in the period 1991-1995, in Kerala.

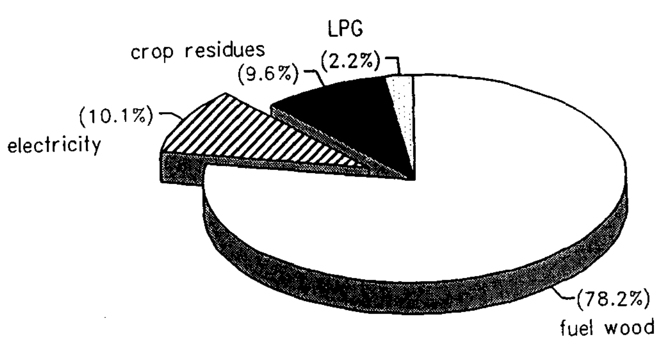


Figure 3.2
Energy mix in Kerala (compiled from different sources in the period 1991-1995).

Source: CMIE, Economic Intelligence Service, India's energy sector, September 1996.

Figure 3.2, was compiled on basis of data from different sources, most of which used different units of measure. All units of measure where, therefore, converted in joule (the way this conversion was executed is shown in the accompanying table). Fuel wood is obviously the major energy source used (78 per cent) and from paragraph 3.1 it will be clear that the use of fuel wood will increase in future if no other suitable sources become available. An increased use of fuel wood will, however, undoubtedly create serious problems. Wood will become scarce, easy access will decrease and prices will go up. A possible solution is to explore and expand the increasing use of other sources of energy and electricity, for a variety of reasons, is a likely candidate for such an expansion. It is an important source, it can be transmitted and distributed with relative ease and converted into useful mechanical action, heat or light at any end use point and whenever required. For some types of use, there is not even a substitute: television, telephone, ceiling fan, etc. In addition, many villages in Kerala are already electrified and, therefore, the necessary infrastructure is largely in place. The more remote rural areas are the exceptions. Of the total urban households, 67.7 per cent is connected and of the rural households 48.3 per cent. Last but not least, it is possible to increase electricity generation because the presently installed hydro capacity is 1492 MW against a proven potential capacity of 2301 MW.

3.3
ELECTRICITY

3.3.1
Physical infrastructure

Electricity is mainly generated by means of hydro power plants, diesel generators, wind mills and sea-wave power plants. Large scale hydro power plants generate some 90 per cent of all electricity and for the time being we will, therefore, focus our attention on these plants.

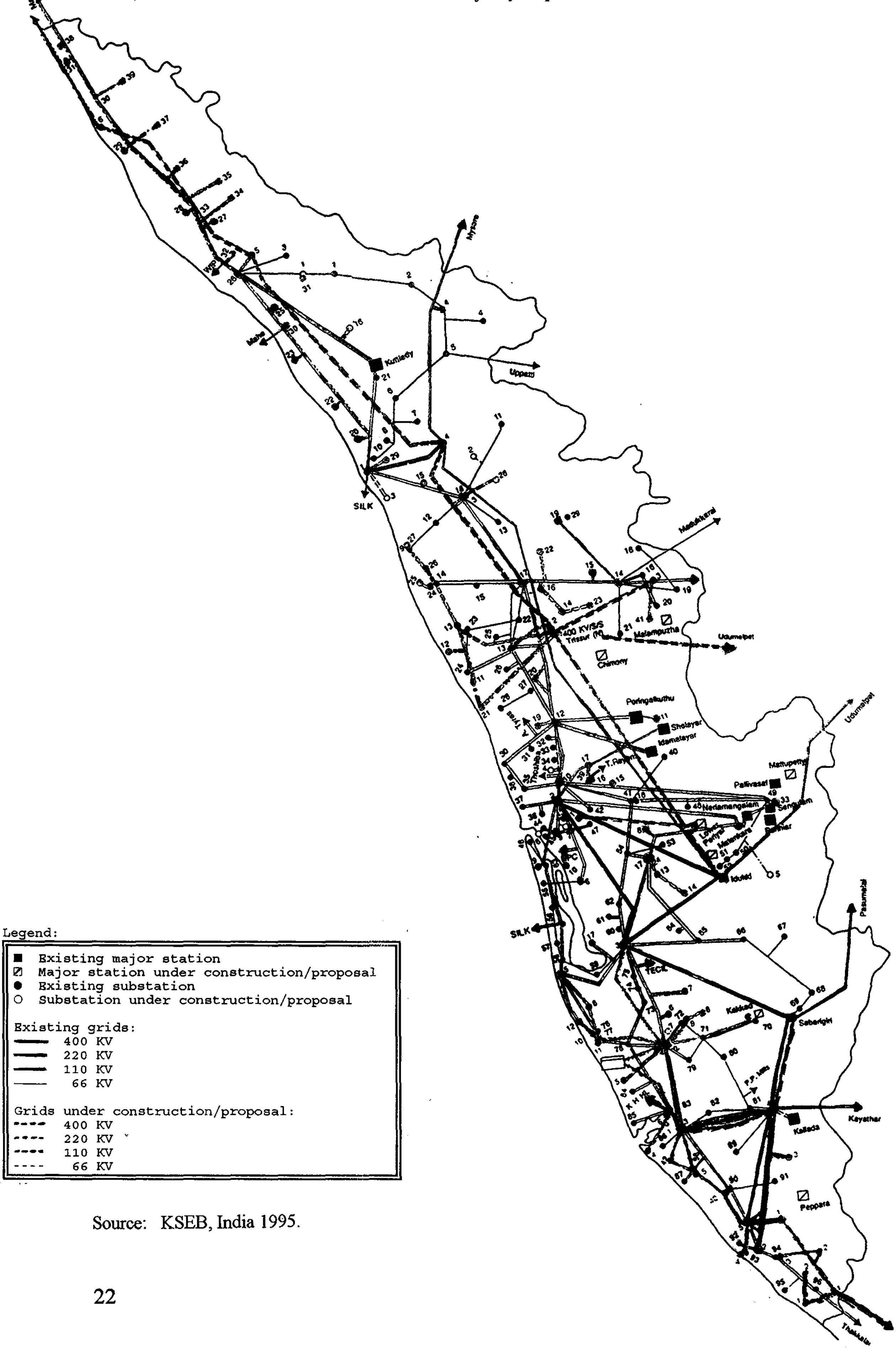
Table 3.b presents the major hydro power stations with their units and the capacity of these units in MWs. Map 3.1 shows the major hydro power stations, sub-stations and grids[10].

Table 3.b
Major power stations with units and installed capacity (1995).

Name station	Number of units	Capacity per unit, in MW
1 Pallivasal	3 3	5 7.5
2 Sengulam	4	12
3 Poringalkuthu	4	8
4 Neriamangalam	3	15
5 Panniar	2	15
6 Sabarigiri	6	50
7 Sholayar	3	18
8 Kuttiadi	3	25
9 Idukki	6	130
10 Idamalayar	2	37.5
11 Kallada	2	7.5

[10] *At present, the total number of sub-stations, with a voltage of 110 kV, are 49 instead of 31 shown in the map. See appendix D for the names.*

Map 3.1
Major hydro power stations, sub-stations and grids.



Legend:

- ■ Existing major station
- ▨ Major station under construction/proposal
- ● Existing substation
- ○ Substation under construction/proposal

Existing grids:
- 400 KV
- 220 KV
- 110 KV
- 66 KV

Grids under construction/proposal:
- 400 KV
- 220 KV
- 110 KV
- 66 KV

Source: KSEB, India 1995.

From table 3.b, it can be seen that there are 11 major power stations and 41 units, with a total installed capacity of 1492 MW. Map 3.1 is, unfortunately, not complete. Apart from the 11 major power stations, there is presently one 400 kV sub-station (Madakkathara), 6 220 kV sub-stations (Kozhikode, Kalamassery, Pallom, Edamon, Trivandrum-North and Kaniampatta), 49 110 kV sub-stations and 101 66 kV sub-stations. This makes a total of 157 sub-stations. Map 3.1 shows the 400, 220, 110 and 66 kV grids. The physical structure of the 11 kV grid is not known and not given in the map. The kV-grid constitutes the primary grid. The transmission losses in the 400, 220 and 110 kV grids are of the order of 3.5 per cent. The losses in the 66 kV grid are about 4.5 per cent and the losses in the 11 kV grid may amount to 7 per cent. Eventually, the electricity is delivered to the consumers in a 380/220 V system. This system constitutes the secondary grid. Pilferage, metering errors and assessment errors in this secondary grid may amount to an additional 8 per cent losses.

3.3.2
Availability and accuracy of information

Statistics were collected from books, magazines, monthly reports and other documents from commercial and public organisations in Kerala. Apart from collecting data from books, data collection proved to be tedious and difficult. Many organisations were visited, but most of them were not very willing to part with their information. Sometimes I even had to promise to leave all the information behind, before I was allowed to copy documents. Often I had to copy information by hand.

With respect to the statistics collected it should be noted that the accuracy of the information is not high. A conclusion which is based on the many errors I discovered when mapping the used energy sources and making graphs. Even the official year books of the Kerala State Electricity Board are full of errors. Because of these errors, it took a lot of time and effort to verify the data and compile reliable reviews. Most data had to be cross referenced with other sources or converted into other units of measure. In some cases, however, this was not possible. Just to get an idea of the kind of errors, a few examples are given. One source mentioned 5135 electricity consumers in the Industry Low Tension sector. Cross reference learned that this had to be 51500. The connected load in the agriculture sector was stated in one source as 42,930 kW, whilst cross referencing learned that this had to be 450,580 kW. But also errors of a different nature occurred. The statistics on electricity import in Kerala were found not to be the real energy import ones, but the balance of the electricity imports and exports. An important fact to be aware of when calculating the power availability for consumption. In addition, various official data ranges had been mixed up and it took a lot of detective work to sort those ranges out properly. Last but not least common typing errors occurred such as, for example, in the Kerala statistics an installed capacity of 375 MW which on checking turned out to be 37.5 MW and 2.5 MW which turned out to be 12.5 MW. The statistics used in the following paragraphs to construct graphs may not be completely without errors, but at least they have been made as coherent as possible.

3.3.3
Electricity generation and consumption

Overall generation (imports/exports) and consumption

Figure 3.3 presents long term electricity generation and consumption trends in Kerala.

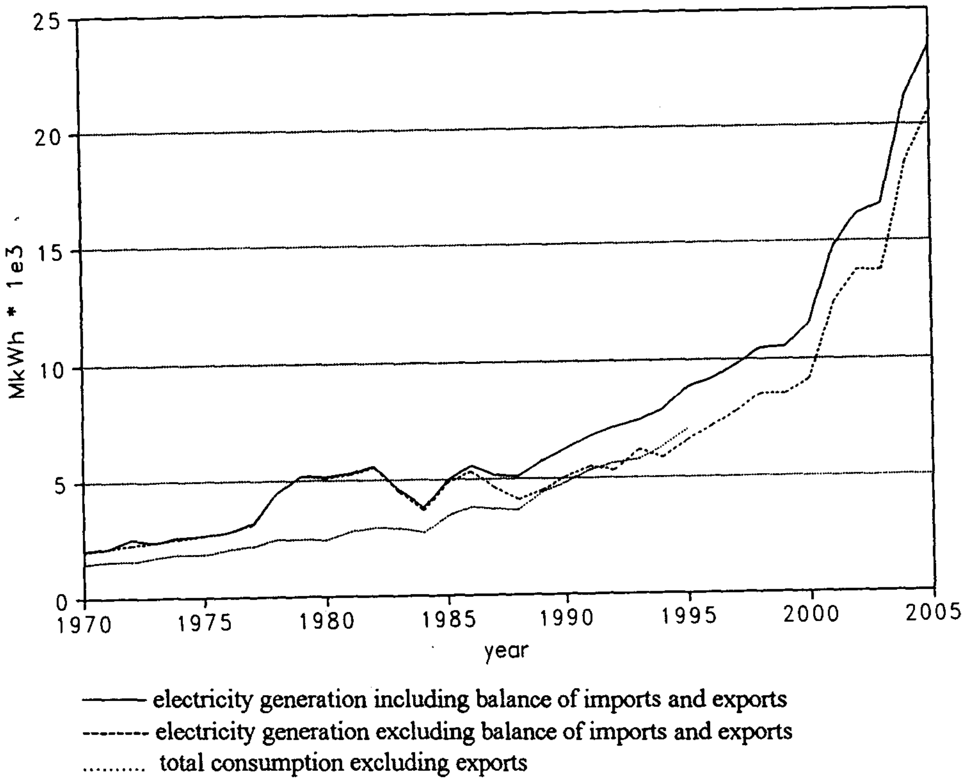


Figure 3.3
Electricity generation and consumption in Kerala in the period 1970-2005.

Sources: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.
KSEB, Eighth Plan '92-'97 and Annual Plan '92-'93 Proposals, Trivandrum September 1991.

One of the curves shown in figure 3.3 is that of the electricity generation in Kerala, India, in the period 1970 up to 1995. Figures for the period 1995-2005 are forecasts. Exclusive import-export generation has lower values than inclusive import-export generation. This means that there have been more energy imports than exports. Until 1985, the balance is almost zero. From 1985 onwards, the imports increase to more than 2000 MkWh in 1995. In 1988, the total available generated electricity depended for 19.78% on imports increasing to 25.5% in 1995. Apparently, it was impossible to increase the own generation capacity and one had to revert increasingly to imports. It is likely that the same will be true in future. The other curve in figure 3.3 presents the total power consumption exclusive the energy exports: total power consumption in Kerala only.

The differences between the two curves are losses. These vary between 20 and 50% and this is confirmed by the loss statistics of the KSEB. To have an idea of comparison: total power consumption in the Netherlands in 1993 was 87,247 MkWh, in Kerala in the same year this was 5,765 MkWh.

Consumption growth per sector

Figure 3.4 presents the electricity consumption per sector in Kerala in the period 1980-1995.

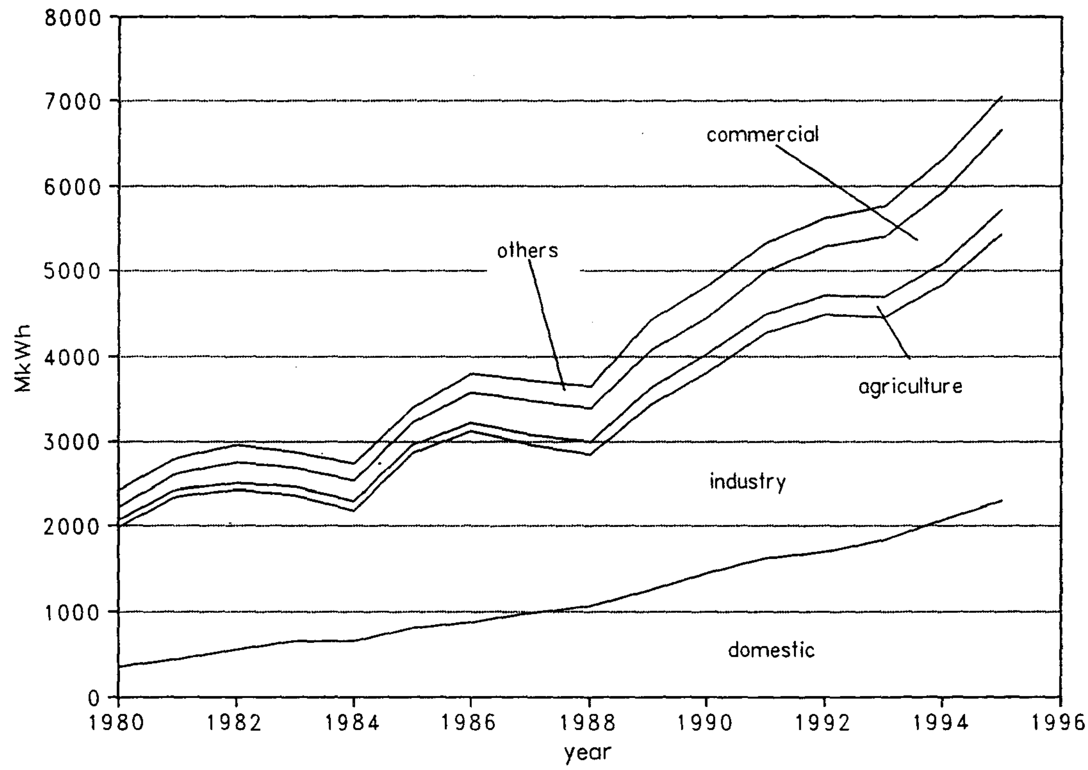


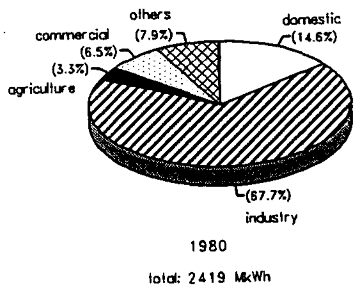
Figure 3.4
Electricity consumption per sector (cumulative) in Kerala in the period 1980-1995.

Note: Others includes public lighting, water works and licensees.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

From the figure it can be seen that the overall electricity consumption increased by a factor 3 between 1980-1995. The largest sector - industry - increased by a factor 2, the second largest sector - domestic - by a factor 6. The agriculture and commercial sectors by a factor 3 and 6. Others by a factor 2. Since the domestic sector has a growth rate 3 times that of the industry, supply to the domestic sector will surely form a future problem.

Sector consumption in 1980 and 1995: a comparison
Figure 3.5 - in the for2m of pie diagrams - presents a comparison of electricity consumption in Kerala for the major economic sectors in the years 1980 and 1995.



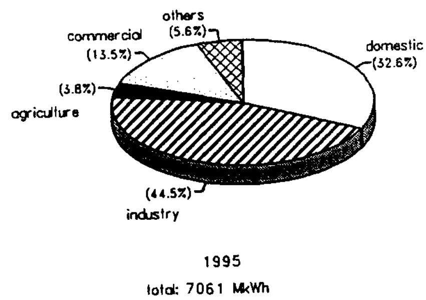


Figure 3.5
Electricity consumption in Kerala: domestic, industry, agriculture, commercial and others (1980 and 1995).

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

From figure 3.5 it can be seen that the total electricity consumption has increased, but the relative domestic share has increased even more. The smaller commercial and agriculture share has increased too. Only the industry share has obviously relatively decreased. Taking into consideration the growth rates presented in figure 3.4, it is predictable that this trend will continue.

3.3.4
Number of connections (consumers) and connected loads

Numbers of connections and per capita consumption
Figure 3.6 presents the increase in the number of connections (including street lights) in the period 1970-1995 and in addition shows the increase in per capita consumption of electricity in kWh.

