OPTIONS FOR RURAL ELECTRIFICATION IN DEVELOPING COUNTRIES

A CASE STUDY IN KASULU, TANZANIA

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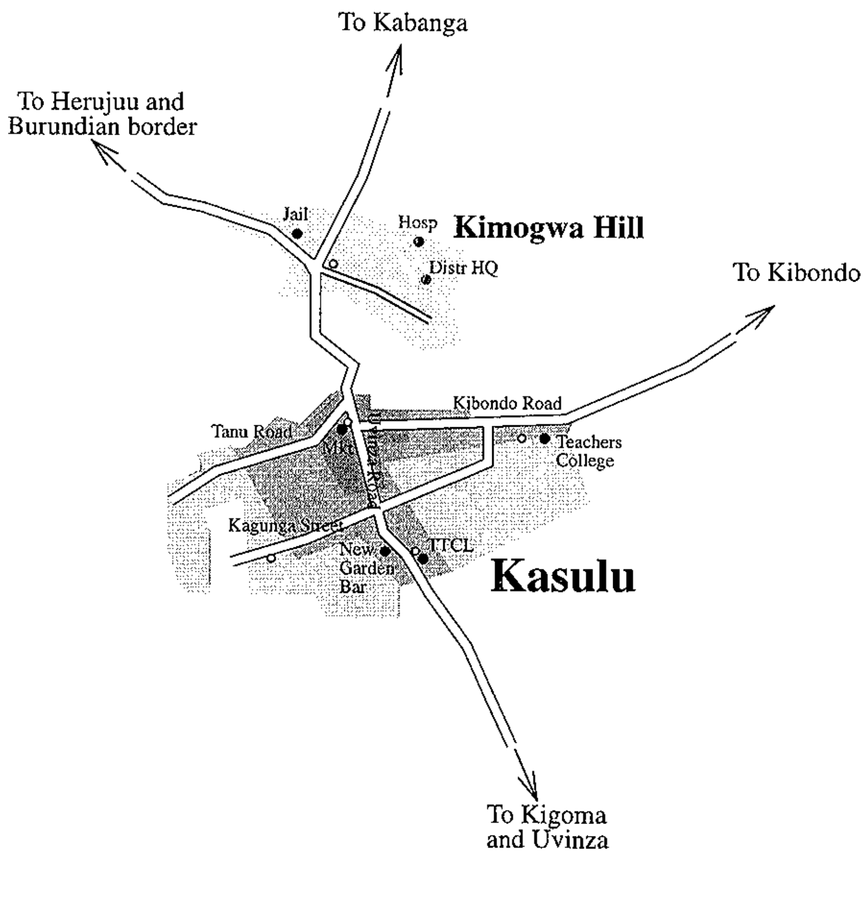
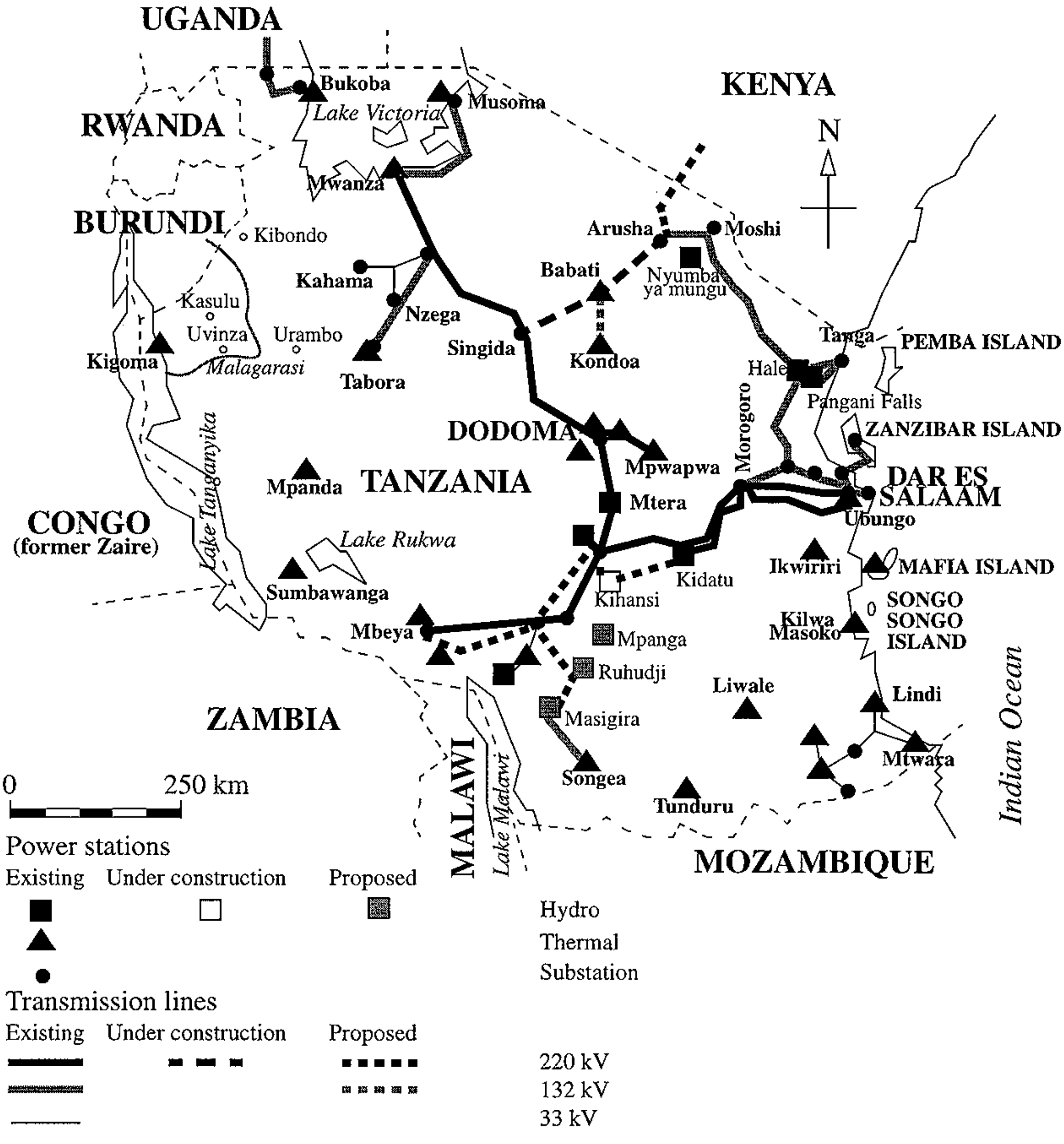


Electric Power Systems, KTH 1997

PREFACE

This report is the result of a master thesis project performed in June to October 1997 by Mikael Amelin and Ellef Hersoug, students at KTH (the Royal Institute of Technology, Stockholm).

MAP OF TANZANIA



Source: TANESCO Distribution & Commercial Services Dept.
Some power stations and proposed transmission lines have been removed by us in order to increase the readability.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

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Finally, would we like to give special thanks to some people who spared no efforts to make our visit to Tanzania pleasant. Thank you, Matiko and Jerome from Dar es Salaam, and Jaffer N. Mohammed, director for Cinderella Adventures Tours & Safaris in Moshi, who we promised to make some advertise for.

LIST OF ABBREVIATIONS

AC	Alternating Current
ACSR	Aluminium Conductor, Steel Reinforced
Ah	Amperehours
BOS	Balance Of System
cal	calorie (= 4.19 J)
C	cost
C_p	power coefficient
c.f.	Coincident Factor
CFL	Compact Fluorescent Lamp
DC	Direct Current
DOD	Depth Of Discharge
diesel genset	An electric generator power by a diesel engine
F(x)	duration curve
f(x)	frequency function
g	acceleration of free fall
HV	High Voltage
I	current
IDO	Industrial Diesel Oil
J	Joule
KAECO	Kasulu Electricity Consumers Cooperative Limited
KTH	Kungliga Tekniska Högskolan (The Royal Institute of Technology in Stockholm)
kV	kilovolt
kVA	kilovoltampare
kW	kilowatt
kWp	kilowatt (peak)
kWh	kilowatthours
L	litres
LDC	Load Duration Curve
LOLP	Loss Of Load Production
LV	Low Voltage
m.a.s.l.	metres above sea level
Matlab	Matrix Laboratory (computer software for numeric computations)
MV	Medium Voltage
MW	megawatt
NGO	Non Governmental Organisation
O&M	Operation and Maintenance
P	active power
p	availability
PV	Photovoltaics

q	unavailability
R (r)	resistance (per length unit)
S	apparent power
SEI	Stockholm Environment Institute
SEK	Swedish Kronor
STC	Standard Test Conditions
T	review period
TANESCO	Tanzanian Electric Supply Company Limited
TSh	Tanzanian Shilling
TTCL	Tanzania Telecommunications Company Limited
U	voltage
UE	Unserved Energy
USD	US Dollar
V	Volt
v	velocity
VAT	Value Added Tax
W	energy
W	Watt
Wp	Watt (peak)
Z	impedance
X (x)	reactance (per length unit)
η	energy efficiency
ρ	mass density
Ω	Ohm

SUMMARY

In this report we have studied available options for electrification of rural areas in developing countries. We have studied diesel generators, photovoltaics, wind power, mini-hydro power and grid extension in perspective of general features, economics, reliability, operation, maintenance, environmental impacts and other effects. We have also made a case study of Kasulu Township in Tanzania concerning the specific possibilities and effects of these supply options.

SUPPLY OPTIONS

Photovoltaics, wind power, and mini-hydro power are all considered as renewable energy technologies since these options use the sun as energy source. Diesel generators are not considered a renewable energy technology since they depend on fossil fuel. The energy in fossil fuel also origins from the sun but the creation of such fuel takes very long time and the usage today will imply that the reserves of fossil fuel is likely to end within one or two hundred years. Grid extension can only be considered as a renewable energy technology if the interlinked power plants only use such technology.

Diesel generators, grid extension and hydro power can individually fulfil the needs of a village or town. Wind power and photovoltaics in an isolated grid must always be used together with a backup system, which could be diesel generators, hydro power with a reservoir or batteries.

Economy

The initial cost is lowest for diesel generators. This fact can partly explain why this option has been the most frequently used for isolated areas, especially if the investment is made by a foreign donator, who might tend to separate this cost from the high cost of operation and maintenance. The costs for operation and maintenance is highest for diesel generators, since these imply a need for fuel which in many developing countries has to be imported.

Considering the economical viability of the supply options, diesel generated power is the only option that is more or less independent of the location of the area that is to be electrified. All the others depend on local conditions. Meteorological conditions affects the choice of photovoltaics, mini-hydro power and wind power. A large daily insolation makes a solution with photovoltaics more profitable. A high head and large flow of water makes hydro power more economical. High wind speeds are extremely important for the economical viability of wind power since the power output of the plant is proportional to the wind speed raised to the power of three. It should though be noted that our study has shown that since the electricity generation costs tend to be high in the considered systems, wind power can be profitable at lower wind speeds than in industrialized countries.

Short distances to a possible mini-hydro power site, areas with good wind conditions and to the national grid makes hydro, wind or grid supplied power less expensive.

The load curve also affects the economical viability of the individual supply option. If the load for instance is large during the sunny hours, it makes photovoltaics more profitable. However many rural areas have their highest load in the evening, when the load is mainly consisting of lighting. The evening peak can be reduced if compact fluorescent lamps (CFLs) are used, because CFLs can give as much light as an incandescent lamp with only 25% of the energy consumption. If the peak load is decreased, the need for installed power in the system is also decreasing.

The economical viability of extending the grid depends on how large the load is in every area or village that is to be connected. This is because several areas can be electrified with a partially common transmission line.

Environmental effects

The environmental impacts of diesel generators can be significant concerning spill oil, greenhouse gases (CO_2) and acidification and must in this respect be considered as the worst supply option. Grid extension will have negligible effects on the local environment but could affect the area around the sites where the power is produced, depending on how the grid power is produced. Photovoltaics as well as wind power plants have by themselves almost no negative effects concerning the environment. These must however, as mentioned above, be used together with a backup system, which of course may imply effects. If batteries are used the heavy metals in them can cause damage. Diesel generators are often used as a backup system and their associated harmful effects are already mentioned. A mini-hydro power plant may interfere with human activities concerning irrigation and farming (if a reservoir is constructed) but a hydro power plant of this size is generally an environmentally benign supply option.

Reliability

In general the reliability of a supply option depends on the size of the system. In order to provide an area with a reliable option and keeping costs down at the same time it is important to have good knowledge of how large the load might be. If the load turns out to be larger than the system is designed for, load shedding might be necessary. On the other hand if the load is lower, the supply might be very reliable but very costly.

It is also important to have good knowledge about the factors that affects the reliability of each supply option. For instance a constant and large flow of water makes hydro power a reliable alternative. Short periods with overcast conditions makes it easier to provide a reliable supply from photovoltaics. Strong and steady wind speeds makes wind power more beneficial considering reliability.

It is important to have a high availability of the power plant in order to get a reliable supply of electricity. In general this is high (close to one) for wind power plants, mini-hydro plants and photovoltaic modules.

For individual diesel generators the availability is low, experiences from Tanzania show that it can be far below 80%. This low figure can be explained by insufficient supply of spare parts, often the case in remote areas, or bad maintenance and the fact that diesel generators tend to be a sensitive technology. The low availability means that a diesel power plant should contain several sets in order to make this option more reliable. Since this option depends on fuel that must constantly be transported to the power plant it makes this option vulnerable to thefts and bad road conditions. The fuel must most often be imported which means that economical problems or international conflicts might affect the reliability of this choice.