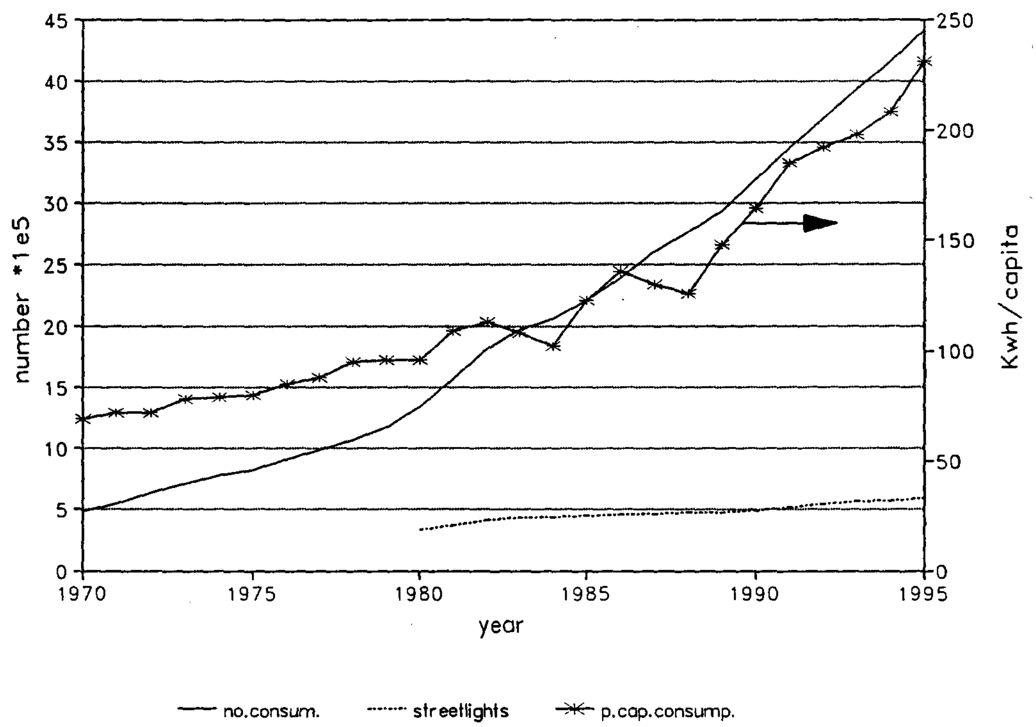


Figure 3.6
Number of connections and streetlights and per capita electricity consumption in Kerala in the period 1970-1995.

Note: Number of consumers includes the sectors domestic, industry, agriculture, commercial and others.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

From figure 3.6 it is apparent that the number of consumers increased by a factor 9 between 1970 and 1995 and the number of street lights by a factor 1.7. The per capita electricity consumption in the period 1980-1995 increased by more than 3 times.

Connections per sector

Figure 3.7 presents the number of connections specified per sector (domestic, industry, agriculture, commercial and others) in Kerala in the period 1980-1995.

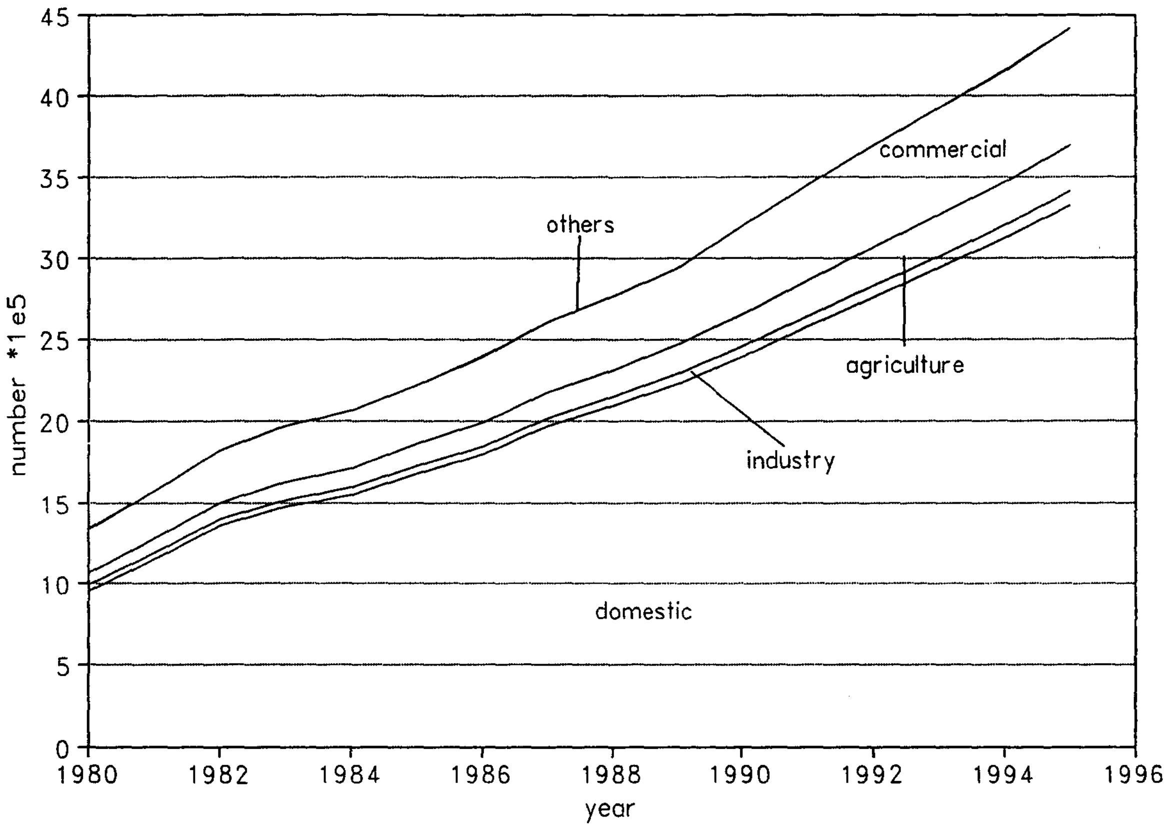


Figure 3.7
Number of connections per sector (cumulative) in Kerala in the period 1980-1995.

Notes: Others include public lighting, water works and licensees.
Agricultural sector includes only irrigation pumps and tube wells.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

In the period 1980-1995, the overall number of connections increases by a factor 3. The domestic sector is by far the largest one (72 per cent of the total) and increases by a factor of around 3.5. An increasing number of households apparently is being connected to the power grid. The commercial sector also constitutes a sizeable part of the connections and increases by a factor of around 2.7. The number of connections in the agricultural and industrial sectors is relatively small, but the number of connections increases with respectively a factor of around 3.6 and 2.5. The number of connections in the sector 'others' is so small that they do not show in this graph.

Connected load per sector

Figure 3.8 presents the connected load per sector (domestic, industry, agriculture, commercial and others) in Kerala in the period 1980-1995.

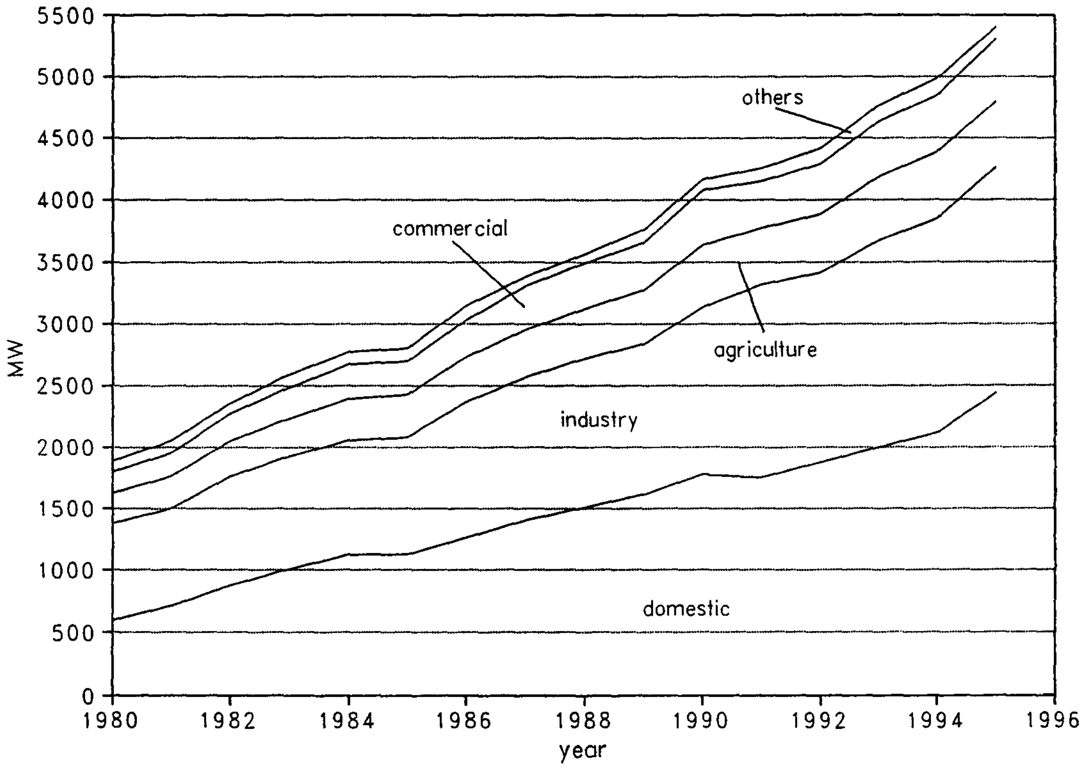


Figure 3.8
Connected load per sector (cumulative) in Kerala in the period 1980-1995.

Note: Others include public lighting, water works and licensees.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

Comparing figures 3.7 and 3.8, it becomes apparent that the number of consumers increases more rapidly than the connected load. In future, therefore, problems can be expected. The domestic and industry sectors together, make up most of the load (32 and 41 per cent respectively in 1980). The connected load in the domestic sector increases twice as fast as the load in the industry sector. Although the loads in the commercial and agricultural sectors increase by respectively a factor 3 and 2, they only constitute a relatively small part of the total load. Given the limits to the possibility of extending the total connected load (the maximum MW that can be delivered to consumers), it is obvious that the domestic load can only increase at the expense of the industrial one, or vice versa.

3.3.5
Installed capacity, generated capacity and utilized capacity

Capacity, generation and consumption

Figure 3.9 presents the installed capacity, the electricity consumed, the projected demand, the available electricity and the electricity generated in Kerala in the period 1970-2005.

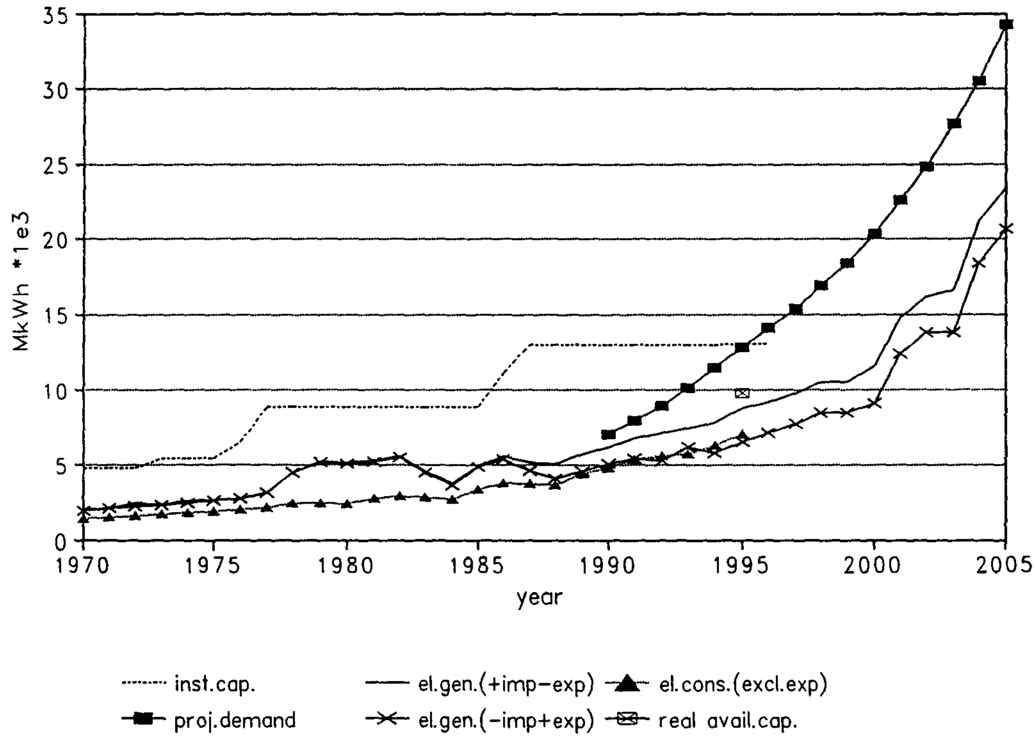


Figure 3.9
Installed capacity, electricity consumed, projected demand, available electricity and electricity generated in Kerala in the period 1970-2005.

Notes: From 1995 onwards, data concern forecasts.
Demand forecasts are also available for the years 2010 (56*10³ MkWh), 2015 (79*10³ MkWh) and 2020 (111*10³ MkWh).

Sources: KSEB, KSEB Power System Statistics 1994-'95, Trviandrum 1996.
KSEB, Eighth Plan '92-'97 and Annual Plan '92-'93 proposals, Trivandrum September 1991.

In the statistics used to compile figure 3.9, installed capacity was expressed in MW and electricity generated, power consumed and projected demand in MkWh. To be able to compare the statistics, the following conversion was employed:

1 MWyear = 1 MJyear/sec. = $1.10^6.365.24.3600$ joule = 32.10^6 J

1 MkWh/year = $1.10^9/365.24$ W = 114 kW = $3{,}6.10^{12}$ J

Available electricity: the electricity generated plus the balance of electricity imports and exports (+imp-exp).
Electricity (power) consumed: refers to the electricity consumed in Kerala only.
Electricity generated: the electricity generated for the use in Kerala plus the electricity generated in Kerala for export to other states (-imp+exp).
Installed capacity: refers to the specified machine capacity (100% availability) of the hydro power stations and their constituting units.
Projected demand: the demand for Kerala only.

From figure 3.9, it is apparent that the installed capacity was increased in various steps and major additions to the hydro power system were made in 1970, 1973, 1977, 1986, 1987 and 1988. Nevertheless, somewhere after 1997 the installed capacity will no longer be able to satisfy the projected demand.

The gap between installed capacity and available electricity and electricity generated is explained by (1) the fact that stations are designed to cope with peak demands and by (2) the loss of capacity due to technical break downs and maintenance.

In 1995, only data of this particular year were available, the *real* available capacity - electricity generated, derived from the actual working hours per station - was 9750 MkWh. Higher, therefore, than the available electricity and the electricity generated. The difference being accounted for by various types of losses.

Until 1985, the balance of electricity imports and exports is almost zero (the same curves). From that year onwards, however, the available electricity increases more than the generated electricity. Hence, the electricity imports from other states become increasingly important for Kerala. In the early 1990s, the electricity (power) consumed begins to exceed the electricity generated.

Power stations
Figure 3.10 presents the installed capacity, the real available capacity and the firm annual generation capacity for each of Kerala's 11 major stations and their units. The installed capacity per station - expressed in MkWh - is the annual generation capability if each unit runs for 365 days without any hitches. The difference between the installed capacity and the real available capacity, is accounted for by break down losses, maintenance and reserve shut down losses and these losses vary between 14 and 50 per cent. The firm annual generation capacity is the possibility to generate at a given level at any time (this given level depends on the minimal water levels as calculated by drought frequency analysis). The real available capacity usually exceeds the firm generation capacity by a factor two.

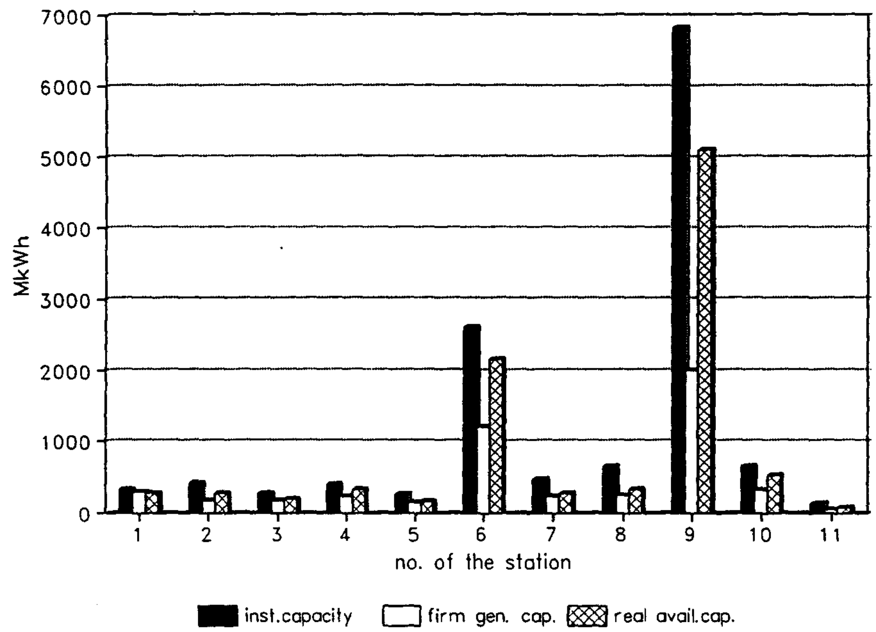


Figure 3.10
Installed capacity, real available capacity and firm annual generation capacity of Kerala's major hydro-power stations.

Sources: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.
KSEB, Eighth Plan '92-'97 and Annual Plan '92-'93 proposals, Trivandrum September 1991.
CMIE, Economic Intelligence Service, Indian's energy sector, September 1996.

Power generation at unit level

Figure 3.11 presents the installed capacity and real available capacity per station and per unit in the operational year 1994-1995. From figure 3.11, it is apparent that in this particular operational year one unit doesn't run at all and that two units work only for 10 per cent. The working time of the other units varies between the 42-96%, so the available capacity varies between 42-96% of the installed capacity of these units.