An electric supply from a national grid is in general a very reliable option since the power is produced in many interlinked power plants.

The reliability of an isolated system with wind power in conjunction with a backup system most often diesel generators, depend on wind speeds and wind distribution as well as the reliability of the backup system. It is the same thing with photovoltaics and a backup system although this option depend on other meteorological conditions and the backup system might be one or several batteries.

CASE STUDY: KASULU

Kasulu, located in the western part of Tanzania, is a township with about 15 000 inhabitants and no public electric supply. Kasulu Township has not been connected to the Tanzanian national grid that ends in Tabora about 350 km from Kasulu. The reason has been that the total load in the area has not been expected to be large enough to justify the cost of extending the grid.

We have made four estimations of daily load curve for Kasulu. These are based on interviews which we made in the township in July 1997. We have made one high load estimation, one low load estimation, and versions of these two where most of the incandescent bulbs have been exchanged with CFLs. The peak in the high load estimation is 795 kW (598 kW with CFLs) and 332 kW (189 kW with CFLs) in the low load estimation. The load curves are made on several assumptions but we believe that the true load a few years after electrification of Kasulu would be somewhere between the low and high estimations.

Options

In Kasulu there has been formed an electricity consumers cooperation that has, for the purpose of public electrification, been granted two diesel generators that are individually rated 170 kVA. These are in the long run not sufficient to fulfil the need of electricity in Kasulu, but can be used together with new diesel generators or as backup together with another supply option.

Mini-hydro power seems like a viable supply option for Kasulu Township. There are several streams in the hills 10 to 30 km northwest of the township that could be worth investigating. In one of them, River Chogo, which we visited, we have estimated from elementary measurements that it is possible to set up a mini-hydro power station which would, over the year, produce a minimum of 331 kW.

Since Kasulu is situated at latitude 4° S the conditions for setting up a photovoltaic system are good. Fixed modules should be tilted 15° from the horizontal to the north in order to receive the maximum amount of energy on annual basis and still having large enough tilt angle for the rain to drain off, washing dust away. The annual total of the daily insolation corrected for a tilt angle of 15° towards north is approximately 1900 kWh/m^2. The daily insolation per month is almost constant and the maximum length of period with overcast conditions can from hearsay be assumed to be three days. These two facts provide for good conditions concerning sizing of the system.

Wind speeds have probably never been measured in the area around Kasulu Township. We experienced however some windy days at 1500 m.a.s.l. close to the town. According to general opinion in this field of work there is not enough wind in the inland of Tanzania. General theory states however that the wind speed increase about 5 - 10% for every 100 m.a.s.l. Since there are hills around Kasulu at an altitude ranging from 1300 to 1600 m.a.s.l., there are good chances of high wind speeds and measurements should definitely be made. In our scenarios, explained below, we have assumed an average wind speed of 4 m/s and 7 m/s.

Diesel generation is of course possible for Kasulu. This imply a need to invest in more diesel generators except for the two existing. The cost for diesel was in July 1997 0.70 USD/L.

Grid extension for Kasulu would probably mean a 132 or 220 kV transmission line from Tabora that also would connect the towns Uvinza and Kigoma. We have only estimated the price for a 220 kV transmission line.

We have made scenarios for different supply options combined with the four estimations of load curve mentioned above. In each scenario we have with probabilistic simulations estimated the cost per kWh and the reliability for the system. Concerning the investments of the power plant and the distribution system, the method of annuity with a real interest of 4% and 7% has been used.

The exchange of most incandescent bulbs will only in the scenario with a mini-hydro plant imply a lower investment cost. In the other scenarios would usage of CFLs leave the generation costs unaffected or increased with a few cents per kWh.

From these scenarios it is clear that a mini-hydro power plant at River Chogo, if our assumptions are correct, would be the least expensive and most reliable supply option. The cost for this option would be from 0.16 USD/kWh to 0.31 USD/kWh depending on which load curve and real interest that is used (compared to 0.36 to 0.46 USD/kWh for diesel generators). A mini-hydro power plant at this site is probably also a very environmental friendly electric supply for Kasulu Township.

RECOMMENDATION

Based on our experiences from this project, we would recommend foreign development aid agencies to support renewable energy technologies whenever possible. Renewable options represents the most environmental benign solution and in many cases also the most economical. The generation cost for power plants using renewable sources is mostly depending on the real interest rate. If the donator provides a loan with low interest, it could be possible for the receiver to build inexpensive power plants. This means three advantages; the cost for the donator is lowered, since loans, unlike gifts, are repaid, the receiver can build power plants with very low generations costs and finally the receiver will have more responsibility.

Chapter 1

INTRODUCTION

This reports treats the subject of bringing electricity to rural areas in developing countries. The study have been focused on Tanzania, but most theory will be valid in other developing countries as well. We have made a case study of the Tanzanian township Kasulu, located in western Tanzania near Lake Tanganyika (see the map on page II). The report is organised like this:

In chapter two we discuss general features, advantages and disadvantages for four possible supply options for rural electric power systems.

In chapter three we describe our case study of the Tanzanian township Kasulu. We present calculations for several possible combinations of power supply for Kasulu and we also give our recommendations for a future electrification of Kasulu.

In chapter four we suggest a general methodology for planning rural electric power systems in developing countries.

After the main part of the report follows several appendices containing theory about probabilistic simulation of production costs, a general discussion of transmission and distribution, more detailed presentation of the results of our power market survey in Kasulu, Matlab functions used in this report and some remarks about coincident factors and CFLs.

1.1 BACKGROUND

A large part of the population of our planet is living in areas with no public electric supply. Electricity is one of the most important conditions to increase the living standard of the rural population in the developing countries. With electric supply it is possible to increase the efficiency of health care, water supply and education and other basic needs. Electricity is necessary for most industries, either large or small. Electric lighting increases safety and makes it possible for people to use the dark hours for studies or recreation.

In many countries there are problems of growing cities caused by a lot of people moving in from the countryside in search for a better life. This is one reason to why it is of major concern that rural areas provide the possibilities to lead a good life. Providing electric power supply is an important part of increasing the standards of living in rural areas.

It is a huge task to bring electricity to the developing countries and it is of vital importance that the electric energy is generated without harming the biosphere. It is also a question of practical limitations; if all people on earth used as much energy per capita as in Europe, the reserves of non-renewable fuels would soon be exhausted.

1.2 OBJECTIVES

Our objective with this report is to provide a general description of the possibilities to use photo voltaics, hydro power, wind power and diesel gensets to supply isolated rural systems. We also intend to present a proposal of a methodology for how to conduct a feasibility study for rural systems.

It is also our objective to demonstrate our general theories with a case study of the Tanzanian township Kasulu. It is our hope that this case study will turn out to be useful as basic data for decision-making when Kasulu is being electrified.

1.3 CHRONOLOGY OF THE PROJECT

This project was planned from December 1996 to May 1997 and the original intension was to study if the usage of solar home systems in Tanzania would reduce the interest for a future public electric network or if maybe solar home system was the most economical solution for rural electrification. In the end of May 1997, when it was decided that the project should be carried out, the objective of the study had broadened to a more general study of possible solutions for rural electrification and a case study of the township Kasulu in western Tanzania.

After a month of preparations in Stockholm we went to Tanzania for the field work, which lasted during July and August 1997 and was performed in cooperation with Mr. Bosco Selemani from TANESCO. Thanks to his assistance, this part of the project could be carried out without any problems. Our only mistake was to not get "residents permissions" for Tanzania, which had reduced the travelling costs considerably.

This report was written in Stockholm during September and October 1997.

Possible future studies

In this report a lot of our results (especially considering Kasulu) is based on assumptions and guesses and a lot of questions are left unanswered. We therefore propose the following possible sequels to our project:

- Since no wind data was available, we could not make a proper study of the possibilities for wind power in Kasulu. Wind power for electricity generation seems unusual in developing countries and since wind power should be able to compete with diesel gensets (which is a common solution in isolated rural systems), it would be interesting to make a deeper study of this subject.
- It would be a good idea to do a follow-up on our power market survey in Kasulu, a few years after Kasulu has been electrified. This would show which assumptions are reasonable to make when planning for rural electrification at other (similar) sites.
- Our studies indicate that photovoltaic household systems is a comparatively expensive solution for electrification. We have however not studied the possibility to - in a diesel genset supplied system - use photovoltaics and inverters to reduce the diesel consumption during the light hours.
- A general study of the initial phase of an electrification project should be performed. The problem to be studied in this phase is if the generation capacity should be increased in the same pace as the demand is growing or if it is more profitable to build larger power plants from the beginning.

Planning future studies

To avoid the situation when a report has to be based on a lot of assumptions, we would like to suggest that similar studies as ours should include two field visits. The first could be performed after a month of preparations and the aim of this visit would be to get an orientation of the project and collect basic facts. When the report work could be performed in the home country of the students. All new questions that have been raised during the report work, could then be answered in a second field visit.

Chapter 2

SUPPLY OPTIONS

In this chapter we will discuss general features for possible supply options in rural systems in developing countries. We will focus on photovoltaics, hydro power, wind power and diesel gensets and briefly mention grid extension. We will not consider bio mass. The reason for excluding bio mass is that in many areas there is a shortage of fire wood supply. Also, small scale bio mass plants have been studied in a master thesis work at Luleå Tekniska Universitet, [10]. Other, more futuristic alternatives like solar thermal technology or fuel cells, have also been excluded from the study.

2.1 PHOTOVOLTAIC SYSTEMS

General features

A photovoltaic system can produce electric power from solar radiation. The intensity of the solar radiation just outside the earth's atmosphere on a plane normal to the suns rays is known as the solar constant. This value varies a bit due to the elliptical motion of the earth, but the average value is 1353 W/m^2. When the radiation passes through the atmosphere an amount of this is lost in scattering and absorption. The solar radiation on the surface of the earth is made up of a direct component and a diffuse component. The sum of these two on a horizontal plane is called the *global irradiance* and can exceed 1000 W/m^2 on a clear day in the tropics.[1]

The amount of energy from the global irradiance over the day is called *daily insolation* and is measured in Langley (cal/cm^2) or kWh/m^2.

The annual total of the daily insolation varies of course due to weather conditions and latitude of the site. I northern europe it is about 1000 kWh/m^2 and in desert areas about 2200 kWh/m^2.[2]

The basic component in a photovoltaic (PV) system is the photovoltaic cell that produces DC electricity directly from solar energy. Photovoltaic modules are flat and consist of several cells connected together to provide voltages and currents high enough for practical use. The modules are encapsulated behind glass to protect them from the weather.

The material used in commercial cells is basically silicon in mono crystalline, poly crystalline or amorphous form. Research is made on cells with other semiconducting materials in order to improve energy efficiency as well as reducing cost.

The maximum practicable energy efficiency for crystalline silicone cells is about 25% but the real energy efficiency of commercial modules with mono crystalline silicon is typically about 14%[3]. This means that 14% of the solar irradiance on the cell area of the modules are converted to electric power.

To compare solar cells and modules it is usual to give the maximum power output in peak watts (Wp) at Standard Test Conditions (STC) which are irradiance at 1000 W/m^2 with an

1. [16], p. 6 - 7.
2. [18], p. 10.
3. [16], p. 8.

energy distribution as the sunlight through 1.5 layers of atmosphere (corresponding a tilt angle of 45°) and a cell temperature of 25 °C. The energy efficiency for modules is given at STC.

For fixed modules the tilt angle (angle from the horizontal) should as a rule of thumb be about the same as the latitude of the site in order to maximize the solar radiation received on an annual basis. This means of course that the panels are mounted towards north for countries on the south side of the Equator and to the south for countries on the north side of the Equator.

If there exists data of the average daily insolation from the specific site per month it is possible to multiply these data with correction factors which gives the daily solar energy of an area at the tilt angle under consideration. In this way it is possible to find the tilt angle that gives the optimal result for the year. These correction factors are tabled in the literature for different latitudes and tilt angles. [4]

However the tilt angle should not be less than 15° to ensure that rain water drains off easily, washing dust away. For sites on latitudes between 15° S and 15° N the tilt angle should then always be 15°. The direction of tilt depends as a rule of thumb on which part of the year has the cloudiest month. For instance if the cloudiest month is July the modules should face north (for all sites with latitudes between 15° S and 15° N). If the cloudiest month is December the panels should face south.[5] The method with correction factors could also be used in order to choose the direction of tilt angle better for sites close to the equator.

It is not always optimal to choose the angle strictly towards south or north, it is also be possible to mount the panels to a bit to east or west if the afternoons or mornings generally tend to be cloudy.[6]

If the modules are mounted on a support structure that tracks the sun through the day the output exceeds that from fixed modules with at least 20%.[7] It is also possible to choose a mounting which provides the possibility to change tilt angle by hand perhaps once in a month.

The modules delivers power only during day hours (smaller amounts on cloudy days). This means that when power is needed on other hours a backup or storage system (rechargeable batteries) is needed.

For a system with a diesel generator the generator tend to be cheaper per kW for a bigger generator. This is not the case with a photovoltaic system. A linearly increase of the system compiles a linearly increase of the number modules needed, which will almost mean a linearly increase in the cost of the modules. This means that a centralized (with a local grid) photovoltaic system which serves a whole village is not necessarily preferred. A household system with individual modules for each consumer may be well as interesting. This system has the main advantage that it avoids the need for a distribution system.

Balance-of-system components

Except for the modules there are other necessary parts in a PV system. These are called balance-of-system (BOS) components and are:

- Cabling
- Mounting
- Batteries or backup generator
- Control unit - to protect the system from short circuits, over charging and over discharging of batteries.[8]
- Inverter - necessary for usage of AC equipment.