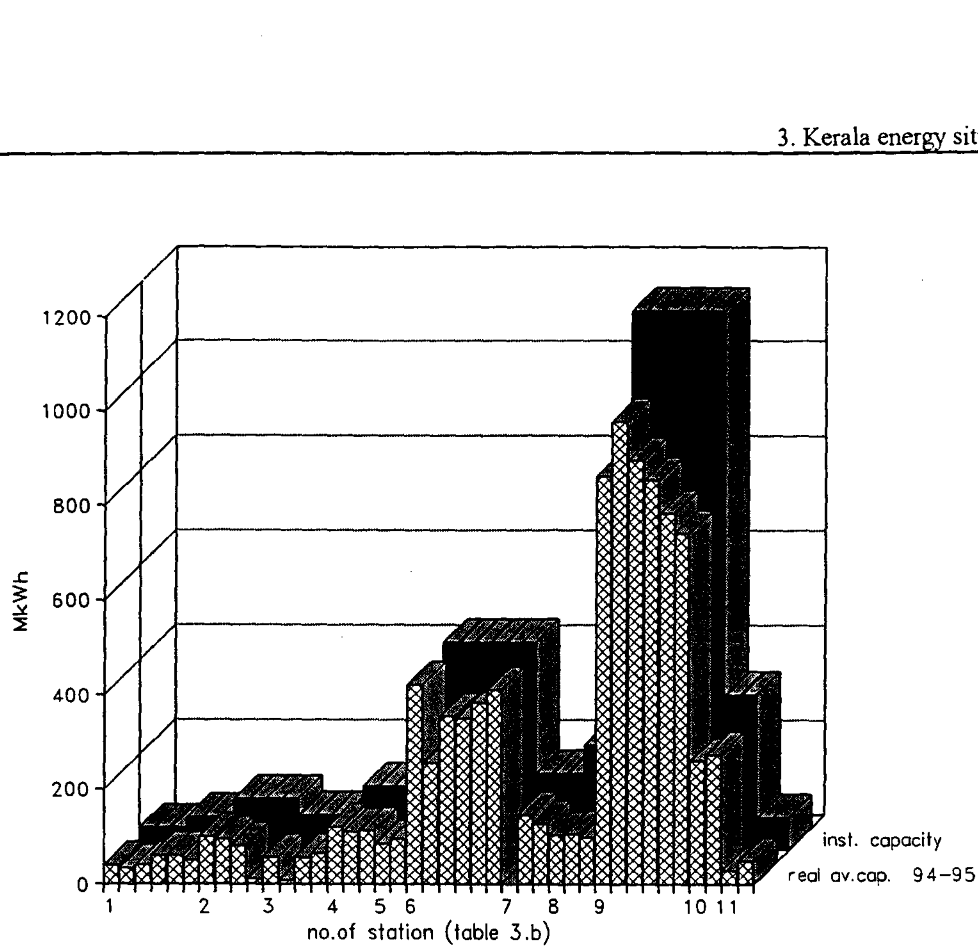
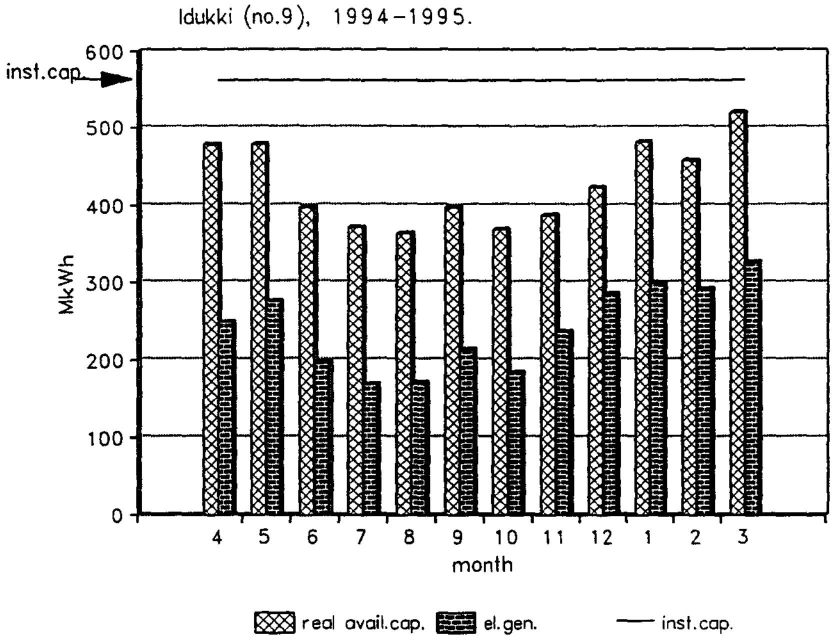


Figure 3.11
Installed capacity and real available capacity per station and per unit in the operational year 1994-1995 in Kerala.

Sources: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.
KSEB, Eighth Plan '92-'97 and Annual Plan '92-'93 proposals, Trivandrum September 1991.
CMIE, Economic Intelligence Service, Indian's energy sector, September 1996.

Power generation at station level (example for the operational year 1994-1995)
Figure 3.12 presents the installed capacity, real available capacity and the electricity generated for both the Idukki (no. 9) and Sabarigiri (no. 6) stations in the operational year 1994-1995. The total installed capacity of the larger Idukki station is 780 MW and for the middle sized Sabarigiri station 300 MW. The electricity generation per month varies between 55-90 per cent for Sabarigiri and 45-65 per cent for Idukki of the real available capacity. The real available capacity is used during the peak hours. If the peak demand and the average electricity generation increase, Sabarigiri station has only a limited possibility to cover a higher peak demand and generate more electricity. Idukki station can cope better with peaks. Larger stations are apparently more flexible. Generally, of course only if they work at sub optimal performance.



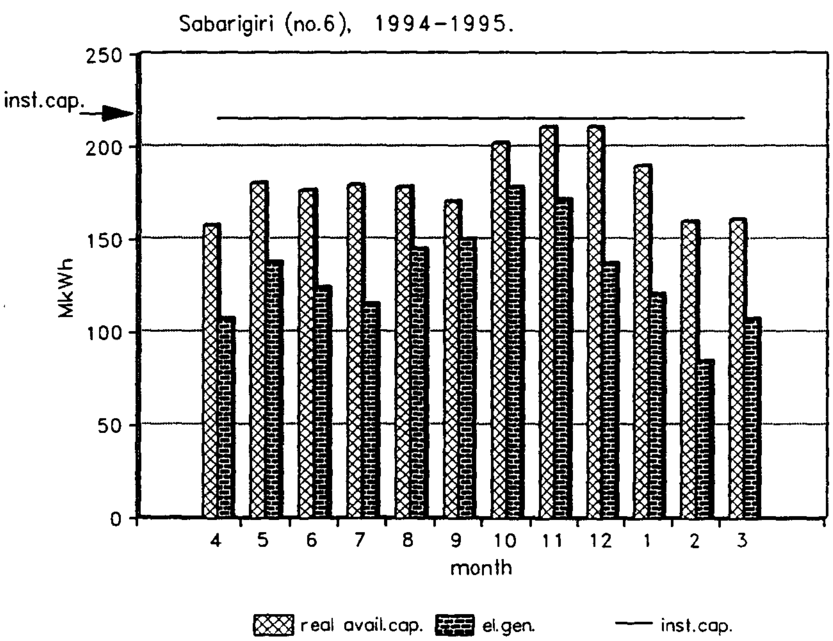


Figure 3.12
Installed capacity, real available capacity and electricity generated for the Idukki and Sabarigiri stations in Kerala in year 1994-1995.

Notes: Idukki is a large station with an installed capacity of 6*130 MW.
Sabarigiri is a middle station with an installed capacity of 6*50 MW.

Source: KSEB, KSEB System Operations 1994-'95, Trivandrum 1996.

Connected load and electricity consumption per sector

Figure 3.13 presents the available connected loads and the electricity consumption in Kerala for the sectors domestic, industry, agriculture, commercial and others (1980-1995).

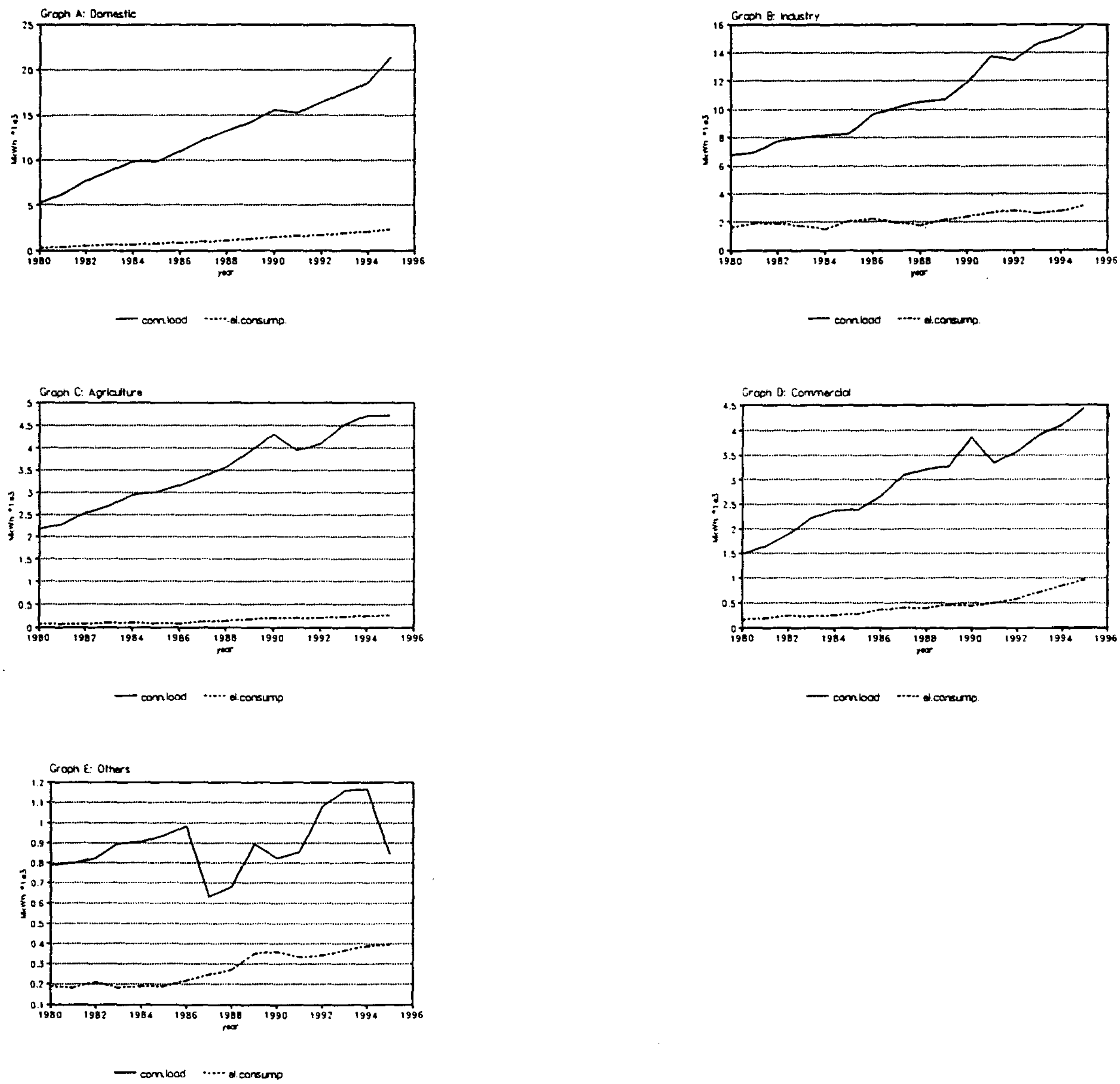


Figure 3.13
Connected load and electricity consumption per sector in Kerala in the period 1980-1995.

Source: KSEB, KSEB Power System Statistics 1994-'95, Trivandrum 1996.

From figure 3.13, we see that the connected load is largest for the domestic and industry sectors. In the domestic sector, the electricity consumed is only 7 to 11 per cent of the connected load in the period 1980-1995. For the industry sector this is 20 to 24 per cent. The agriculture, commercial and 'others' sectors - constituting only a small part of the connected load - have an electricity consumption of 4 to 47 per cent of the connected load. The sector 'others' has the smallest difference. The reason of the large difference between connected load and electricity consumption is that the connected load has to cover the peak demands.

3.3.6 Review of pricing mechanisms

For detailed list with references see appendix A. The hydro power plants are under the control of the Kerala State Electricity Board (KSEB). KSEB is a wholly state - government - owned company. There are, however, plans in future to stimulate the private sector to invest in hydro power plants. At present there are already a few hydro power plants in which the private sector participates. These plants are situated in Maniyar (12 MW), Wanchiam (3 MW) and Chathankottunada (stage I with 2.5 MW). Power plants with private participation constitute a new situation and no information is presently available with respect to price settings and responsibilities.

For its own plants, the government sets the prices and KSEB is responsible for collecting the charges from the consumers and receives the revenues. The government has set the electricity prices for the domestic and agriculture sectors relatively low and KSEB incurs heavy losses in these two sectors. The losses are partly compensated by government subsidies and partly by the profit made in other sectors.

There are six categories of consumers and they all have a specific tariff system. Each category of consumers has to meet a minimum sale condition against specific rates. In table 3.c, the consumer prices, the minimum sales conditions, the actual revenue and the total electricity consumption is presented.

Table 3.c
Electricity costs, minimum sales conditions, revenue and total consumption per sector (1995)[11].

Categories	Minimum sales conditions against costs indicated	Consumer price in Paise/kWh	Actual average revenue in Paise/kWh	Total consumption (1995) in MkWh
Domestic	100 kWh/month	77.00	58.67	2301
Commercial	200 kWh/month	313.50	120.64	954
Industry LT	small ind: 1361 kWh/month	119.04	111.55	543
Industry HT&EHT	medium: 14600 large: $2.19*10^6$ kWh/month	115.65 118.33	98.91	2598
Agriculture	10 HP/20% PLF	14.21	23.94	271
Public lighting Water works Licensees			105.58 125.87 67.88	394

From table 3.c, we see that within the industry category there are two divisions: 'Industry Low Tension' (small industry) and 'Industry High Tension & Extra High Tension' (medium and large industry).

The cost per kWh includes interest charges at every level of the process and at the generation end is 10.001 Paise. After generation, the electricity has to be transmitted in transformers and substations. The cost at the transmission end is 44.821 Paise/kWh. The distribution through the grid finds place after transmission and there is distribution via high and low voltage. The cost at the 'distribution high voltage end' is unknown. The cost at the 'distribution low voltage end' is 99.532 Paise. The low voltage grid has more losses than the high voltage one and this is translated in higher costs. The costs at the 'distribution high voltage end' varies between 44.821 and 99.532 Paise/kWh. The costs of establishment and administration are 16.8 Paise per sold kWh. The costs of operation and maintenance are 5.2 Paise per sold kWh. The cost price range of electricity varies between 66.821 and 121.532 Paise per kWh sold.

[11] *US $ 1 = Indian Rupees 35 = Indian Paise 3500.*
Industry LT and Industry HT&EHT mean Low Tension industry and High Tension & Extra High Tension industry.
PLF is the plant load factor and HP is the unit for horse power.

When the electricity costs are compared with 'dry fuel wood' costs, it is clear that electricity is expensive. Assume that the electricity is 100 Paise/kWh, which is equal to $277.8*10^{-7}$ Paise/joule. Fuel wood costs 100 Paise/kg[12], which is equal to 18 Paise/kWh. So there is a large price difference and difference in heat effectiveness.

Furthermore, from the table it is apparent that there are large price differences between the sectors. The government sets the prices and these are relatively low for the domestic sector and really low for the agriculture one. Apparently Kerala aims at stimulating the consumption in these sectors. This contrasts with the policy in, for example, the Netherlands, where one aims at decreasing electricity consumption. Here, some policy papers recently even suggest to increase the electricity price for households by a factor two.

Table 3.d presents a percentage comparison of sales and revenues for the various categories mentioned earlier.

Table 3.d
Comparison (percentages) of sales and revenues for the categories 'domestic', 'commercial', 'industry LT', 'industry HT&EHT', 'agriculture' and 'public lighting, waterworks and licensees' (1995).

Categories	Sales in % of 7061 MkWh	Revenue in %
Domestic	33	22
Commercial	13	19
Industry LT	8	10
Industry HT&EHT	37	42
Agriculture	4	1
Others	5	6

The total sales are 7061 MkWh with a total revenue of 6110 million Rs. KSEB should have received 7590 million Rs so there is a deficit of about 1500 Rs. The losses and profits per sector are calculated on basis of the real cost price of electricity of 1 Rs/kWh, except for the categories 'industry LT' and 'industry HT&EHT'. The power supply to the low tension industry costs more than 1 Rs, so a cost price of 119.04 Paise/kWh is taken. The power supply to the high tension industry is cheaper and is taken at 67 Paise/kWh. It can be seen now that KSEB incurs heavy losses in the domestic sector with -951 million Rs and in the agriculture sector with -206 million Rs. The commercial sector has profits with +197 million Rs and the 'industry HT&EHT' with +829 million Rs. The 'industry LT' has a small loss of -40 million Rs and the sector 'others' has a small loss of -25 million Rs. The balance of the profits

[12] *1 kg dry fuelwood is equivalent to 19.68 MJ.*

and losses is negative with -196 million Rs. In the balance of profits and losses the government subsidies for the domestic and agricultural sectors have to be accounted for. Unfortunately no information is available on this matter.

3.4
ANALYSIS

As we have seen in figure 3.2, fuel wood constitutes 78 per cent of the energy consumption in Kerala with electricity as a runner up at a considerable distance (10 per cent). Population growth, particularly in rural areas, already results in unacceptable levels of deforestation and rising prices of fuel wood and in the near future the fuel wood situation will become critical[13]. But also the electricity situation is reason for concern. Only because of the electricity imports from other states - about 25 per cent in 1995 - supply can presently keep up with demand. The projected demand, however, will begin to exceed supply before the turn of the century (see figure 3.9). The electricity consumption is highest in the domestic and industry sectors and the consumption will continue to grow in future (figure 3.4). Since there is a limit to the growth of the connected load, the domestic and industry sectors soon will have to compete for electricity

If nothing is done, by the turn of the century serious electricity shortages will occur and will hamper both rural and urban development. This, of course, leads to the question of possible solutions. Alone, or in combination with each other. We will briefly discuss some of these.

With the presently installed capacity, more electricity could be generated. This means that the stations have to run more hours. This, in turn, implicates that maintenance time, number of break downs and reserve shut down time will all have to be reduced and this will be difficult to achieve. Then, there are the peak demands to consider. The small power stations have only a small margin to cope with the peak demands. The big stations have enough capacity to cope with peaks, but there are only 2 real large power stations. Last but not least, even if all the power stations work at 100 per cent, the installed capacity will not be sufficient in the near future. Whether small scale hydro could contribute to solving some of the problems we will see in chapter 5 and 6.

The efficiency of end-user equipment could be improved. In view of the fact that consumers will have to be convinced to buy new equipment, or modify existing equipment, and in the light of the low per capita incomes, more efficient end-user equipment is not a realistic solution.

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[13] *Lean, G. and Hinrichsen, D. (and others), Atlas of the environment, the most up-to-date report on the state of the world, Banson Marketing Ltd., London 1990, pp. 73-76.*

Another possibility - and in the medium long term probably the only one - is to expand the hydro electric generation. In principle this is possible since the presently installed capacity is 1492 MW and the estimated potential of the order of 2301 MW. When increasing the hydro electric generation, one has the choice between large and small stations and units. In Kerala, a large station, is a station with a capacity of more than 15 MW, a small station has a capacity of less than 15 MW (note that the international standard for a small station is 10 MW). Small stations (with units of 1-5 MW) are divided again in two categories: mini stations (with units of 0.1-1 MW) with a capacity of less than 2 MW and micro stations (with units of 0-0.1 MW) with a capacity of less than 100 kW.