4. [17], pp. 377.
5. [17], p. 174.
6. [17], p. 174.
7. [16], p. 10.
8. [17], p 75.

Batteries [9]

Batteries are often used in a PV system and functions as energy storage and output regulation. This means that batteries are very important BOS-components.

If a battery is deeply discharged the cycle life, the number of times the battery can be discharged and recharged, is affected. The manufacturers specify a depth of discharge, called DOD, as a percentage of the rated storage capacity which is given in Amperehours (Ah). The DOD is the extent to which a battery should be discharged under normal conditions and the battery can be permanently damaged beyond the maximum permissible DOD.

For a PV system, a battery with long cycle-life is obviously preferable since charging and discharging happens continuously. But a high DOD as well as a high rated storage capacity are important characteristics since they reduce the number of batteries that are needed in the system.

The performance of batteries is affected by temperature. The rated capacity is most often quoted at 25 °C. It will be lower below this temperature and higher above up to about 40 °C. Continuous operation above 25 °C will reduce life span of the batteries. Below 0 °C freezing of the electrolyte can cause permanent damage.

There are basically two types of batteries that are used in PV systems; lead acid batteries and nickel-cadmium (Ni-Cd) batteries. The Ni-Cd batteries performs better but are more expensive.

There are several versions of the lead acid type. The version used in cars is able to give a high current (to the electric generator that starts the engine), but has a cycle life of about 1000 cycles at a repeated depth of discharge of 20% which can be compared to about 12 000 cycles for the Ni-Cd version at the same depth of discharge. This means that car batteries are not optimal for use in a PV system. There are however other types of lead acid batteries that are more suitable as storage system.

Ni-Cd batteries has besides good performance concerning depth of discharge and cycle life the advantages that they can be fully discharged without damage and that they have a high tolerance to being overcharged.

Vented lead acid batteries need maintenance. They loose water from gassing during operation and need topping up. There are sealed lead acid batteries with large electrolyte reserve and catalytic recombination of gasses which reabsorbs the water. These do not need maintenance during their life. Ni-Cd batteries need almost no maintenance.

Centralized system

This means that one large array of PV modules provides power for all consumers in the area. Centralized systems has been built up to at least 50 kWp (kilowatts peak) for rural electrification. On Pellworm Island in Germany, a PV system with 300 kWp in conjunction with diesel generators has been set up for a holiday centre.[10]

This type of system means that a piece of non-shadowed land and a control building with batteries (or backup generator) are necessary. A distribution system must be built and the DC voltage must be converted to AC and transformed to higher voltage in order to reduce energy losses in the distribution system. This also means that standard AC products may be used by the consumers.

9. [5], p 29 - 31.
10. [9], p. 6.

Household system

With household system we will mean a system where each consumer, that is not necessarily a household, has their own module or array of modules and BOS-components and no distribution system is connecting the consumers together.

An inverter is not needed if the appliances can use DC and the voltage delivered (often 12 V). When the power is to be used for lighting or other appliances during night or cloudy days batteries are needed. A small diesel (or gasoline) generator as backup for a household system would probably be an expensive option, since it in general has a low energy efficiency.

Household system versus centralized system

The household system has many advantages[11] compared to the centralized, such as:

- A distribution system is not required.
- No metering system is needed.
- No distribution system means that there will be no unauthorized connections.
- A failure in the system affects only one consumer.

The centralized system have some other advantages:

- In a household system each consumer must have a system which is large enough for their peak load demand. The consumers might not have their peak demand at the same time of the day or the same day of the month. This means that a centralized system could be built smaller in terms of total number of modules and batteries (if used).
- Thanks to the distribution system that connects the consumers together a backup generator is more favourable, since this can be higher rated and therefore more economical viable.
- Operational cost may be lower.
- This system could provide power for bigger load during day hours. This could contribute to economical development of the area.

Reliability

It is important to size the system correctly in terms of the number of modules and batteries (or size of back-up system) so that electricity is available when the consumer needs it. To do that it is important to have good data concerning irradiance over the year. It is not only the average value per day, month or year that is interesting, it is also important to know how many overcast days there can be in a row in order to size the storage system.

Many household systems have been set up in developing countries in rural electrification programs and the performance of these systems have generally been satisfactory.[12]

It is difficult to find data concerning experiences about centralized PV systems but according to one source these "have in general shown poor reliability in practice".[13] According to another source some of these systems have had problems with inverters and other components while others have worked well.[14] The centralized system is of course more complicated which makes it more sensitive.

Operation and maintenance

Maintenance consists of cleaning the modules once in a while. In Kasulu in Tanzania, which seasonally is very dusty, one user of a household system reported that cleaning was necessary

11. [16], p. 60.
12. [16], p. 66.
13. [7], p. 61.
14. [16], p. 66.

once a week. It can also be necessary to check for shadowing from growing trees.

About maintenance of batteries see ***Batteries*** on page 5. If diesel generators are used as backup there are of course maintenance issues concerning them (see section 2.4).

Environmental effects

A PV system is a very environmentally friendly supply option for electrification. It does not produce any pollution and the materials used in the panels are generally harmless.

However the production of panels with mono crystalline silicon cells is very energy demanding and the energy pay-back time for such panels is about eight years. This means that it takes eight years for the cell to produce the same amount of energy that was used in the production of it. But the life span of the panels seem to be unknown and it could be more than thirty years which of course reduce the effect of long energy pay-back time. The production of the thin film type of PV cells that is now being developed will need less energy.

The environmental problems, if any, are mainly in the backup system. If a diesel generator is used as a backup system there are many negative effects (see section 2.4). Acid and heavy metals are often used in rechargeable batteries. The acid cause acid burns in contact with skin and even blindness in contact with eye. The heavy metals can cause severe negative environmental effects if the batteries are not disposed or recycled properly. Heavy metals are accumulated in living organisms and affects the organism. In the human body, lead affects synthesis of blood and cadmium affects kidney functions.

Costs in general

The investment in a PV system consists mainly of the modules. The production cost for PV modules have decreased during the last twenty years; from about 35 USD/Wp to about 5 USD/Wp (1994), and the cost is expected to decrease even further. According to one source the cost might be as low as 2 USD/Wp by the year 2000.[15]

Concerning cost of complete household systems see section 3.7.

2.2 MINI-HYDRO POWER

The definition of mini hydro varies in literature and will here be used to describe systems from 100 kW up to approximately 500 kW.[16]

General features

Hydro power is a renewable energy technology since it is the sun that powers the hydrological cycle. About one quarter of the sun's radiation that enters the atmosphere of the earth results in evaporation of water. This vaporized water condenses in the atmosphere and precipitates as rain or snow. Some of this precipitation will occur on land and if the landform is suitable the water, on its way to the oceans, can be collected in a river and made fall through a turbine in a hydro power station and produce electricity.