The advantages and disadvantages of large and small stations can only be analysed when considering the respective target groups and their situation. In this light it is important to realize that the domestic sector is and will be in future the fastest growing one in Kerala. Both consumption and number of consumers will grow much faster than in industry. The domestic sector concerns households and some 75 per cent of these will be situated in rural settings. In other words, in villages scattered throughout often the more remote areas of Kerala. Although almost all villages are presently electrified, this usually means that there is only one 11/22 kV line and one transformer and that electricity is not available near most of the dwellings.

Mini and micro hydro power stations would appear to be a feasible solution to contribute to solving the electricity provision problems of Kerala for a number of reasons:

- energy costs and investments required for distribution networks to remote areas have been escalating steeply, resulting in an increasing cost effectiveness of micro/mini systems;
- particularly micro plants can be built quickly, the civil works are simple and local labour can be used;
- there is no need for long transmission lines and line losses are minimal;
- operation of the stations is simple, little maintenance is required and in most cases full-time staff is not required for surveillance;
- foreign exchange is hardly required;
- return on investment is faster than is the case with large hydro plants since the gestation period is brief;
- damage to the environment is minimal;
- in view of the dense road network and general engineering workshop facilities available in Kerala, construction costs at most sites will be minimal and the projects are expected to be cost effective.

Before dealing into detail with the various issues of small hydro power in Kerala we will, however, first look into Kerala's electricity shortages into some more detail and into the various aspects of sustainable energy systems.

Chapter 4
Kerala Energy Shortages

4.1
OVERVIEW OF CONFLICTING DATA

In the previous chapter we already saw that serious problems can be expected in future with respect to the balance between the electricity supply and demand. Table 4.a, shows the 1995 power consumption, installed capacity, electricity generated, available electricity and number of connections and the forecasts for the years 2000 and 2005. In addition, figures on rural and urban population growth are presented. Figures were compiled from a variety of sources (see bibliography) and made coherent as well as possible. Large inconsistencies particularly occurred in the power consumption estimates (see notes table 4.a).

Table 4.a
Power consumption, installed capacity, electricity generation, available electricity, number of connections and population growth in Kerala, India for the years 1995, 2000 and 2005.

	1995	2000	2005
Power consumption (MW)	*806*	*1380*	*3000**
Domestic	263	462	954
Industry	358	598	1015
Agriculture	31	52	384
Commercial	109	197	432
Others	45	71	215
Installed capacity (MW)	1492	2800	4500
Electricity generation (MW)	750	1042	2359
Available electricity (MW)	1007	1316	2679
Number of connections (millions)	*4.417*	*5.445*	*6.472*
Domestic	3.329	4.120	4.910
Industry	0.079	0.096	0.111
Agriculture	0.285	0.354	0.423
Commercial	0.721	0.872	1.024
Others	0.003	0.003	0.004
Population (millions)	*30.71*	*32.66*	*34.83*
Rural	24.30	25.10	25.92
Urban	6.41	7.56	8.91

Notes: The lowest total power consumption forecast for the year 2005 is 2650 MW, the highest 3912 MW
Installed capacity = specified plant capacity at 100% availability
Electricity generation = electricity generated for use in Kerala with the exports added
Available electricity = electricity generated in Kerala with the balance of imports and exports added

Despite the inconsistencies, it is obvious from table 4.a that the total *power consumption* in Kerala between 1995 and 2005 will increase by a factor 4 to 5 to somewhere between 3000 and 3912 MW. The domestic, agriculture, commercial and 'other' sectors are likely to be the fastest growing ones.

The *installed capacity* - plant capacity at 100% availability - is forecasted to increase from 1492 MW in 1995 to 2800 MW in 2000 and 4500 MW in 2005. Estimates have already been upgraded with 50% of losses (losses incurred at the plants themselves and with distribution). Whether this forecast is realistic is doubtful since few concrete construction plans are available and since already approved constructions are repeatedly seriously delayed.

The *electricity generation* - generated in Kerala plus de exports which are small and likely to remain small - is forecasted to increase from 750 MW in 1995 to 1042 MW in 2000 and 2359 MW in 2005.

The *available electricity* - electricity generated in Kerala plus electricity imported from other states (exports do no longer take place to any significant extent) - between 1995 and 2005 is forecasted to increase from 1007 to 2679 MW. The share of imports from other states - difference between available electricity and electricity generation - is forecasted to increase slightly from 247 MW in 1995, to 274 MW in 2000 and 320 MW in 2005. Imports in de longer run, however, are not likely to solve the problem of rising power consumption in Kerala since other states face similar discrepancies between electricity supply and demand.

Although the total *number of connections* as a forecast increases from 4.4 to 6.5 million between 1995 and 2005, this increase is not proportional to the forecasted increase in power consumption, installed capacity, electricity generation and available electricity. This indicates that those already connected to grids are expected to use more electricity per connection in future. Unfortunately, no further information appeared to be available on this issue.

Also the forecasted *increase in population* is not proportional to the increase in the other indicators mentioned. Again this would appear to indicate that existing consumers of electricity will use more electricity in future.

In the most likely best case scenario, in 2005 power consumption will exceed available electricity by some 321 MW. In the worst case scenario - more likely anyhow - by some 1233 MW. The available electricity (consisting already for about 25% of imports) should not be confused with the necessary installed capacity. The latter will, of course, be higher.

The question thus arises in which ways the forcasted electricity shortages can be avoided. Various sources mention different ways. These will be briefly discussed and analysed in the next paragraph.

4.2
PRELIMINARY ANALYSIS

Four sources were available for information on possible ways to avoid electricity shortages in the future:

1. KSEB, *KSEB Power System Statistics 1994-'95*, Trivandrum 1996.
2. Western Ghats Co-ordinated Research Programme Committee, *Feasibility Survey of Micro and Mini Hydro Power Potential in Kerala*, Thiruvananthapuram 1985.
3. CMIE, Economic Intelligence Service, *India's Energy Sector*, September 1996.
4. KSEB, *Eighth Plan '92-'97 and Annual Plan '92-'93 Proposals*, Trivandrum September 1991.

The four sources mentioned contain conflicting information, to say the least. What follows, therefore, has to be treated with a fair amount of scepsis. First of all, there is no agreement on the estimates of the potentials for electricity generation by large scale hydro power in Kerala. Estimates vary from some 2500 MW to 6000 MW. If the former estimate is anywhere near the truth, other energy convertors (such as thermal plants, wind generators and nuclear plants) will have to play a dominant role in increasing the installed capacity. In the latter case, hydro power plants will go a long way to increase the installed capacity but will eventually not be able to increase the installed capacity sufficiently to cover the projected power consumption with the plans presently available and in the period projected. On the potential for small scale hydro power there is a fair agreement between the four sources. The potential is estimated between 150 and 156 MW. Whether this potential is included in the overall hydro power potential is neither clear nor of much consequence.

The first KSEB report mentions plans to increase the hydro power installed capacity by constructing one large plant (180 MW), two small ones (both 50 MW) and a mix of extensions to existing stations and small scale hydro power (62 MW). Bringing the total for hydro power up to 342 MW. Two more thermal plants - to be constructed by private enterprises - are planned with a total installed capacity of 220 MW. Together with the existing installed capacity of 1492 MW, this would bring the overall capacity up to 2054 MW. This is still 746 MW short of the forecasted installed capacity of 2800 MW for the year 2000 and 2446 MW short of the forecasted installed capacity of 4500 MW in the year 2005.

The second KSEB report unfolds plans to establish a 1000 MW nuclear power plant in Kerala. If this plant would be established, the forecasted power consumption for 2005 could easily be met. However, detailed studies are still to be carried out, particularly with respect to the availability of cooling water. It is not certain that the plant will ever leave the drawing board. If it is ever commissioned this will be well after the year 2005.

The report of the CMIE, plans to increase the installed hydro power capacity to some 2457 MW. Private sector plans to install a 190 MW station bring the installed capacity to 2647 MW. This is still 1853 MW short of the forecasted 4500 MW in 2005. Plans are mentioned for the private sector to install an additional 4003 MW as thermal power. If this would materialize, installed capacity would easily match forecasted consumption in 2005. Again, however, it is highly unlikely that any thermal plant will really be commissioned before 2005.

Although private sector plans are mentioned frequently, it is not at all clear whether Indian politics have made any real progress with creating the pre-requisites (such as conditions for capital transfer and adequate laws) for privatising the traditionally state owned and managed power generating sector. Furthermore, this source estimates the small hydro power potential at 156 MW, distributed over 140 suitable sites.

The report of the Western Ghats Co-ordinated Research Programme Committee outlines that the hydro power potential of Kerala might be as high as 6000 MW, but does not present detailed information on how this potential could de harnased. The report mentions a small scale hydro power potential of 150 MW, distributed over 44 suitable sites.

All sources mention the potential for small scale hydro power, particularly in the more remote rural areas as the (only) possibility to satisfy the increasing demand for power. However, no information is provided with respect to the most suitable technologies available. In the next chapter, this issue will be further pursued.

Chapter 5
State of the art of hydro power technology

5.1
HISTORICAL REVIEW[14]

Water power was used for thousands of years throughout Asia, Europe and parts of Africa to drive a variety of industrial machinery, from grain mills through forge bellows and tripe hammers to pumps and textile mills. The fall of running water was converted to mechanical shaft power by a water-wheel with either a vertical shaft (the oldest) or horizontal shaft. The original, simple vertical-shaft Norse wheel (fig. 5.1), evolved out of Scandinavia[15], is still used today in Afghanistan and the Himalayan region. The horizontal shaft water-wheels, originated in the Mediterranean civilisations, became sophisticated water-wheels with gear trains, mechanical over-speed protection using fly-ball governors, and scientifically shaped curved iron paddles. The four most common water-wheel configurations are presented in figure 5.2.

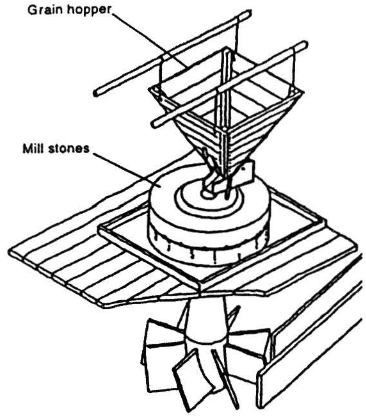

Figure 5.1
Vertical-shaft Norse wheel.

Source: Fraenkel, P. and Paish, O(and others)., Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.

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[14] *Cornell, T. and Matthews, J., Atlas van het Romeinse Rijk, Elsevier, Amsterdam 1988.*
Debier, J. and Deléage, J., In the servitude of power: energy and civilization through the ages, Zed Books, London 1991.
Fraenkel, P., Water-pumping devices, a handbook for users and choosers, Intermediate Technology Publications, London 1986.
Fraenkel, P and Paish, O. (and others), R., Micro-hydro power, a guide for development workers, Intermediate
Technology Publications, London 1991.
Holland, R., Micro hydro electric power, Intermediate Technology Development Group, Rugby 1983.
Meier, U., Local experiences with micro-hydro technology, harnessing water power on a small scale, SKAT, St. Gallen 1981.

[15] *Fraenkel, P and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.*

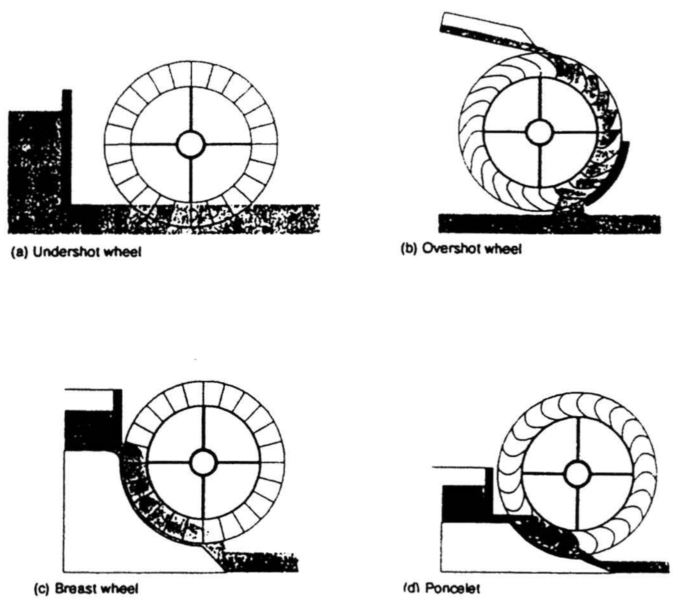


Figure 5.2
Four types of water-wheels.

Source: Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.

The overshot wheel - utilizing gravity - is the traditional and probably the most efficient water-wheel. The water is supplied via a flume to the buckets, which when full, fall, as a result of dead weight, thus turning the wheel. The supply of water to the wheel is regulated by a hand operated sluice gate. The wheel itself must be clear of the tail-water. The efficiency is usually between 60-65%. Rotational speed ranges from 6 rpm (revolutions per minute) for large wheels up to 20 rpm for small ones. The other three types of water wheels - principle of undershot wheel, which relies on interaction between the flowing water and the wheel - which operate on heads too small for use with an overshot, are the Breast, Undershot and Poncelot wheel. The Breast wheel is less efficient than the overshot wheel, but involves the same amount of work to construct. The Undershot wheel is the most basic and primitive of all wheels. Maximum actual efficiency is about 25%. If anything can be said in its favour it is that it can operate, or at least turn, on only a 30 cm. head. The Poncelot wheel is an improved undershot wheel and the forerunner of the Crossflow turbine and Pelton turbine. It depends not upon the dead weight of water in buckets, but upon the velocity of water forced through a narrow opening to strike the curved vanes. Efficiencies as high as 50% to 60% have been claimed for it. It is suitable for use on any head under 1.8 metres. All these water wheels used only a low head of water up to a maximum of 6 or 7 metres.

The main disadvantage of water wheels is their slow speed. It requires heavy gearing to take the speed from the shaft up to the minimum of 1500 rpm needed for an alternator, to generate electricity. It takes very heavy gearing to be capable of withstanding the high torque from the wheel. The other disadvantage of water wheels is their bulk. A lot of material and work goes into their construction. On the other hand maintenance is minimal and repair is usually simple.

Improved engineering and metallurgical skills during the eighteenth century, combined with the need to develop smaller and higher speed devices to be able to generate electricity without the need for large gear trains, led to the development of turbines. (In 1820s, Benoît Fourneyron designed a hydraulic motor. In fact this was the first hydro-turbine). The water turbines invented in the nineteenth century gave much higher speeds and allowed the use of higher heads of water. In this way more potential energy could be extracted from the same quantity of water.

The compact size and ease of installation of a turbine, and the possibility of using higher heads and flows to produce greater power and so satisfy the increasing demand for electricity, caused the turbine to take over from the water-wheel almost completely by the end of the century.

Oil and electricity prices and concern with the environment have, since about 1970, led to a tendency to look again at power sources that function independently of a fuel supply. This has encouraged new technical developments in the field of micro-hydro power. The most important one is the evolution of electronic control systems that offer, for the first time, accurate control - necessary for a good quality AC (alternating current) output with only small variations in voltage and frequency - of even the smallest micro-hydro installations at reasonable cost.

The hydraulic ram pump, or hydram, concept was first developed by the Montgolfier brothers in France in 1796. Essentially, a hydram (shown schematically in fig. 5.3), is an automatic pumping device which utilizes a small fall of water to lift a fraction of the supply flow to a much greater height. The main virtue of the hydram is that it has no substantial moving parts, and is therefore mechanically extremely simple, which results in very high reliability, minimal maintenance requirements and a long operational life. The efficiency of a hydram is between the 30-60%.

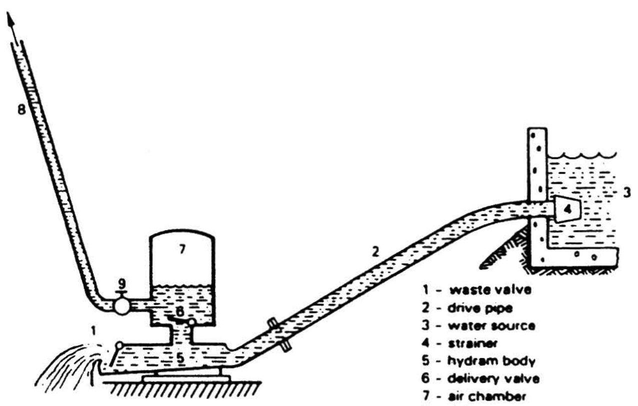


Figure 5.3
A hydram installation.

Source: Fraenkel, P., Water-pumping devices, a handbook for users and choosers, Intermediate Technology Publications, London 1986.

The working principle of a hydram is like a water hammer and the overall efficiency can be quite good under favourable conditions. Figure 5.3 illustrates the principle. Initially the waste valve (1) will be open under gravity and water will therefore flow down the drive pipe (2) from the water source (3) having been drawn through a strainer (4) to prevent debris entering the hydram. As the flow accelerates, the hydraulic pressure under the waste valve and the static pressure in the body of the hydram (5) will increase until the resulting forces overcome the weight of the waste valve and it starts to close. As soon as it starts to close, and the aperture decreases, the water pressure in the valve body builds up rapidly and slams the waste valve shut. The moving column of water in the drive pipe is no longer able to exit via the waste valve so its velocity must suddenly decrease. This continues to cause a considerable rise of pressure which forces open the delivery valve (6) to the air-chamber (7). Once the pressure in the open chamber exceeds the static delivery head, water discharges through the delivery pipe (8). Air trapped in the air chamber is simultaneously compressed to a pressure exceeding the delivery pressure. Eventually the column of water in the drive pipe comes to a halt and the static pressure in the casing then falls to near the static pressure due to the supply head. The delivery valve will then close, due to the pressure in the air-chamber exceeding the pressure in the casing. Water will continue to be discharged through the check valve (9), after the delivery valve has closed, until the compressed air in the air-chamber has expanded to a pressure equal to the delivery head. At the same time, as soon as the delivery valve closes, the reduced pressure in the casing of the hydram allows the waste valve to drop open, thereby allowing the cycle to start again.

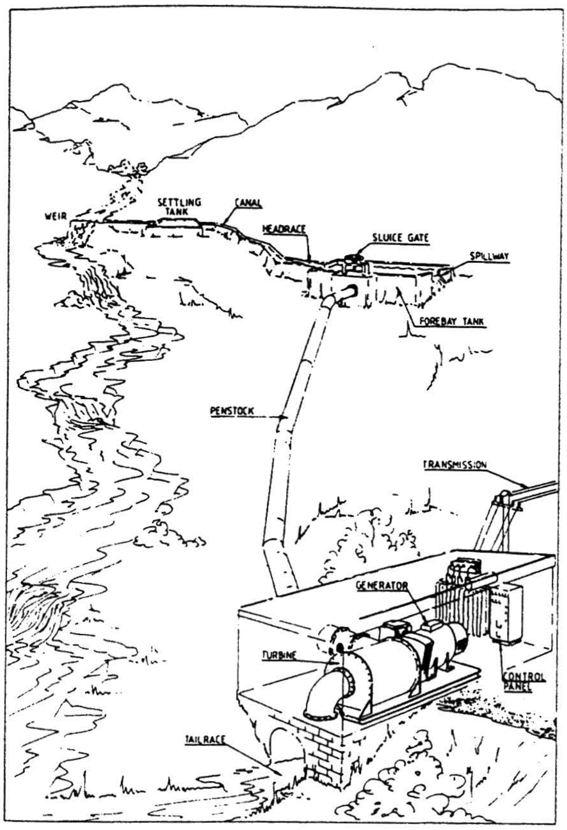
Although the costs of hydrams are apparently low, as soon as high flow rates are needed at lower heads, the size of hydram and more particularly of drive pipe, begins to result in significantly higher costs. Therefore, hydrams are best suited to relatively low flow rates and high head applications. Hydrams are mostly intended for water supply duties. Their excessive operational noise is a serious draw back.