The principle of hydro power is that water piped from a high level to a low level can do work at the low level. Two site specific variables determine the theoretical power P [W] that is available. These are the head H [m], which is the height of the water falls, and the flow rate of water Q [m^3/s]. P also depends on the density $\rho = 1000$ kg/m^3 of water and the gravity $g \approx 9.81$ m/s^2

$$P = \rho g Q H = 9810\ QH \qquad (2.1)$$

15. [12], pp. 77.
16. [7], p. 48.

According to equation 2.1, a high head and a large flow rate are desirable in order to get a high power output from the system.

Mini-hydro power systems

Before setting up a hydro power station at a river the head and flow must be known. The head can be measured once and for all but the flow must be measured over a period of time. The flow may of course vary throughout the year as well as from year to year.

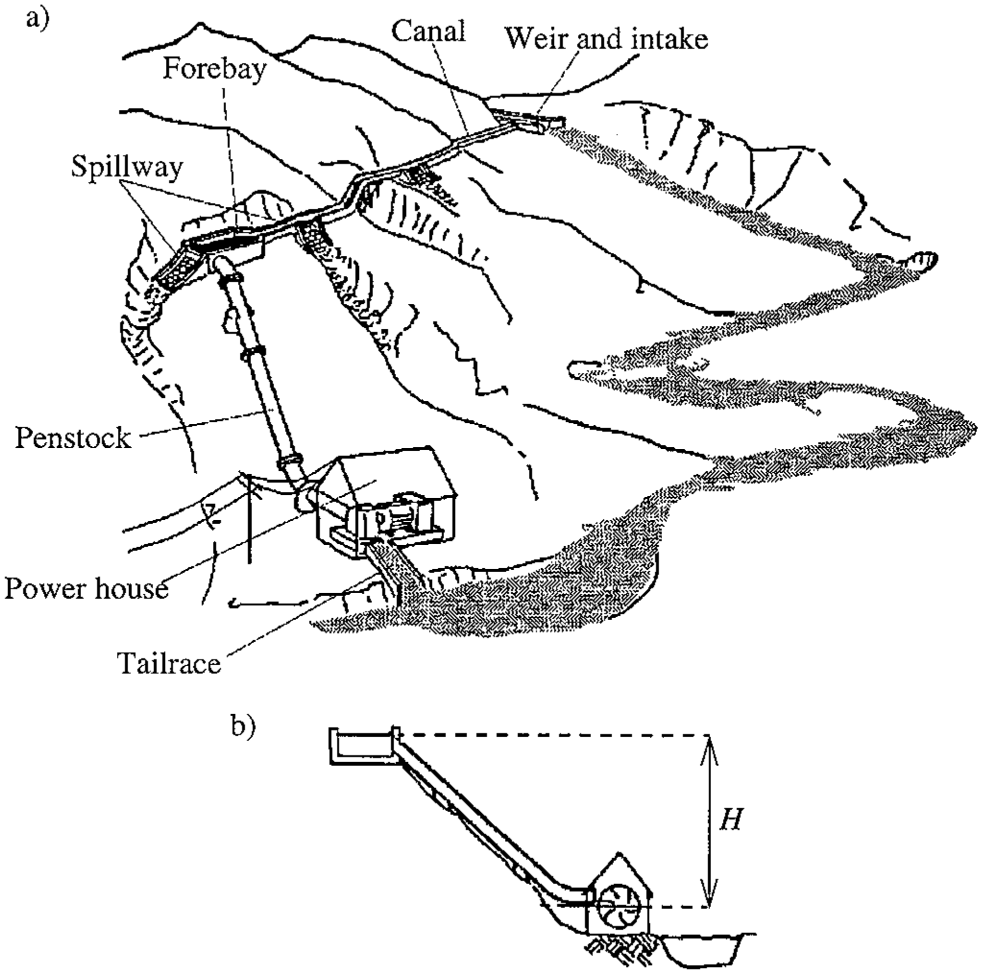

Figure 2.1: a) Components of a run-of-the-river mini-hydro power plant
b) Definition of head

A mini-hydro power system generally consists of:

- Weir or dam
- Canal with forebay and spillways
- Penstock
- Powerhouse with turbine, generator and control system.

A dam is most often built across the river to form a reservoir. The reservoir makes it possible to store water (energy) for a period. The dam can be made of concrete or soil. Hydro power plants without a dam are called run-of-the-river plants. They have instead a weir which is a barrier across the river that is built in order to keep the water level constant to provide for constant flow through the intake.

The intake is protected by metal bars from debris in the water. The intake should of course be placed as high above the turbine as possible in order to maximize the power.

The canal transports the water to the penstock. The water should loose as little head as possible in the canal. The canal is not really necessary in the system but since the penstock is expensive the canal reduce costs. The canal has a forebay where the water is slowed down and the suspended particles settle out on bottom. There should also be spillways associated to the canal. The spillways lead the water safely back to the river when the sluice or the valve on top of the penstock is shut for instance on occasions of turbine overhauling.

The penstock transports the water under pressure from the forebay to the turbine. It is typically made of concrete, wood, plastic or steel. In high head constructions the cost of the penstock tends to be 40% of a mini-hydro budget.[17] The capital cost of the penstock decreases of course with decreasing diameter of the penstock. But head losses, that is reduction of effective head due to friction, increases with decreasing diameter. Therefore sizing a penstock means choosing between high cost and good performance or low cost and bad performance.

There are two types of turbines; impulse turbines and reaction turbines. In impulse turbines the water under pressure is turned to a jet that strikes the blades of the turbine. The typical impulse turbines are the Pelton wheel and the Turgo wheel. The impulse turbines are mainly used in high to medium head applications.

The reaction turbines runs waterfilled. The blades are shaped in such a way that when the water flows through the turbine a pressure difference is created across the blades which causes the turbine to rotate. Examples of reaction turbines are the Francis turbine which is mainly used in medium head installations and propeller turbines like the Kaplan model which is used at low head installations.

The rotor in for example a four pole generator needs 1500 rpm to produce electricity at standard 50 Hz (one phase or three phase). This means that the turbine should have a speed as close to 1500 rpm as possible in order to minimize the need of speed-changing (the need is most often to increase the speed) gears, pulleys or belts. This is the reason why different turbines are used at different heads (different turbines have different speeds when used at same heads).[18]

The speed of the turbine is controlled by the governor. It is important to have a constant turbine speed in order to keep the frequency constant. This is because electrical equipment is sensitive to fluctuations of frequency. When the load is increased the speed of the generator decreases. The governor senses the increase of load by mechanical or electrical means and opens appropriate valves to provide a larger flow through the turbine.[19]

The turbine efficiency can reach 90% in optimum conditions and the generators used in small hydro power plants usually have an efficiency of 85 - 95%. This means that the overall efficiency for a mini-hydro power plant is in the order of 70 - 85%.[20]

Operation, maintenance and reliability

The work concerning O&M consists for instance of keeping all water ways free, lubrication of bearings and other moving parts and checking for leaks. Some of this work should be performed daily.

This supply option is a very reliable one concerning the technology, if well maintained. The flow of water can nevertheless be irregular. Some areas can for instance have several years of drought. So good records of data from a long period of time concerning rainfall is important to have before setting up a power station.

17. [6], p. 54.
18. [6], p. 7, 74.
19. [6], p. 89.
20. [7], p. 48.

Environmental effects

Mini-hydro power is basically a very environmentally benign supply option. But there are a few problems.

In some rivers, in some countries, there exist migrating species of fish and for these the power station must be specially designed. There must be a by-pass of water or a fish-ladder (a series of pools) that provides the possibility for the fish to go up- and downstream.

A hydro-power scheme may conflict with the irrigation needs in the area. This must be investigated before constructing. If a reservoir is built this could be designed to actually enhance the conditions for irrigation.

Overtopping of a dam as a result from exceptional flood conditions can be disastrous. The water can undermine foundations and scour away the downstream river banks which could lead to a collapse of the dam. But this can be avoided with a proper design of the dam with spillways that lead excess water safely back to the river.[21]

A reservoir may increase spreading of water related diseases. Close to the Mtera reservoir in Tanzania the prevalence of malaria in the population has doubled compared to the time before construction of the dam.[22] This reservoir is however very large and stores water for a 80 MW power station which is not in the scale of what is discussed in this paper. But still it is possible that construction of a reservoir of any size may have effect in this respect.

Costs in general

The initial cost for hydro power plants are in general higher than the one for diesel generators with the same output, but it is difficult to state an initial cost per kW for hydro power plants since a lot of the investments are site specific.

In the cost of this supply option it is necessary to include the transmission lines from the site to the load centre since this must be considered an extra cost compared to for instance diesel power plants which can be placed almost everywhere. The initial cost of the hydro power plant therefore depends on the distance from the site to the load centre. The construction of canal, penstock and roads also depends on the site and the location of the site. The cost for buying or renting land should also be included.

A hydro power plant with a reservoir has in general a higher initial cost than a run-of-the-river system, but the reservoir can increase the production of electric energy.

There should however be possible to build mini-hydro power plants that are not more expensive than 10 000 USD/kW.[23] According to another source[24] it should be possible to set up a mini-hydro power plant to the cost of 2000 USD/kW to 7000 USD/kW.

The costs for operation and maintenance are not very high, at least not compared to diesel generators, since there are no expenses for fuel with this supply option. In Sweden for instance the cost for O&M is about 0.005 USD/kWh in mini hydro power stations.

2.3 WIND POWER

General features

About 0.25% of the energy in the solar radiation that reaches earth is transformed into kinetic energy in the atmosphere; wind energy.[25] The power P of the wind depends on two variables;

21. [7], p. 48.
22. [4], p. 22.
23. [6], p. 13.
24. Mr. Katyega, Chief Technical Engineer at TANESCO, Dar es Salaam, Tanzania.

the wind speed v [m/s] and the area A [m^2] under consideration, where the area is vertical to wind direction. P also depends on the density ρ of air. This density ranges approximately from 1.1 kg/m^3 to 1.3 kg/m^3 depending on temperature and air pressure.

$$P = \frac{1}{2}\rho A v^3 \tag{2.2}$$

With a wind turbine some of this power can be used as mechanical work in for instance a mill or converted into electrical power, which we will concentrate on in this paper, with a generator. To compare the performance of different types of turbines one uses the power coefficient C_p which is defined as the ratio between the assimilated power P_a and the power P in the wind.

$$C_p = \frac{P_a}{P} \tag{2.3}$$

It is however not possible to extract all of the energy in the wind, not even theoretically. To assimilate power in a wind power plant the wind has to pass the plant and this means that the wind must contain energy when leaving the plant. 1927 Albert Betz showed that C_p can not be greater than 16/27. In other words it is only possible to extract 59.3% of the power in the wind.

It is important to realize that P (and P_a) depends on the wind speed v to the power of three. For instance a doubling of wind speed means eight times as much power. This means that the wind speed is extremely important for the output of a power plant.

The best places for strong steady winds are in the temperate latitudes (between 40° and 50° N and S) and areas close to the sea.[26] The wind speed increases with the height of the ground above sea level. Typically it increases 5 - 10% for every 100 meters.[27] It also increases with the height above the ground. If the wind speed v_1 at height h_1 is known the dependence can in general be described with

$$v_2 = v_1 \cdot \left(\frac{h_2}{h_1}\right)^{\gamma} \tag{2.4}$$

where γ depends on the structure of the surface. $\gamma = 1/7$ is often appropriate for very smooth sites. This value is higher for more obstructed sites.

The wind speeds at a given site can be well described by the Weibull distribution, stated in equation 2.5. This distribution $F(v)$ tells which proportion of a period (typically one year) the wind speed exceeds v. From F it is possible to calculate mean wind speed, power, variance etc.

$$F(v) = e^{-\left(\frac{v}{\alpha}\right)^{\beta}} \tag{2.5}$$

F depends on the site in two parameters, the scaling parameter α and the shape parameter β. If the distribution function for the wind speed at a site is known α and β can be calculated. However this is not often the case. It can for many sites be assumed that $\beta = 2$, which gives the Rayleigh distribution (see figure 2.2). Then α is proportional to the average wind speed and the distribution function will be known.[28]

A wind power plant consists of a turbine connected to the machinery (brakes, gearbox, generator etc.) with an axis and mounted at a tower that is usually made of steel. The blades of the

25. [11], p. 158.
26. [12], p. 92.
27. [11], p. 163.
28. [19], equation 3.8.

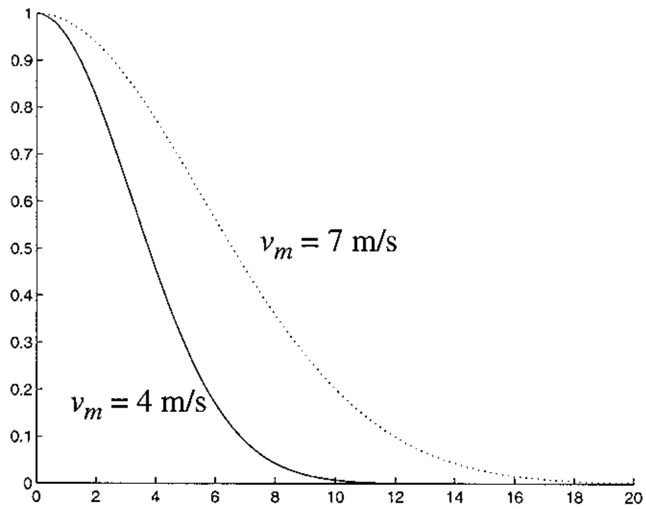

Figure 2.2: Example of the Rayleigh distribution for two average wind speeds

turbine are often made of fibre-glass or plastic.

According to equation 2.2 and equation 2.4 the wind turbine should have a large swept area (the area that is swept by the blades) and be placed high above the ground in order to get a high output. The limit of this is of course the investment cost.