5.2
TYPES OF TURBINES[16]

Hydro power installations transport the energy embedded in flowing water into useable energy like, for example, electricity. The principle of hydro power installations is illustrated in figure 5.4.

The components 1, 2, 3, 5, 7, 11, 12, 13, and 14, are necessary for operating a hydro power plant. Additional components are 4, 6, 8, 9, 10, 15, 16, 17, they are used to suit and improve the hydro power plant with its site and to the consumers. Or they are designed as a precaution for reducing damage to the power plant.

[16] *Bruin, B. de, Small hydro power, an assessment of its socio-economic impacts, TUE, Eindhoven March 1988.*
Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.
Holland, R., Micro hydro electric power, Intermediate Technology Development Group, Rugby 1983.
Meier, U., Harnessing water power on a small scale, SKAT, St. Gallen 1979.
Visser, A., Kleine waterkrachtcentrales, CICA, Eindhoven October 1984.



Legend:

1. River
2. Weir
3. Intake
4. Settling tank
5. Canal
6. Headrace
7. Forebay
8. Trash rack
9. Spillway
10. Sluice gate
11. Penstock
12. Power house
13. Turbine
14. Tail race
15. Generator
16. Control Panel
17. Transmission lines or Machine use

Figure 5.4
Components of a hydro power installation.

Source: Holland, R., Micro hydro electric power, Intermediate Technology Development Group, Rugby 1983.

A **weir** is a man-made barrier across the river which is built to keep the water level at that point at a constant level to maintain a continuous flow through the **intake**. A temporary weir may be only 5% of the cost of a permanent concrete weir, but it will require regular rebuilding. Low concrete weirs which have base widths at least one-third greater than their height are automatically stable and are called gravity weirs. The weir and intake must divert the correct flow volume wether the **river** is in low

or high flow. The intake structure is designed to regulate the flow to within reasonable limits when the river is in high flow. An intake should be placed as high as possible above the turbine so as to maximize the head and hence the power.
The **canal** needs a **settling tank** to remove large stones and heavy silt just after it has left the river. The channel should be constructed cheaply, preferable with earth banks, and the water velocity kept low to minimise erosion. With a channel it is important to note that many of the problems associated with open earth channels, such as excessive seepage loss and blocking from falling debris, can be solved by the use of closed pipes, or by covering or lining the channels. Although the costs of improved channels are high, they will usually be lower than penstock costs.
At the end of the channel will be a **forebay** to remove remaining suspended matter, and a **trash rack** to remove branches, leaves and other debris. A **spillway** takes all excess water in the canal and provides a further regulation of the canal flow.
A **penstock** pipework is usually considerably more expensive than an open channel. The penstock should always be as short and steep as possible and over-, rather than under-sized (to reduce the velocity and thus the wear in the pipes and the head loss due to friction). The head loss at full flow in some long penstocks can be as high as 30%, but generally the marginal cost of the extra power that can be generated makes it worth paying for larger pipes to reduce this to around 5%.
It is usual for the penstock to be fitted with a **sluice gate** before the entry. This is to allow the operator to stop the penstock flow altogether so that the turbine can be isolated for maintenance. Sluice gates must not be used as flow control devices by partially closing them, because the excessive turbulence created around the lip of the gate tends to produce cavitation effects which will quickly cause damage.
The **turbine** and **generator** will be housed in a **power house** with the turbine and generator **control gear**. The siting of the power house will depend on flood levels and on where the power is required. Sometimes, it is preferable to use all or some of the power simply as direct **mechanical shaft drive** from the turbine rather than using **electricity**. For decentralized plants up to 100 kW it is best to avoid high voltage distribution, if possible, so the generator should ideally be within 1 or 2 km of the load, because of the cost of transformers. Via the **tailrace**, usually a short open channel, the water flows back to the river. The **transmission lines** are used to distribute the electrical energy generated from the plant to the point of consumption.

In principle, **turbines** are hydraulic motors that convert the water energy into mechanical energy. There are two types of turbines: the impulse turbine and the reaction turbine. The **impulse turbine** converts the kinetic energy of a **jet**(s) of water - a nozzle converts the pressurized low velocity water into a high speed jet - in air into movement of the turbine buckets or blades that it strikes. In **reaction turbines** the blades or buckets are totally immersed in the flowing water. The flow of water through the rotor is deflected in such a way that it creates pressure differences across the blades which cause them to rotate (they are turned by the hydrodynamic lift forces acting on the runner blades). Another possibility to use hydro power is via **reverse pump turbines**. Centrifugal pumps and mixed-flow pumps can be used as turbines by passing water through them in reverse. Both types of pumps are converted into a Francis-type turbine.

The water flow through the turbine has an axial or a radial direction. With a **radial water flow**, the water flow enters the runner radially. With an **axial water flow**, the water enters the runner in the direction of the axis of the runner.

To get an idea of the explanation given, figure 5.5 shows an impulse turbine with a radial water flow. In addition it shows a v-belt gear, by which the mechanical energy of the turbine has been increased into a higher speed. The mechanical energy is converted by the generator in electricity.

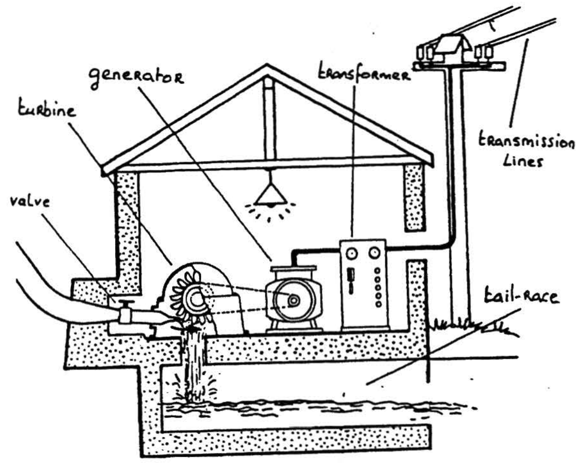


Fig 5.5
A powerhouse.

Source: Bruin, B. de, Small hydro power, an assessment of its socio-economic impacts, TUE, Eindhoven March 1988.

The term **head** refers to the actual height the water falls through, from the turbine up to the point where the water enters the penstock. A division of high, medium and low head is made. High head is the head above 60 metres., middle head is between the 15-60 metres and low head is below the 15 metres. The **flow rate** is the quantity of water flowing past a point in a given time, in litres or cubic feet per second. **Power** is the energy converted per second, i.e. the rate of work being done. **Energy** is the total work done in a certain time.

Via the head and the flow rate, the potential power can be approximated with the formula[17]:

$$P = Q_v * \rho * H * g$$

P	theoretical power in W
Q_v	flow rate in m^3/s
ρ	density of the water in kg/m^3
H	head in m
g	gravity in m/s^2

An estimation of the available power is: $P = Q_v * H * 5$
Or the real output[18] is: $P_{real} = k * P$ and k is the efficiency of the turbine.

The **specific speed** relates the output power of the turbine to its running speed and the head across it. Via the specific speed it is a possibility to select a turbine which runs at exactly the required speed[19].

$$N_s = n_a P_o^{0.5} / G H^{1.25}$$

N_s	specific speed, in metric units
P_o	shaft power, in kW
H	pressure head across turbine, in m.
$n_t = n_a / G$	turbine speed, in revolutions per minute (rpm)
n_a	alternator speed, in rpm
G	gearing ratio

The **part-flow efficiency** is the relative efficiency at part-flow, Q/Q_{max}. Some turbines retain very high efficiencies when running below design flow. In contrast with other turbines where the efficiencies fall away sharply if run at, for example, below half the normal flow.

Water leaving a reaction turbine discharges through a **draft tube** which is carefully shaped to slow down the water so that it enters the tailrace with minimum energy. Slowing down the water increases the pressure drops across the turbine and hence the available power.

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17 *Visser, A., Kleine waterkrachtcentrales deel 1, CICA, Eindhoven Oktober 1984.*

18 *Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991, p. 87.*

19 *Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991, p. 76.*

Since water has to leave the turbine runner at a relatively high velocity in order to exit from the turbine, it still possesses a substantial quantity of energy. To recover this energy efficiently, the water velocity must be reduced gradually by widening out of the exit passageway. The velocity head is thereby converted into suction pressure head which increases the pressure difference across the turbine.

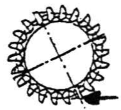
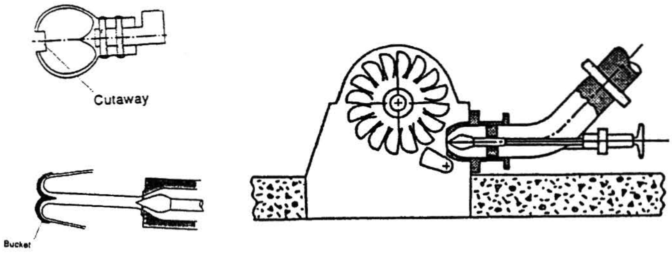
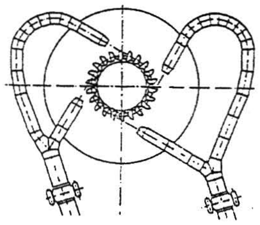
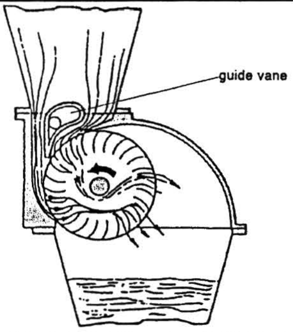
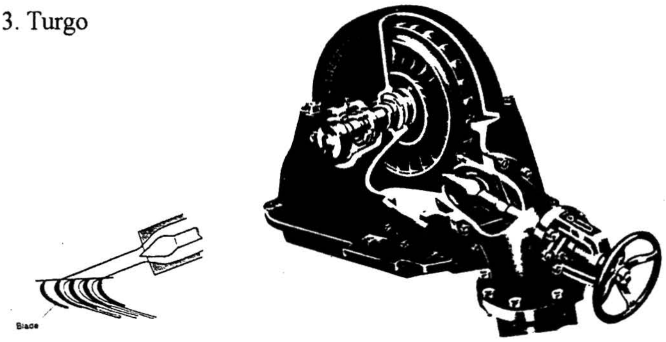
The draft tube generally contains a partial vacuum, so the outlet must remain well submerged below the water surface to prevent air being sucked into the tube and displacing the water column. The difference in level between runner exit and tailwater level is called the **suction head**. In the case of reaction turbines, the head may also include the suction head of the draft tube below the turbine down to the tail race water level.

The magnitude of the useable suction head is limited by the **cavitation** effect. This arises because very low water pressures are induced on the blades of a reaction turbine which is running under high suction. If the pressure falls below the vapour pressure of water at its current temperature, tiny bubbles of water vapour will form. The bubbles are carried by the flow to higher pressure regions where they suddenly collapse and give rise to shock waves which after a period of time will cause serious pitting and cracking of the blades. The need to avoid cavitation often leads to the runner being set lower than ideally desired, so that the suction head is reduced.

Now we have briefly reviewed the principles of hydro power and carefully defined the most important relevant technical terms, we present an overview of the types of turbines presently in use in the world (table 5.a)[20].

[20] *Ibidem as footnote 16.*
Butler, J.G., How to build and operate your own small hydroelectric plant, Tab books, Slough 1982.
McGuigan, D., Small scale water power, Prism Press, Dorchester 1978.
Meier, U., Local experience with micro-hydro technology, harnessing water power on a small scale, publication no. 11, vol. 1, SKAT, St. Gallen 1981.
Portegijs, J., The firefly micro hydro system, Wageningen September 1995.
Technology and Development Group, International course on rural energy planning 2 May - 3 July 1983, THT, Enschede March 1983.

Table 5.a
Types of turbines.

Turbine type	Water flow	Head	Name
Impulse 	Radial 	High	1. Pelton 
			2. Multi-jet Pelton 2-jet Pelton 3-jet Pelton 4-jet Pelton → 6-jet Pelton 
			3. Turgo
		Medium	4. Crossflow 
			3. Turgo 
			2. Multi-jet Pelton — 2-jet Pelton, 3-jet Pelton, 4-jet Pelton, 6-jet Pelton
		Low	4. Crossflow

From table 5.a, a number of aspects become apparent. Impulse turbines are generally used in medium to high-head applications. (The limits on the head are also a function of the turbine size). Reaction turbines have high specific speeds which make them particularly suited to low-head applications. Impulse turbines are only suitable for relatively high heads.

Reaction turbines rotate faster than impulse turbines given the same head and flow conditions. Therefore, it is sometimes possible to couple a reaction turbine directly to an alternator, without using a speed-increasing drive system. Significant cost savings are made in eliminating the drives and the maintenance of the hydro unit is very much simpler.

A distinction can be made between low head and medium head turbines. Low head turbines of a given power rating are much larger, and hence more expensive. Also the cost of civil works is often higher because of the greater amount of excavation necessary and concrete used in low head installations. However, the cost of the penstock is much lower or even avoided, which can considerably compensate for the other costs.

5.3
WORKING PRINCIPLES OF THE VARIOUS TYPES OF TURBINES[21]

1. *Pelton*

A jet of water, from a fixed nozzle, strikes the buckets, which deflect the flow and reverse it so that, ideally, the absolute velocity of the jet is reduced to zero and the water falls away with all its kinetic energy removed. The efficiency is at a maximum when the speed of the bucket is half that of the jet. Because they work on high heads, Pelton wheels have a high power-to-weight ratio. The buckets have a complex shape and their manufacture normally requires skilled casting, from bronze, steel or even aluminium (for very small powers). However, the casing shape is not critical and a steel or concrete box shape can be made very simply. Pelton wheels can be mounted horizontally and vertically and are used under conditions where large heads of water are available. The efficiency can reach 85%. With a part-flow efficiency of Q/Q_{max} > 0.2, the efficiency is between 75-85%. So a large flow range with a high turbine efficiency.
Specific speed of a Singe-jet Pelton is between 10-35 (metric).

In large-scale hydro installations, Pelton turbines are normally only considered for heads above 150 metres, but for micro-hydro applications Pelton turbines can be used effectively at heads down to about 20 metres. Pelton turbines are not used at lower heads, because their rotational speed becomes very slow and the runner required is very large and unwieldy. If runner size and low speed do not pose a problem, then a

[21] *Ibidem as footnote 20.*

Pelton turbine can be used efficiently with fairly low heads. If a higher running speed and smaller runner are required, then there is the option of increasing the number of jets.

2. *Multi-jet Pelton*

One or more fine jets of water from fixed nozzles strike the buckets, which deflect the flow and reverse it so that, ideally the absolute velocity of the jet is reduced to zero and the water falls away with all its kinetic energy removed. A Pelton can be mounted horizontally and vertically. The efficiency can reach 85%. With a part-flow efficiency of $Q/Q_{max} > 0.2$, the efficiency is between 75-85%. The Pelton has a large flow range with a high turbine efficiency.
The specific speed of a Multi-jet turbine increases with the square root of the number of jets. The specific speed for a 2-jet Pelton is 10-45, 3-jet Pelton 10-55, 4-jet Pelton 10-70 and 6-jet Pelton with 10-80 (metric).

Having two or more jets, enables a smaller runner to be used for a given flow and increases the rotational speed. The required power can still be attained and the part-flow efficiency is especially good because the wheel can be run on a reduced number of jets with each jet in use still receiving the optimum flow.

The flexibility of a Multi-jet Pelton can be achieved at modest cost by using electronics to adjust the electrical output rather than expensive spear valves to control the flow of water.

3. *Turgo*

The Turgo turbine is designed to have a higher specific speed than the Pelton turbine. The jet is aimed to strike the plane of the runner at an angle (typically 20°). Otherwise the Turgo wheel is similar to a Pelton wheel. The water enters the runner on one side and exits on the other. Therefore, the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner than a Pelton for an equivalent power. Turgo wheels can be mounted horizontally and vertically. The efficiency can reach 80%. With a part-flow efficiency of $Q/Q_{max} > 0.2$, the efficiency is between 75-80%. The Turgo has a large flow range with a high turbine efficiency. The specific speed is between 20-80 (metric).

Its design and construction are simple, as is the installation and maintenance of the unit. A Turgo runner is more difficult to make than a Pelton one and the vanes of the runner are more fragile than Pelton buckets.

It is competitively priced against the Francis and Pelton turbines. With smaller and faster spinning runners, it is more likely to be possible to connect Turgo turbines directly to the generator, rather than having to go via a costly speed-increasing transmission.

4. *Crossflow*

The Crossflow turbine is the same as a Mitchell-Banki or Ossberger turbine.
This turbine has the water entering the runner as a rectangular jet, passing through the runner radially. The jet of water strikes the blades above the rotor axis, then passes through the rotor and strikes the blades below the axis on exit, imparting angular momentum on each occasion. Although strictly classed as an impulse turbine, because there is air inside the casing, hydro-dynamic pressure forces are also involved, so it is a mixed impulse/reaction turbine.
A Crossflow turbine always has its runner shaft horizontally (unlike Pelton and Turgo).

While heavier and more complex than a Pelton wheel it can operate over a wide range of heads and its efficiency stays reasonably constant over a wide range of flow rates. With a part-flow efficiency of $Q/Q_{max} > 0.2$, the efficiency is between 75-85%. The specific speed is between 20-90 (metric).

Due to the symmetry of a Crossflow turbine, the length of the runner can, at least in theory, be increased to any value without changing the hydraulic characteristics of the turbine. Hence doubling the runner length merely doubles the power output at the same speed. At high heads the Crossflow runner tends to be compact. The lower the head, the longer the runner becomes for a given output. There are practical limits to length in both cases (length runner and blade length). In the case of a short runner operating at high head, efficiency losses at the edges become significant. At low flows, the water can be channelled through either 2/3 or 1/3 of the runner, thereby sustaining a relatively high turbine efficiency. So it is a design suitable for a very wide range of heads and power ratings.

Advantage of the configuration is that the water enters and discharges perpendicularly to the shaft, which allows a compact and simple installation. Furthermore, compared to the other common types of turbine, it lends itself particularly to simple fabrication techniques. The runner blades, for example, can be manufactured from lengths of pipe cut into strips. It can be manufactured in one or more standard diameters, with the width being varied to suit different sites with different power potential.

The Crossflow turbine has higher initial costs compared to, for example, a diesel plant but has only little running costs. This higher initial costs will be compensated in a few years time. This becomes even more evident with rising fuel costs. Since the Crossflow turbine is of the low pressure type, the effect of silt suspended in the water is harmless. Only in rare cases, where silt content is extremely high, a desalting basin must be added to the installation. That, of course, increases the costs.

5. *Francis, Volute-cased*

This is a reaction turbine with a snail-shaped casing, for use with medium head. The water enters tangentially and is directed radially inwards to flow into a rotor which is turned by the water so as to discharge it axially. The runner is completely submerged in water and both the pressure and the velocity of water decrease from inlet to outlet. The water first enters the volute, which is an annular channel surrounding the runner and then flows between the fixed guide vanes, which give the water the optimum direction flow. It then enters the runner and flows radially through the latter, i.e., towards the centre. The runner is provided with curved vanes upon which the water impinges. The guide vanes are so arranged that the energy of the water is largely converted into rotary motion and is not consumed by swirls and other undesirable flow phenomena causing energy losses. The guide vanes are usually adjustable so as to provide a degree of adaptability to variations in the flow rate and in the load of the turbine. The water is discharged through an outlet from the centre of the turbine.
The efficiency of the Francis turbine falls away sharply if run at below half its normal flow ($Q/Q_{max} > 0.5$). If the flow is above half its normal flow, the efficiency is 70% up to 90%. The specific speed is between 70-500 (metric).

The Francis turbine is complex to manufacture due to the difficult shape of castings required and, therefore, tends to be expensive. Runner and housing are usually cast on large units welded housings. Or it is common to cast them in concrete at the site. With a big variety of designs, a large head range from about 30 up to 700 metre of head can be covered. But for small turbines the head range is 5-20 metre.

It may appear strange that the Francis turbine is as popular as it is, given that it tends to be a more complex machine and has such a poor part-flow efficiency. The reason is that the Francis turbine is the only turbine suitable within a certain range of specific speeds. An impulse turbine operating under these conditions would be large and cumbersomely slow-turning.

6. *Francis, Open-flume*

The Francis Open-flume is a reaction turbine for low head. It is often chosen for low head applications because it is far simpler to install and significantly cheaper than a volute cased Francis turbine. The turbine can be placed in a water-filled chamber with its axis horizontal. Guide vanes still direct the flow, but there is no volute casing.

7. *Propeller, Vertical-shaft*
Propeller turbines - in which a rotor shaped like a ship's propeller is immersed in a flow of water - are used at low heads. The water enters the turbine radially, is deflected by guide vanes, spiralling in from above and flows axially through the propeller. Fixed pitch propeller turbines perform very poorly except above 80% of full flow ($Q/Q_{max} > 0.8$) with an efficiency between 75-90%. Propeller turbines are high speed reaction turbines. The specific speed is between 600-900 (metric).

Propeller turbines have the advantage of simplicity of construction. Consisting of a rotor and casing, the latter with either guide-vanes or spiral casing. They can be manufactured using casting or other fabrication techniques. In fact the machine can be designed to be made with the very minimum of machining and the casing shape can be cast in concrete if required. The pitch of the propeller blades can be adjusted for large changes in head and flow rates.

The application is limited to heads from 1 to about 30 metres. Under such conditions, a relatively larger flow as compared to high head turbines is required for a given output. These turbines, therefore, are comparatively larger. Manufacture of small Propeller turbines is possible in welded constructions without the need for casting facilities.
If the Vertical shaft turbine works in an open flume, without casing, it requires less civil works. (So if only the propeller runner is used, seen in table 5.a).

8. *Kaplan*
Another name of the Kaplan turbine, is the Variable-pitch turbine and it is a sophisticated Propeller turbine. The water enters the turbine radially, is deflected by the guide vanes and flows axially through the propeller. Kaplan turbines have blades which can be rotated about their point of attachment to the hub so that they cut the water at different angles depending on the flow rate through the turbine, thus maximising the efficiency. The part-flow efficiency is $Q/Q_{max} > 0.2$ with an efficiency between 80-92%. This means that Kaplan turbines retain very high efficiencies when running below design flow. The specific speed is between 350-1100 (metric).

The flow rate of the water through the turbine can be controlled by varying the distance between the guide vanes. The pitch of the propeller blades must then also be appropriately adjusted. Each setting of the guide vane corresponds to one particular setting of the propeller blades in order to obtain high efficiency. Specially in smaller units, either only vane adjustment or runner blade adjustment is common to reduce sophistication. However this affects part load efficiency.

Their application is limited to heads from 1 to about 30 metres. Under such conditions, a relatively larger flow as compared to high head turbines is required for a given output. These turbines, therefore, are comparatively larger.

The blades of the Kaplan and/or guide vanes are automatically adjusted to suit flow conditions, but this degree of mechanical sophistication on a micro installation would be unacceptable expensive, unless it was manually operated. Furthermore, it is complicated to build.

9. *Propeller, Tube*
Other names of the turbine are the Fixed-blade-axial-flow turbine or the S-turbine. Water is entered in a tube with fixed guide vanes. The fixed guide vanes counteract the rotation of the water caused by the rotor. The turbine is mounted inside a tube and this tube can be bolted to the penstock flange, or more often to an intake built directly into the weir. This layout allows easy access to the generator and permits the use of belt drives.

10. *Propeller, Geared-bulb*
A more normal method for very small turbines, is to have a drive shaft coming out through seals and driving the alternator by belt and pulleys to give the required speed. It has a right-angle drive (using bevel gears) within the expanded hub of the turbine which allows the alternator drive-shaft to exit vertically from the tube, therefore avoiding the need for a bend. Gearboxes are best avoided for very small machines because of cost and maintenance problems.

11. *Propeller, Ungeared-bulb*
Bulb turbines, in which the generator/alternator is packaged into the turbine hub and submerged in the flow so that the need for a powerhouse can be eliminated. The alternator can even be constructed around the rim of the casing, called a **straflo** turbine. These two methods tend to be expensive and more suited to higher powers, although some cheap bulb turbines are available and can have the advantage of being immune to flooding.

Bulb turbines offer the most compact installation. They are more compact than tube turbines, but for a micro-hydro plant bulb turbines are often expensive because they generally need an epicyclic (planetary) gearbox. Furthermore, there is the complication of having the alternator sealed into a watertight enclosure, which carries the rotor, in the centre of the stream of water.

Bulb turbines also reduce the need for excavation at very low-head sites and there is no need for a powerhouse to protect the alternator. However, the special alternators required tend to make bulb turbines relatively expensive.

12. ***Reverse pump turbine***

Centrifugal pumps (a) and mixed-flow pumps (b) can be converted into a Francis-type turbine by operating them in reverse. The principle of both the pumps is that the passage through the rotor reduces in cross-section and serves to accelerate the water and impart energy to it. While the fixed guide vanes are designed as a diffuser to convert speed into pressure and thereby increase both the pumping head and the efficiency.

The turbine centrifugal pump, shown in table 5.a, presents a set of smoothly expanding diffuser channels (six) serving to slow the water down and raise its pressure at the same time. The diffuser channels also deflect the water into a less tangential and more radial path to allow it to flow smoothly into the annular constant cross-section channel surrounding the diffuser ring, from where it discharges at the top. So if it runs in reverse, it's a Francis-type turbine. These pumps are available as turbines for a head of 6 to 305 metre. In some instances, there are turbine-pumps available for heads as low as 3 metre. Normally the pumps have a head range between 4-60 metre, with an efficiency of 30-80%.

The mixed flow pump (table 5.a) presents a surface mounted, suction mixed-flow pump and its installation. Here the swirl imparted by the rotation of the impeller is recovered by delivering the water into a snail-shell volute or diffuser, identical in principle to that of a centrifugal volute pump. The pump has internal blades in the impeller which partially propel the water, but the discharge from the impeller is at a greater diameter than the inlet so that some radial flow is involved which adds velocity to the water from centrifugal forces that are generated. Mixed flow pump can achieve higher efficiency and larger flow rates than a centrifugal volute pump. The efficiency is between 50-90% and the head range varies between 2-10 metre.

When a pump operates as a turbine:

- its mechanical operation is smooth and quiet;
- the peak efficiency as a turbine is essentially the same as its peak efficiency as a pump;
- the head and flow at the best efficiency point as a turbine are higher than they are as a pump at its best efficiency point;
- the power output of the turbine at its best efficiency point is higher than the pump input power at its best efficiency point.

Furthermore it's found that the peak efficiency of reverse running pumps is usually lower than turbines. However, some designers disagree with this[22].

[22] *Sulzer, B., Reverse running pumps as energy recovery turbines, San Francisco.*
Butler, J.G., How to build & operate your own small hydroelectric plant, Tab books, Slough 1982.
Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.

Advantages are that pumps are readily available and many items are stock items. Also pumps are less sophisticated (compared with conventional turbines), easier to install and maintain, and simpler to operate. Additionally pumps are available in a broader range of configuration than conventional turbines (for example wet pit, dry pit, horizontal, vertical, and even submersible). A characteristic is that the turbine maximum efficiencies tend to occur over a wide range of capacity. Consequently, relatively wider ranges of turbine operating head can be accommodated without too adverse an effect upon efficiency.
A disadvantage is that a pump, functioning as a turbine, does not have the flexibility of, for example, a Pelton wheel to run on reduced amounts of water. The efficiency of the pump turbine falls off rapidly as the flow rate reduces, and at 50% flow no power is delivered at all. A possibility is to use more than one pump-turbine set to drive the alternator. At low flow rates, the number of sets in use can be reduced. Furthermore there is a value of head at which the turbine power output is zero even though there is a flow through the unit (this point is called the runaway speed). Reduction in head below this value, causes the turbine to begin absorbing power assuming the connected load is capable of providing that power.

For high-head turbines, the energy remaining at the outlet is normally very small in relation to the total energy and no pronounced effect on efficiency will occur. However, for low head applications it is important to minimize the remaining energy after exit from the runner in order to keep the efficiency high. Consequently, specially designed diffusers and draft tubes may be required at these lower heads when efficiency evaluations are made.

13. ***Firefly***

The Firefly uses the principle of a Crossflow turbine. Difference with the Crossflow is that the runner is much smaller and that the runner has no axis. This is possible because the generator is directly connected to the runner at one side.
Firefly turbines can be mounted vertically (shown in table 5.a) and horizontally. Usually they are mounted vertically because then you have lesser problems of a wet generator.

Because of the generator is directly connected to the runner, the minimal operation head is 5 metre. Below this head the turbine speed would not be enough (below the 1000 RPM) for the generator. Above the head of 25 metre, the runner will probably run too fast for the generator. Besides, the runner cannot stand the forces. However, it needs already a blocking timber in the nozzle for operations above the 15 metres, otherwise the blades might break out. This means that the power output is restricted too. The efficiency is about 65% and the specific speed about 51.

The turbine is not complex. Furthermore it is light, so it is portable. The manufacturing of the turbine is simple and it can be made of locally available materials. Another thing is that the generator can be a second hand car dynamo.

Fireflies are used to charge big batteries, instead of supplying electricity direct to the consumers.

The Firefly is still in development. At present there exists already a new Firefly design, from which the nozzle has been changed. Further investigation is necessary to know the characteristics of this turbine.

Table 5.b presents an overview of the most important characteristics of the various types of turbines. The table can be used for a quick first matching of characteristics and construction requirements. In other words, given a specific construction environment (e.g. low head, irregular flow, limited construction skills) a preliminary choice of technology can be made.

Furthermore, impulse turbines are usually cheaper than reaction turbines because there is no need for a specialist pressing the casing, nor for carefully engineered clearances.

Table 5.b
Characteristics of turbines.

no.	Specific speed (metric)	Range of head in m	Part flow efficiency in Q/Q_{max}	Efficiency	Com-plexity	Weight	Manufacturing
1. Pelton	10-35	20-250	> 0.2	75-85%	only buckets are complex	high power to weight ratio	requires skilled casting, but casing is not critical
2. Multi-jet Pelton 2-jet 3-jet 4-jet 6-jet	 10-45 10-55 10-70 10-80	20-250	> 0.2	75-85%	only buckets are complex	high power to weight ratio	requires skilled casting, but casing is not critical
3. Turgo	20-80	10-150	> 0.2	75-80%	no	< than Pelton	runner more difficult to make than Pelton
4. Crossflow	20-90	6-60	> 0.2	75-85%	yes	> than Pelton	compact and simple
5. Francis Volute-cased	70-500	5-20	> 0.5	70-90%	yes	heavy	difficult shape of castings required
6. Francis Open- flume	70-500	< 8	> 0.5	70-90%	no	< than Francis Vol.-cased	no difficult shape required
7. Propeller Vertical-shaft	600-900	1-30	> 0.8	75-90%	no	larger than high head turbines	simple construction
8. Kaplan	350-1100	1-30	> 0.2	80-92%	no	larger than high head turbines	complicated to build
9. Propeller Tube	600-900	1-30	unknown*	65-90%	no	unknown	complicated to build
10. Propeller Geared-bulb	600-900	1-30	unknown*	65-90%	yes	unknown	relatively complicated to build
11. Propeller Ungeared-bulb	600-900	1-30	unknown*	65-90%	yes	unknown	compact and complicated
12.a Centrifugal pump 12.b Mixed-flow pump	unknown unknown	4-60 2-10	unknown	30-80% 50-90%	no no	unknown unknown	unknown unknown
13. Firefly	51	5-25	unknown	65%	no	light	simple construction

* Completely design dependent.

5.4
AUXILIARY COMPONENTS OF TURBINES[23]

The aim of the turbines we reviewed earlier is to convert hydraulic into mechanical energy and eventually electrical energy. This, however, is impossible without a **governor** and **drives**. In addition, of course, **civil works** are required. Last but not least, mechanical energy has to be converted into electricity by means of a **generator**. All these elements will be briefly discussed in the following paragraphs.

5.4.1
Governors

Electric motors and appliances require a stable voltage and frequency. An electric generator, on the other hand, produces such stable voltage and frequency only if it is run at constant speed. A water turbine delivers such constant speed at a given gate opening if the load on its shaft is kept constant. A governor is a speed regulator which keeps the turbine revolving at a constant speed and consequently maintains the electrical energy generated at a constant frequency. To achieve control, there are chiefly two possibilities that may be applied. By load-control, where the flow of water through the turbine is kept constant and where, therefore, the load has to be kept constant within tolerable limits. The first possibility concerns with electronic controllers that switch any part of the load not consumed by the regular circuit into a ballast circuit, thus keeping the total load on the turbine-alternator set constant. The second possibility is flow-control, where the flow of water flowing through the turbine is adjusted mainly by mechanical controllers, depending on the load on the turbine-generator set. The flywheel may be considered as a part of a flow-control governor. A flywheel serves to 'smooth-out' speed deviations in the transitory period immediately following load changes and gives the governor time to do its job, while keeping speed deviations within limits.

In cases where load fluctuations can be limited, e.g. where changes in load on a plant are small in relation to total output, and relatively infrequent, manual control may be acceptable. As soon as load changes become evident from instrument readings, one can make necessary adjustments on a hand-wheel.

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[23] *Bruin, B. de, Small hydro power, an assessment of its socio-economic impacts, TUE, Eindhoven March 1988.*
Butler, J.G., How to build & operate your own small hydroelectric plant, Tab Books, Slough 1982.
Fraenkel, P., Water-pumping devices, a handbook for users and choosers, Intermediate Technology Publications, London 1986.
Fraenkel, P. and Paish, O. (and others), Micro-hydro power, a guide for development workers, Intermediate Technology Publications, London 1991.
Holland, R., Micro hydro electric power, Intermediate Technology Development Group, Rugby 1983.
McGuigan, D., Small scale water power, Prism Press, Dorchester 1978.
Meier, U., Local experiences with micro-hydro technology, harnessing water power on a small scale, SKAT, St. Gallen 1981.
Portegijs, J., Firefly news 3, Wageningen March 1996.

The mechanical governor seems suitable for installations with a single turbine. It has the advantage of keeping water that is not strictly required for power generation from running through the turbine. This may be important where excess water from the head-race canal is used for irrigation.

A mechanical governor may require much more frequent adjustments and maintenance than an electronic device although the skills required are fewer by far. An electronic load-controller, on the other hand, is a sophisticated piece of equipment. Still, it is solid state, without moving and wearing parts, and if a breakdown occurs, repair could be attempted by semi-skilled personnel, with plug-in modules and according to a prescribed routine. In addition, it might prove cheaper to use an electronic load controller on a station where two turbine-alternator sets work in parallel, instead of two mechanical governors.

5.4.2
Drives

The drive system transmits power from the turbine shaft to the generator shaft. It also has the function of changing the rotational speed from one shaft to the other when the turbine speed is different to the required synchronous speed of the alternator.

Transmission drives may be classified as follows: (1) Belt drives (flat and V-belts), (2) Chain drives, (3) Gear drives (bevel, spur and helical gears), (4) Motor vehicles gear boxes and back axles. In table table 5.c the characteristics of the different drives are summarized.

Table 5.c
Drive characteristics.

Type of drive	Transmission ratio	Efficiency	Others
1. Belt drives Flat V	 < 5:1 < 5:1	 93 - 95% 85 - 95%	Flat belt needs higher tension than V-belt.
2. Chain drives	< 20:1 and higher possible	85 - 99%	Requires less space than belt drives, noiseless in operation, high cost and poor availability.
3. Gear drives Bevel Spur Helical	 < 7:1 < 10:1 < 10:1	 98% 98% 98%	Bevel gear connects a horizontal-shaft with a vertical-shaft. Spur gear connects parallel-shaft. Helical gear is an improved spur gear, it has a longer life and makes less noise than a spur gear.
4. Motor vehicle Gear boxes and back axles	< 7:1	unknown	The torque from the turbine will destroy the gear in a matter of months.

It is usually necessary to provide a step-up speed transmission. A step-up ratio of 5 in a single step from the turbine to a line shaft is then done using either flat belts or vee-belts with pulleys that give the desired line shaft speed. This is a very simple, inexpensive and conventional technique. A properly designed belt drive, with a correct belt tension, requires little care and is quite efficient and durable. If a two step transmission would be required with vee-belts, it will make the construction somewhat more expensive. Other advantages are that the belt drives are standardised and mass-produced, making them relatively cheap.
There is another step-up arrangement, which is the chain drive. The chain drive has a high step-up ratio of up to 20. Advantages of the chain drive compared to belt drives are that they require less space and are noiseless in operation. Disadvantages are the high costs and poor availability. If parts of the chain drive can be made locally, it is a possibility to decrease the costs. Belt drives and chain drives are both used for mechanical power use.

Gear drives have a step up ratio of up to 10 and motor vehicle gear boxes and back axles up to 7. Bevel gears are used for driving horizontal-shaft generators off vertical shaft turbines. Whereas bevel gears enable one to turn a corner, spur gears connect in parallel. The helical gear is an improved spur gear. Basically it has a longer life and makes less noise.
A gearbox is a quite sophisticated piece of equipment and, therefore, costlier than most alternatives. Gearboxes are best avoided for very small machines because of cost and maintenance problems. The gearboxes are used with larger machines when belt drives become too cumbersome and inefficient. Problems of specification, alignment, maintenance and cost rule them out. The torque of the turbine will destroy most motor vehicle gear boxes in a matter of months. The chain drive may be considered as a cost-effective solution compared with the gear boxes.

5.4.3
Generators

A generator converts mechanical power into electricity. It consists of a drive pulley, magnet wheel (rotor), armature winding (stator), direct current for magnetic field and a current output. Figure 5.6 shows a generator with rotating magnetic field and stationary armature winding and the magnet wheel is in the form of a two-part T-rotor.

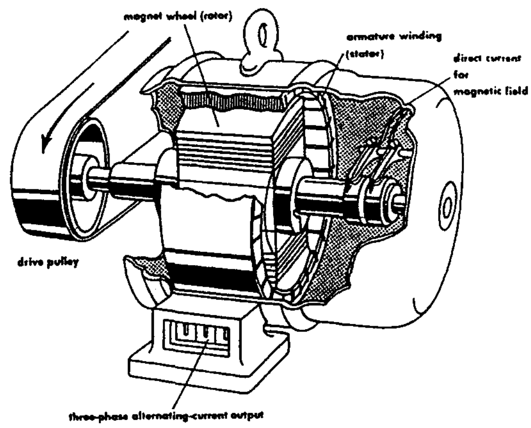


Figure 5.6
A generator.

Source: Meier, U., Local experiences with micro-hydro technology, harnessing water power on a small scale, SKAT, St. Gallen 1981.

The most common type of generator produces alternating current (AC) and is known as an alternator. The other type of generator produces direct current (DC) and is sometimes called a dynamo. A dynamo is used for special applications and low outputs only. Table 5.d presents some features of direct current and alternating current. Direct Current is current which moves in only one direction. Alternating Current is electrical current which periodically rapidly reverses direction.

Table 5.d
Direct and alternating current.

DC	AC
- is lethal much above 110 V. - is single phase - maximum voltages are used at the end-users' supplies and for electrical appliances - is used for low-powered systems of a few hundred watts or less, the current can be fed to batteries	- is lethal much above 240 V. - frequency is 50 or 60 hertz and can be single phase or three phase (for > 5 kW power level) - at usual voltage, there is less line loss during transmission - can be changed efficiently and with a high degree of reliability. DC cannot. - can easily transmit efficiently at high voltages and then back to low, safer voltages close to the point of use - international standard

The advantages of using DC at low power levels are that speed control is not critical and that the low voltages are acceptable because the power does not need to be transmitted over any distance and that battery storage is easily accommodated. AC power can be produced from the DC solid state invertors, but invertors tend to be expensive. Furthermore, there is not a complicated governor required for its generation. A disadvantage of DC is a more dangerous system at higher voltage.

The alternators may be single phase, supplying a voltage of 200 to 240 volts (depending on standard) or more often three phase. Single phase alternators are available in sizes commonly not exceeding 12 kW and may well be used in small installations. Three phase alternators are more versatile in relation to electricity end-use. They are cheaper per kilowatt than single phase and the transmission of three phase saves 25% of conductor costs compared with single phase. Alternators are simpler and less expensive than DC generators, since they do not require commutators.

5.4.4
Civil works

Various possibilities exist for the general layout of a hydro plant. The design approach should work out the layout options that are technically feasible. To determine what are the possibilities, a competent survey is necessary. The surveyor maps the distances, so the available head for a hydro plant can be calculated.
Because the river flow varies throughout the year and the hydro installation is designed to take a constant flow, civil engineering expertise is needed. Furthermore, flowing water in the river may carry small particles of hard matter and sediment. These can cause wear to the turbine if they ar not removed before the water enters the penstock. Sediment may also block the intake or cause the channel to clog up if adequate precautions are not taken. Flood waters will carry larger suspended particles. Unless careful design principles are applied, the diversion weir, the intake structure and the embankment walls of the river may be damaged.
Allignment of channels is important, including the weir, the intake and the channels, because sudden alterations to the flow direction will create turbulence which erodes structures and causes energy losses.
An earth moving expertise is necessary to find suitable foundations to build a weir. Furthermore such expertise can advice about the possibility to build channels on a steep slope.
Building expertise is necessary to choose the most suitable type of weir and to build it. Further, for example, for constructing channels and basins.

Chapter 6
Hydro power possibilities in Kerala

6.1
ELECTRICITY SUPPLY AND DEMAND NOW AND IN FUTURE

The available energy in Kerala (own generation with imports) in 1995 was 1007 MW, whilst the power consumption was 806 MW. In 2000 and 2005, the available energy is forecasted to increase to respectively 1316 and 2679 MW and the power consumption to respectively 1380 and 3000/3912 MW. The electricity is presently almost totally generated by 11 large and middle sized hydro power plants.

6.2
SUPPLY SHORTAGES

On basis of the available information, supply shortages are difficult to forecast with certainty. In the best case scenario consumption will exceed available electricity by 321 MW in 2005. In the worst case scenario consumption will exceed available electricity by 1233 MW in 2005. The installed capacity requirements for 2005 will, of course, be considerably higher (factor 1.5 to 2.0).

6.3
POSSIBLE WAYS TO COVER SUPPLY SHORTAGES

The available information on the future construction of large hydro power plants indicates that supply shortages cannot be met by far by new large scale installations. Small scale hydro power can certainly not solve the overall energy problem. Thermal plants could solve the problem, but whether they will get off the drawing board and see commissioning in time remains to be seen. If a nuclear plant of 1000 MW would be established, power consumption could easily be met by 2005. In face of the available information, however, it is unlikely that a nuclear plant will materialize in time.

6.4
SMALL SCALE HYDRO POWER

Small scale hydro power potential in Kerala is estimated at approximately 150 MW. The number of suitable sites is estimated between 44 and 140. The report of the Western Ghats Co-ordinated Reserach Programme Committee appears to be the most accurate and attractive one and we have, therefore, taken this report as the basis for our further considerations.

Small scale hydro power is particularly important in areas where there is no electricity grid and no other kind of energy supply than the non-commercial energy sources like wood, dung cakes and agricultural waste. These, generally remote, regions will never be connected to a major distribution grid or, if at all, only in the very distant future.

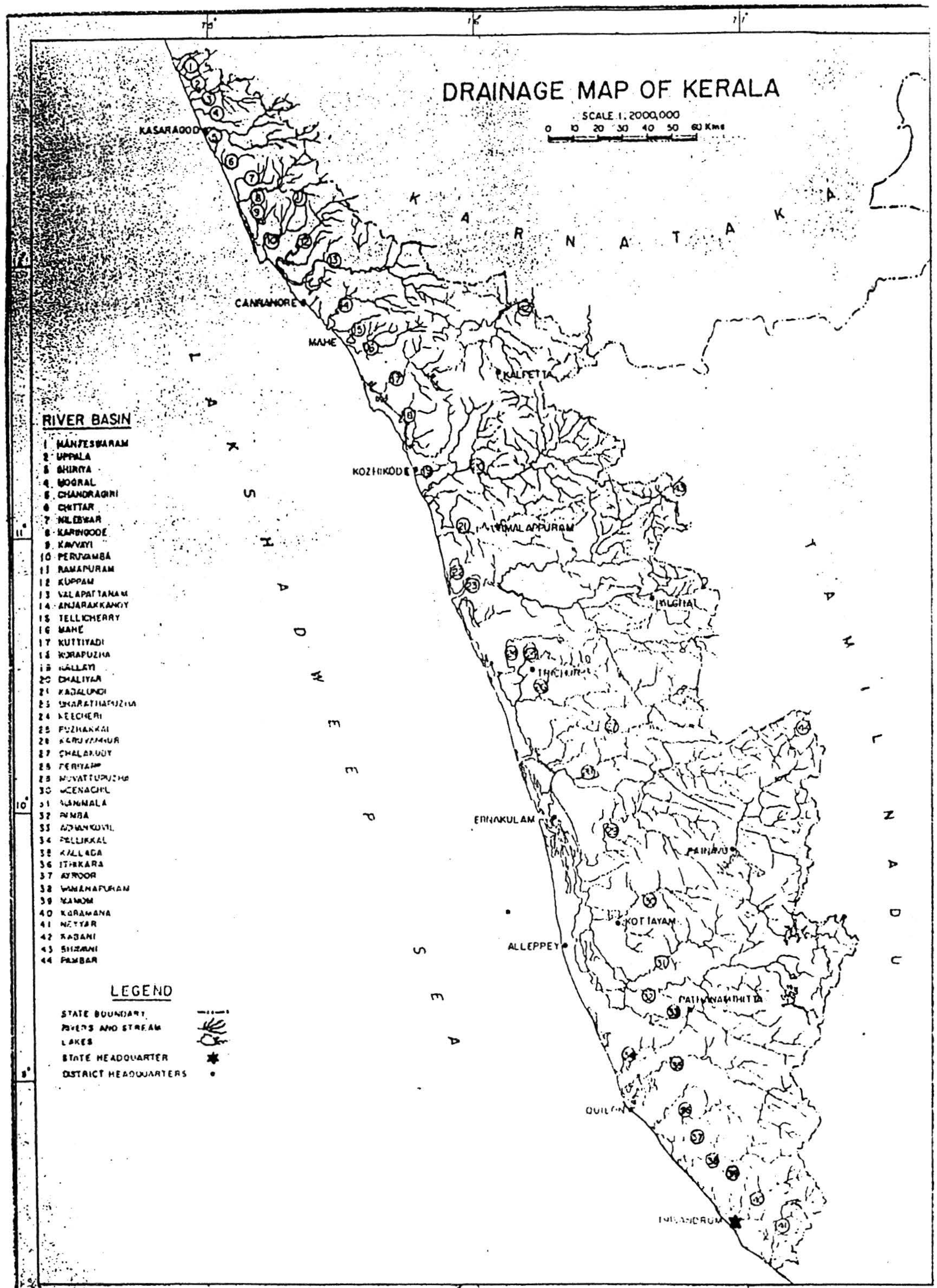
Furthermore, the investments required on distribution networks to remote areas have been escalating steeply, resulting in increasing cost effectiveness of small/mini/micro hydro systems.

6.5
SMALL SCALE HYDRO POWER IN DIFFERENT LOCATIONS

Map 6.1 presents a drainage map of Kerala with 44 suitable sites for mini and micro hydro plants.

If one compares the map with the map of the electricity grid (map 3.1) one sees that there is not yet a grid at the sites suitable for small scale hydro power. At some sites, a grid is proposed but has not yet been realised. It is unknown which sites will really get an electricity grid in the near future, if any.

The sites suitable for small scale hydro power are situated in different environments. Based on general characteristics, it is usually impossible to select the most suitable technologies (turbines). However, to throw some light on the first choice of technolgy we decided to make a distinction between 'low land areas' and 'hilly and mountainous areas'. River regimes tend to be significantly different in the two areas. Twenty suitable sites are situated in hilly or mountainous areas and 24 sites in low land areas.



Map 6.1
Drainage map of Kerala with suitable sites for mini/micro hydro power generation

Source: Western Ghats Co-ordinated Research Programme Committee, Feasibility Survey of Micro and Mini Hydro Potential in Kerala, Thiruvananthapuram 1985.

6.6
SUITABILITY FOR DIFFERENT LOCATIONS

For the selection of a suitable turbine it can be generally said that the part flow effiency has to be good because water flows vary according to geographical location and season. This means that preferably a turbine has to run well even if it runs below optimal water flow. Furthermore, it is an advantage if the specific speed of the turbine is high. The transmission ratio to the generator can then be small. With a small transmission ratio you can use the most simple and cheapest drives. Last but not least, it is better if the manufacturing of a turbine is simple and can be done by the people in the industry in Kerala. Taking the above mentioned criteria into consideration, the following turbines are suitable:

- 6-jet Pelton
- Turgo
- Crossflow
- Francis Open-flume
- Propeller Tube
- Propeller Geared-bulb

Sites which are situated in the mountains and hills, always have a good head. For a turbine this means that when the head is larger, the flow can be smaller. With a small water flow, the part flow efficiency becomes important, because every relatively small variation will affect the water flow. Turbines in principle suitable for mountainous and hilly sites are:

- 6-jet Pelton
- Turgo
- Crossflow
- Propeller Tube
- Propeller Geared-bulb

For flat land sites, with less head, turbines will strongly depend on larger water volumes. For these sites, the following turbines are suitable:

- Crossflow
- Francis Open-flume
- Propeller Tube

6.7
FEASIBILITY

To come anywhere near to solving the overall energy shortage in Kerala by small scale hydro power - with individual plants of a maximum capacity of 5 MW - one needs at least 500 and probably more turbines. If one would choose for mini or micro hydro power installations the number would run in the thousands. Obviously for such a policy one would need to establish a large manufacturing industry and extensive repair and maintenance services. The investment costs - not even considering other disadvantages - would be prohibitive.

Although small scale hydro power cannot solve the overall energy shortage, it can bring economic and social development to the more remote rural areas of Kerala which would otherwise probably remain backwaters forever. The preliminary proposals made in the report of the Western Ghats Co-ordinated Research Programme Committee for installing small scale plants in 44 locations would, therefore, warrant a sound follow up. The advantages of such a plant are obvious:

- small scale plants can be built quickly
- civil works are relatively simple
- local labour and artisans can be used for most of the work
- transmission lines can be short and therefore cheap
- operation is simple and maintenance minimal
- no full-time supervisory staff is required for surveillance
- foreign exchange requirements are minimal
- return on investment materialises much faster than with large plants
- environmental damage can almost totally be avoided.

A good case could be made for carrying out a full fledged feasibility study. Such a study would be the perfect undertaking for two students of our Department.

Chapter 7
Conclusions and recommendations

7.1
RESEARCH QUESTIONS 1 AND 2

The collection, storage and particularly processing of information in Kerala with respect to energy in general and electricity in particular is in a deplorable state. Different units of measure are used, data series do not match and 'writing errors' are at the order of the day. A considerable part of the research time, therefore, went into making data as coherent and reliable as possible. In view of the importance long term statistics for policy making in the field of energy in Kerala, it is recommended that statistics be carefully collected, stored and processed at all relevant levels: production organisations, districts and the state. In addition, the state agencies concerned should introduce consistent units of measure and establish clear and logical channels of communication.

The existing power shortages will increase in future. The two largest consumption sectors are the domestic and industry ones. These sectors soon will have to compete for electricity because the growth rate of consumption is higher than the growth rate of connected load. Therefore, the domestic sector with the highest growth rate can only grow at the expense of the industry. This eventually will hamper further development. By changing the price mechanism one controls and affects the consumption. At the moment the domestic and agriculture sectors are highly subsidized and KSEB sells electricity below the cost price. By increasing the electricity prices for the domestic and agriculture sectors, the consumption growth of these sectors will slow down and enable industry to develop.

The electricity generation is much lower than the installed capacity, mainly due to maintenance and break down losses. Furthermore, the stations are designed to cope with peak demand. Large stations are more flexible to cope with peak demands than small stations but even then - there are only 2 real large stations - there is a limited possibility to cover higher peak demands and generate more electricity in the future. The same applies to the large difference between connected load and electricity consumption. The connected load has to cover the peak demands. Even if all power stations work at 100 per cent, the installed capacity will not be sufficient by far in the near future.

The only possibility to solve the power shortages is by increasing of the total installed capacity through large scale hydro power and other plants. Although many plans are available for large scale hydro power, thermal and even for a nuclear plant, it is doubtful at least whether they can be implemented at such speed to make any difference by the year 2005. Besides, large scale hydro power plants cannot supply adequately remote rural areas. Therefore, and predominantly from a social point of view, small scale hydro power has its merits to bring further development to rural areas. As the research shows, however, small scale hydro power plants cannot solve the future shortages because more than 500 stations would have to be constructed.

7.2 RESEARCH QUESTION 3

At present there are 12 types of small hydro power installations operational in the world which can be classified on basis of their technical principles, like turbine type, water flow and head. With the exception of the 'Firefly', in the past 15 years very little development has taken place in the field of small scale hydro power. The 'Firefly' in principle is a Crossflow turbine. The advantages of the 'Firefly' are that it is small and not heavy, easy to produce and cheap because it can be made of locally available material. The 'Firefly' is recommended for further research because of its unfamiliarity, unknown parameters and possibilities for further development.

At the onset of the research, the researcher did not realise that Mixed-flow pumps and Centrifugal pumps can be used as turbines if the entry point of water is reversed. Little could be found in literature on this type of turbines. In view of the cheapness of the pumps, it is recommended that these aspects are further investigated.

7.3 RESEARCH QUESTION 4

Although small scale hydro power cannot solve the problems of electricity generation in Kerala, small scale hydro power still has a field of application in rural areas. Mainly because of the short building time, low investment costs, the fact that no foreign exchange is required, damage to the environment is kept minimal and access to remote and rural areas is easy. Furthermore, there is no need for long transmission lines, so transmission and distribution losses are lower, the operation of the stations is simple and little maintenance required.

A survey of suitable sites revealed that there are 44 suitable sites in Kerala. already identified. These sites would have a generation capacity of 150 MW. From the map 6.1 it is obvious that suitable sites are to be found mostly in mountainous and low land areas. An estimated 20 sites are situated in mountains and 24 in low land areas. For the mountainous areas, the 6-jet Pelton, the Turgo, the Crossflow, the Propeller Tube and the Propeller Geared-bulb are recommended. In the low land areas, the Crossflow, the Francis Open-flume and the Propeller Tube designs are most suitable.

These recommendations apply to the design of installations with respect to parameters as head, water quantity and regularly of flow. Detailed feasibility studies are necessary for the accurate size of installations, infrastructural works and auxiliary equipment.

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Appendix A: List of references

This appendix contains a list of persons I interviewed during the field work in India. Interviews were recorded in personal notes. In addition, seemingly relevant information was collected at various institutes. Most of this information, however, appeared to be of less relevance to the research. For completeness sake, however, it has been included. Relevant information collected is presented in the bibliography.

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Appendix B: List of names

Since a few years back, the names of cities have been changed back into the old names they had before the English rulement of India. Furthermore, take into account the different types of writing of the same name. Often the pronunciation will be the same.

Different written names for the same city, in Kerala

old names	**new names**
Aluva, Alwaye	
Alleppey	Alappuzha
Calicut	Kozhikode
Cannanore	Kannur, Kannoor
Changanacherry	Changanassery
Cochin	Kochi
Kizhieseri, Keezhussery	
Palghat, Palaghat	Pallakad
Quilon	Kollam
Sultan's Battery	Suthanbatheri
Tellicherry	Thalasseri
Thrichur	Thrissur
Trivandrum	Thiruvananthapuram
Vadagara, Badagara	

Districts have been changed in two districts

Cannanore -> Kasaragod
-> Kannur
Quilon -> Pathanamthitta
-> Kollam

Appendix C: List of definitions

* Available electricity: the electricity generated plus the balance of electricity imports and exports (+imp-exp).
* Draft tube: a tube after the turbine, carefully shaped to slow down the water so that it enters the tailrace with minimum energy.
* Electricity (power) consumumption: refers to the electricity consumed in Kerala only.
* Electricity generation: the electricity generated for the use in Kerala plus the electricity generated in Kerala for export to other states (-imp+exp).
* Electrified village: a village is officially declared as 'electrified' even if a single connection is provided there. For giving even a single connection in a village it is necessary to set up atleast one 11/22 KV line and one transformer.
* Energy: the total work done in a certain time.
* Firm annual generation capacity: the possible capacity to generate at a given level at any time (this given level depends on the minimal water levels as calculated by drought frequency analysis)
* Flow rate: is the quantity of water flowing past a point in a given time, in litres or cubic feet per second.
* Gross Domestic Product: equivalent to value added in the form of incomes of factors of production.
* Gross Domestic Product at market prices: the sum of GDP at factor cost and indirect taxes, less subsidies.
* Gross National Product: the GDP at market prices plus net factor income from abroad.
* Head: the vertical height the water falls through, from the turbine up to the point where the water enters the penstock.
* High head: the head above 60 metres.
* Household: group of persons who commonly live together and would take their meals from a common kitchen. There may be a household of persons related by blood or unrelated persons.
* Impulse turbine: it converts the kinetic energy of a jet(s) of water - a nozzle converts the pressurized low velocity water into a high speed jet - in air into movement of the turbine buckets or blades that it strikes.
* Installed capacity: refers to the specified machine capacity (100% availability) of the hydro power stations and their constituting units.
* KWh: the power produced at the rate of one kilowatt for one hour.
* Low head: the head below the 15 metres.
* Medium head: the head between the 15-60 metres.
* Micro hydro plants: hydro electric stations with a total installed capacity up to 100 KW, having individual generating units with capacities from a few KW to 100 KW.
* Mini hydro plants: hydro electric stations with a total installed capacity of 2000 KW or near around with capacities of individual units from a 100 KW to 1000 KW.

* Part-flow efficiency: the relative efficiency at part-flow, Q/Q_{max}.
* Plant Load Factor: the ratio of the working output of the plant and the capacity of the plant.
* Primary distribution: the power distribution with 11 kV sub-transmission.
* Power: the energy converted per second, i.e. the rate of work being done.
* Power grid: the network of transmission and distribution lines to distribute the electricity generated form the plant to the point of consumption
* Projected demand: the expected power consumed in the future in the state Kerala only.
* Reaction turbine: the blades or buckets of the turbine are totally immersed in the flowing water. The flow of water through the rotor is deflected in such a way that it creates pressure differences across the blades which cause them to rotate (they are turned by the hydrodynamic lift forces acting on the runner blades).
* Real available capacity: the installed capacity (100% availability) minus the break down losses, maintenance losses and reserve shut down losses.
* Secondary distribution: the power distribution with pilferage, metering errors and assessment errors.
* Small hydro plants: hydro electric stations with a total installed capacity up to 15 MW, with individual units having capacities from a 1 MW to 5 MW.
* Specific speed: relates the output power of the turbine to its running speed and the head across it.
* Suction head: the difference in level between runner exit and tailwater level.
* Turbine: a hydraulic motor that converts the water energy into mechanical energy.

Appendix D: Sub-stations

The total number of sub-stations with voltage 110 KV is 49, instead of 31 (presented in the map), at present.

The new stations, which were under construction or proposal in 1990, work at present, named:

New sub-stations with 110 KV
Parassala
Kavanad
Chengannur
Aroor
Keezhussery
Kuttiadi
Kamarkam
Malampuzha
Panoor
Mala
Kanjikode
Athani
Malayattoor
Sengulam
Kaloor
Pathanamthitta

Appendix E: Tables

3.1
Overall, rural and urban population growth in Kerala in the period 1971-2005.

Year	Population in Mln			Density
	Total	Urban	Rural	persons/km2
1971	21.35	2.33	19.02	549
1972	21.73	2.64	19.09	559
1973	22.11	2.96	19.15	569
1974	22.50	3.29	19.21	579
1975	22.90	3.39	19.51	589
1976	23.31	3.46	19.85	600
1977	23.72	3.64	20.08	610
1978	24.14	3.93	20.21	621
1979	24.57	4.14	20.43	632
1980	25.00	4.43	20.57	643
1981	25.45	4.77	20.68	655
1982	25.75	5.00	20.75	663
1983	26.05	5.24	20.81	670
1984	26.38	5.50	20.88	679
1985	26.72	5.77	20.95	688
1986	27.07	6.05	21.02	697
1987	27.42	6.34	21.08	706
1988	27.89	6.65	21.24	718
1989	28.19	6.97	21.22	725
1990	28.63	7.31	21.32	737
1991	29.03	7.67	21.36	747
1992	29.51	7.33	22.18	759
1993	29.92	7.01	22.91	770
1994	30.56	6.70	23.86	786
1995	30.71	6.41	24.30	790
1996	31.11	6.62	24.49	800
1997	31.49	6.85	24.64	810
1998	31.88	7.08	24.80	820
1999	32.27	7.31	24.96	830
2000	32.66	7.56	25.10	840
2001	33.05	7.81	25.24	850
2002	33.50	8.07	25.43	862
2003	33.94	8.35	25.59	873
2004	34.38	8.62	25.76	885
2005	34.83	8.91	25.92	896

3.2
Energy mix in Kerala (compiled from different sources in the period 1991-1995).

Source	Consumption	Unit	Conversion factor GJ/unit	Consumption in 1e16 Joule/yr
Fuelwood	10000000	ton	19.68	19.68
Power grid	7081	MkWh	3600	2.55
Crop residue	1600000	ton	15.07	2.41
LPG (cooking gas)	116000	ton	46.7	0.54
Kerosene	291000	litre	0.0375	-
Dung cakes	3390	ton	2.1	-
charcoal/soft coke + coal/coak/lignite	1500	ton	25.8	-
Biogas	11390	M^3	0.0006	-
Diesel	969000	litre	0.0356	-

3.3
Electricity generation and consumption in Kerala in the period 1970-2005.

Year	Electricity generation (excl. imp-exp) MkWh	Electricity generation (incl.imp-exp) MkWh	Total power consumption (excl.exp) MkWh
1970	2006	2032	1449
1971	2126	2147	1536
1972	2293	2498	1579
1973	2351	2354	1749
1974	2510	2612	1825
1975	2659	2660	1862
1976	2783	2785	2038
1977	3151	3164	2159
1978	4471	4473	2460
1979	5190	5204	2457
1980	5119	5170	2419
1981	5242	5286	2806
1982	5539	5593	2947
1983	4488	4571	2875
1984	3643	3790	2726
1985	4885	4964	3402
1986	5357	5585	3802
1987	4642	5154	3724
1988	4093	5102	3652
1989	4548	5775	4413
1990	5075	6235	4820
1991	5491	6795	5358
1992	5326	7182	5622
1993	6193	7441	5765
1994	5822	7858	6318
1995	6572	8819	7061
1996	7171	9171	
1997	7768	9768	
1998	8482	10482	
1999	8522	10522	
2000	9124	11524	
2001	12374	14774	
2002	13752	16152	
2003	13792	16592	
2004	18380	21180	
2005	20667	23467	

3.4 and 3.5

Electricity consumption per sector in Kerala in the period 1980-1995.

Year	Total power consumption (excl.exp) MkWh	Energy consumption per sector in MkWh				
		Domestic	Industry	Agriculture	Commercial	Others
1980	2419	354	1638	80	158	190
1981	2806	443	1913	80	185	185
1982	2947	549	1876	88	226	211
1983	2875	650	1712	107	222	184
1984	2726	649	1531	110	247	190
1985	3402	800	2060	92	260	190
1986	3802	877	2244	101	360	220
1987	3724	991	1962	131	395	245
1988	3652	1073	1770	146	391	272
1989	4413	1254	2178	186	446	350
1990	4820	1443	2377	217	429	359
1991	5358	1621	2661	206	499	334
1992	5622	1693	2798	224	566	341
1993	5765	1841	2617	235	706	366
1994	6318	2068	2764	261	836	389
1995	7061	2301	3141	271	954	394

3.6

Number of connections and streetlights and per capita electricity consumption in Kerala in the period 1970-1995.

Year	No. of consumers Lakhs	No. of streetlights Lakhs	Per capita consumption KWh
1970	4.87		69
1971	5.44		72
1972	6.38		72
1973	7.11		78
1974	7.77		79
1975	8.25		80
1976	9.1		85
1977	9.88		88
1978	10.72		95
1979	11.72		96
1980	13.37	3.31	96
1981	15.69	3.72	109
1982	18.2	4.12	113
1983	19.7	4.34	108
1984	20.6	4.4	102
1985	22.17	4.52	123
1986	23.96	4.61	136
1987	26.06	4.71	130
1988	27.69	4.76	126
1989	29.37	4.81	148
1990	31.92	4.98	164
1991	34.5	5.21	185
1992	36.98	5.45	192
1993	39.3	5.69	198
1994	41.54	5.74	208
1995	44.17	5.89	231

3.7

Numbers of connections per sector in Kerala in the period 1980-1995.

Year	Total no. of consumers Lakhs	No. of cons. per sector in Lakhs				
		Domestic	Industry	Agriculture	Commercial	Others
1980	13.37	9.57	0.33	0.78	2.67	0.02
1981	15.69	11.50	0.38	0.87	2.93	0.02
1982	18.20	13.55	0.40	1.01	3.21	0.02
1983	19.69	14.72	0.42	1.11	3.42	0.02
1984	20.63	15.47	0.43	1.18	3.52	0.02
1985	22.17	16.75	0.46	1.32	3.62	0.02
1986	23.96	17.95	0.49	1.45	4.06	0.02
1987	26.07	19.64	0.52	1.58	4.30	0.02
1988	27.70	20.90	0.55	1.71	4.51	0.02
1989	29.37	22.30	0.58	1.83	4.63	0.02
1990	31.92	23.91	0.61	2.00	5.39	0.02
1991	34.50	25.78	0.65	2.18	5.86	0.02
1992	36.98	27.61	0.68	2.38	6.28	0.02
1993	39.30	29.42	0.71	2.60	6.54	0.03
1994	41.54	31.22	0.75	2.71	6.84	0.03
1995	44.17	33.29	0.80	2.85	7.21	0.03

3.8

Connected load per sector in Kerala in the period 1980-1995.

Year	Total conn. load MW	Connected load per sector in MW				
		Domestic	Industry	Agriculture	Commercial	Others
1980	1887	601	778	249	169	90
1981	2045	711	793	262	188	91
1982	2360	879	882	290	215	94
1983	2588	1009	915	309	253	102
1984	2774	1128	934	337	271	103
1985	2803	1130	948	345	273	107
1986	3144	1262	1104	362	303	112
1987	3379	1407	1164	384	353	72
1988	3568	1512	1206	407	366	78
1989	3758	1618	1218	447	373	102
1990	4166	1779	1359	493	440	94
1991	4243	1748	1567	451	380	97
1992	4414	1873	1543	468	407	123
1993	4763	1998	1671	516	447	132
1994	4980	2120	1723	537	467	133
1995	5397	2445	1811	538	507	96

3.9
Installed capacity, electricity consumed, projected demand, available electricity and electricity generated in Kerala in the period 1970-2005.

Year	Installed capacity MkWh	Electricity generation (excl.imp-exp) MkWh	Available electricity MkWh	Electricity consumption MkWh	Projected demand MkWh	Real avail. capacity MkWh
1970	4792	2006	2032	1449		
1971	4792	2126	2147	1536		
1972	4792	2293	2498	1579		
1973	5449	2351	2354	1749		
1974	5449	2510	2612	1825		
1975	5449	2659	2660	1862		
1976	6588	2783	2785	2038		
1977	8865	3151	3164	2159		
1978	8865	4471	4473	2460		
1979	8865	5190	5204	2457		
1980	8865	5119	5170	2419		
1981	8865	5242	5286	2806		
1982	8865	5539	5593	2947		
1983	8865	4488	4571	2875		
1984	8865	3643	3790	2726		
1985	8865	4885	4964	3402		
1986	11143	5357	5585	3802		
1987	12939	4642	5154	3724		
1988	12939	4093	5102	3652		
1989	12939	4548	5775	4413		
1990	12939	5075	6235	4820	7068	
1991	12939	5491	6795	5358	7960	
1992	12939	5326	7182	5622	8979	
1993	12939	6193	7441	5765	10140	
1994	13000	5822	7858	6318	11467	
1995	13070	6572	8819	7061	12833	9750
1996	13070	7171	9171		14096	
1997		7768	9768		15316	
1998		8482	10482		16890	
1999		8522	10522		18425	
2000		9124	11524		20395	
2001		12374	14774		22623	
2002		13752	16152		24883	
2003		13792	16592		27653	
2004		18380	21180		30477	
2005		20667	23467		34268	
2010					56423	
2015					79137	
2020					110996	

3.10

Installed capacity, real available capacity and firm annual generation capacity of Kerala's major hydro power stations.

No. of the station	Name of station	Installed capacity MW	Installed capacity MkWh	Firm annual generation capacity MW	Firm annual generation capacity MkWh	Real available capacity in '94-'95, MkWh
1	Pallivasal	38	329	33	285	278
2	Sengulam	48	420	21	182	278
3	Poringalkuthu	32	280	20	172	194
4	Neriamangalam	45	394	27	237	333
5	Panniar	30	263	17	149	167
6	Sabarigiri	300	2628	139	1213	2167
7	Sholayar	54	473	27	233	278
8	Kuttiadi	75	657	28	245	333
9	Idukki	780	6833	230	2015	5111
10	Idamalayar	75	657	37	320	528
11	Kallada	15	131	6	53	83
		1492	13066	583	5103	9750

3.11
Installed capacity and real available capacity per station and per unit in the operational year 1994-1995 in Kerala.

No.of the station	Name of station	No. of unit	Installed capacity MW	Installed capacity MkWh	Operation hours per year	Real available capacity '94-'95 MkWh
1	Pallivasal	1	5	44	7886	39
		2	5	44	6666	33
		3	5	44	7817	39
		4	7.5	66	7924	59
		5	7.5	66	7857	59
		6	7.5	66	6656	50
2	Sengulam	1	12	105	8275	99
		2	12	105	7719	93
		3	12	105	6709	81
		4	12	105	899	11
3	Poringalkuthu	1	8	70	6976	56
		2	8	70	887	7
		3	8	70	6941	56
		4	8	70	7908	63
4	Neriamangalam	1	15	131	8024	120
		2	15	131	7261	109
		3	15	131	7392	111
5	Panniar	1	15	131	5621	84
		2	15	131	6206	93
6	Sabarigiri	1	50	438	8457	423
		2	50	438	5097	255
		3	50	438	7085	354
		4	50	438	7003	350
		5	50	438	7672	384
		6	50	438	8222	411
7	Sholayar	1	18	158	0	0
		2	18	158	8018	144
		3	18	158	7046	127
8	Kuttiadi	1	25	219	4125	103
		2	25	219	4156	104
		3	25	219	3951	99
9	Idukki	1	130	1139	6644	864
		2	130	1139	7526	978
		3	130	1139	6903	897
		4	130	1139	6571	854
		5	130	1139	6036	785
		6	130	1139	5703	741
10	Idamalayar	1	37.5	329	6915	259
		2	37.5	329	7281	273
11	Kallada	1	7.5	66	3657	27
		2	7.5	66	6418	48
			1492	13066	260116	9744

3.12

Installed capacity, real available capacity and electricity generated for the Idukki and Sabirigiri stations in Kerala in year 1994-1995.

Iddukki station with a total installed capacity of 6*130 MW										
Month	Hours of operation per unit						Total hours of all units per month	Real available capacity MkWh	Electricity generation MkWh	Installed capacity MkWh
	1	2	3	4	5	6				
April	696	659	710	425	576	612	3678	478	248	562
May	705	385	707	688	629	558	3672	477	276	562
June	489	497	623	541	479	422	3051	397	197	562
July	79	724	654	515	376	506	2854	371	169	562
August	690	725	671	347	364	0	2797	364	171	562
September	579	711	629	425	188	517	3049	396	213	562
October	648	662	708	311	85	422	2836	369	184	562
November	597	345	407	595	666	364	2974	387	236	562
December	731	744	1	737	587	454	3254	423	285	562
January	296	735	620	667	710	674	3702	481	300	562
February	661	620	476	609	659	489	3514	457	291	562
March	472	718	695	711	716	686	3998	520	327	562
	6643	7525	6901	6571	6035	5704	39379	5119	2897	6739

Sabarigiri station with a total installed capacity of 6*50 MW										
Month	Hours of operation per unit						Total hours of all units per month	Real available capacity MkWh	Electricity generation MkWh	Installed capacity MkWh
	1	2	3	4	5	6				
April	714	0	702	336	693	711	3156	158	107	216
May	693	0	727	735	722	723	3600	180	138	216
June	702	0	711	707	703	711	3534	177	124	216
July	685	0	726	704	731	734	3580	179	115	216
August	744	166	744	644	697	570	3565	178	145	216
September	669	668	701	0	688	689	3415	171	150	216
October	734	734	736	470	718	649	4041	202	178	216
November	711	705	711	667	703	720	4217	211	171	216
December	727	736	707	727	685	640	4222	211	138	216
January	721	712	286	657	735	686	3797	190	121	216
February	637	641	0	663	596	654	3191	160	84	216
March	719	735	334	691	0	734	3213	161	107	216
	8456	5097	7085	7001	7671	8221	43531	2177	1578	2592

3.13
Connected load and electricity consumption per sector in Kerala in the period 1980-1995.

Year	Connected load in MkWh					Electricity consumption in MkWh				
	Domestic	Industry	Agriculture	Commercial	Others	Domestic	Industry	Agriculture	Commercial	Others
1980	5265	6817	2180	1483	789	354	1638	80	158	190
1981	6230	6948	2292	1644	802	443	1913	80	185	185
1982	7696	7724	2542	1886	822	549	1876	88	226	211
1983	8839	8014	2709	2214	896	650	1712	107	222	184
1984	9882	8180	2952	2377	907	649	1531	110	247	190
1985	9899	8304	3022	2391	933	800	2060	92	260	190
1986	11053	9673	3175	2655	985	877	2244	101	360	220
1987	12323	10194	3364	3088	634	991	1962	131	395	245
1988	13243	10565	3566	3204	682	1073	1770	146	391	272
1989	14169	10668	3916	3269	894	1254	2178	186	446	350
1990	15586	11905	4317	3858	826	1443	2377	217	429	359
1991	15316	13724	3947	3325	854	1621	2661	206	499	334
1992	16405	13517	4101	3561	1081	1693	2798	224	566	341
1993	17500	14636	4519	3911	1160	1841	2617	235	706	366
1994	18570	15093	4705	4088	1167	2068	2764	261	836	389
1995	21416	15869	4709	4443	844	2301	3141	271	954	394