There exists wind turbines with both vertical and horizontal axis, but most modern wind turbines are today of the horizontal type and has two to three blades. These can have a C_p of 0.4 to 0.5.

Most wind turbines operate at constant angular frequency locked to the frequency of the grid.[29] C_p can be described as a function of the ratio of the rotor velocity to wind velocity and has a high value for many turbines when this ratio is between 4 and 8. The constant angular frequency will thus, because of this function, imply that C_p depends on the current wind speed.

Increasing the number of blades will slightly increase C_p. For instance a turbine with three blades has a C_p that is 2 - 3% higher than for a turbine with two blades, which has a C_p that 10% higher than a turbine with one blade. More blades will of course also increase the cost and the increased C_p will not always motivate this extra cost.

The force that makes the turbine rotate and produce power in the generator through the axis evolves on the blades. Simply explained, this force evolves from a pressure difference between the back side and front side of the blade when the wind pass it.

If the wind power plant should be able to use all the wind available on the site it would have to be equipped with a generator that can handle very high wind speeds. However those wind speeds are not often occurring so in order to make the power plant economical sound a generator with low rated power is chosen. This means that above a certain wind speed, called the rated wind speed, the wind is "spilled" by for instance pitching the blades. The rated wind speed corresponds to the rated power of the power plant. However the power plant is not constructed to tolerate any wind speed, which means that above a stop speed the breaks in the machinery are activated and the rotor is stopped.

Wind power systems

Since the wind speed is not constant it is not possible to use only wind power in an isolated grid. It is theoretically possible but then there will be power only when there is wind and this is not

29. [11], p. 140.

acceptable if the needs of a town or a village should be met. A back up generator or a storage system is therefore necessary.

For systems up to 250 W it is possible to use battery storage.[30] In larger systems it is necessary to have a back up generator with controllable output. Diesel generators and hydro power plants with a reservoir has that property. We have in literature only seen systems with the diesel option. For instance on Block Island in the USA a diesel generator has been set up in conjunction with a 200 kW wind turbine.[31]

Wind energy in these wind-diesel systems will be highly variable since wind speeds varies and the system might consist of only one turbine. Diesel generators can be slow to start or to respond to fluctuations in demand, and their performance are generally low at low or varying output. This means that sophisticated control of the system is necessary to exploit the advantages of wind energy. Fuel savings as great as 80% has however been obtained and there exists now standardized packages for system design of this hybrid solution.[32]

Operation and maintenance

A wind power plant does not normally need much maintenance. What should be done is for instance to make sure the moving parts are lubricated, check blades for cracks and check the brake pads. According to Vestas A/S, a Danish supplier of wind power plants, the cost for O&M is less than 0.001 USD/kWh for a 600 kW power plant. According to another source the cost for O&M for wind power plants in the order 100 kW to 500 kW is 0.007 USD/kWh.[33]

Environmental effects

Wind power itself is a very environmentally benign supply option. It produces no pollution, land requirements are small and the produced noise is slightly above wind noise.[34]

If diesel power is used as back up there are of course several problems that occur. But wind power can be thought of as a way to reduce the diesel consumption in the generating units. A wind-diesel system is therefore more environmentally friendly than a system based solely on diesel.

Costs in general

As with hydro power the cost of the transmission line from the wind power plant to the load centre has to be included. The cost for buying or renting land must also be included.

An example of investment cost for a wind power plant is given in section 3.8.

2.4 DIESEL GENERATORS

General features

A diesel generator consists mainly of a diesel engine and a generator. Commercially available diesel generators vary in size from about 5 kW to 30 MW. They are most often equipped with fuel injections, cables for connection to the local grid and automatic controls that ensures that the voltage and the frequency remains constant if the load is varied. The fuel may be gas oil or

30. [14], p. 286.
31. [14], p. 286.
32. [11], p. 176.
33. [25], p. 60.
34. [11], pp. 177.

IDO (Industrial Diesel Oil). Lubricant oil is also necessary.

Diesel generators are often rated in kVA. The amount in kW is the power factor times the amount in kVA. The power factor is always equal or lower than 1. It there is reactive load in the system the power factor will be lower than 1 and if the load only consists of light bulbs it will be close to 1.

The life span of a diesel generator is about 7 to 10 years, but this depends very much on the maintenance. The life span of diesel generators have often been shorter than this because of poor maintenance.[35]

The energy efficiency of a diesel generator is expressed as specific fuel consumption, i.e. the consumption of fuel, in grams, per produced kWh electricity. For example a specific fuel consumption of 0.35 kg fuel per kWh electricity corresponds to an energy efficiency of 25% since the calorimetric content of energy in gasoil or IDO is about 11.6 kWh/kg.

The energy efficiency depends on the size of the generator. A unit of 1 MW can have an efficiency over 40% while a smaller unit of about 50 - 100 kW has an efficiency of about 20 - 25%. However it can be far below this if maintenance is poor.[36]

The load pattern also affects the efficiency. Intermittent operation implies extra fuel for each time the unit is started which of course reduce the efficiency. If the generator is used at partial load, that is a lower load than the one it is designed for, the efficiency is reduced.[37]

Diesel power plants

A diesel power plant for a village may typically consist of three diesel generators. One for base load, the second for peak load and the third on stand-by in case of a break down or overhauling of one of the other two. Parallel usage of diesel generators means that equipment of synchronisation is necessary. A power house and storage facility for the fuel are also necessary in the plant.

Operation, maintenance and reliability

The fuel supply is of course very important in order to establish a reliable system with diesel generators as supply option. In developing countries, this may cause problems since many of these countries need to import oil products and can only do so with foreign currency. Lack of foreign currency will therefore mean lack of fuel, and even when fuel is available, problems with transportation may occur, particularly in remote areas.

The diesel generators need careful operation, regular maintenance and replacement of parts as they wear out. This means that the diesel generators must be operated by skilful people which could be difficult to find for work in remote areas.

Spare parts can be difficult to obtain in remote areas. If there are several diesel generators of the same kind in an area the availability of spare parts is likely to be better.

Environmental effects

There are several negative environmental effects concerning diesel generators. The problems are mainly in air pollution and oil spill.

All combustion of fossil fuels imply pollution of carbon dioxide (CO_2), nitrogen oxides (NO_x) and sulphur oxides (SO_x).

The pollution of CO_2 from fossil fuels could cause global warming, but is not dangerous in any other way. The question of global warming is of major concern in the western world and

35. [7], p. 46.
36. [7], p. 43.
37. [7], p. 43.

international treaties have been signed where countries commit to reduce their pollution of CO_2. In the third world the pollution of CO_2 per capita is at the moment only a fraction of the one in the western world. It therefore can be considered fair to only restrict usage of fossil fuel in the western world. However, if usage of fossil fuel becomes habituated it can be difficult to find other options later. This means that supply options that does not imply usage of fossil fuels should be sought from the start in these countries. Since the pollution of CO_2 is a global problem it seems reasonable that donating countries, that are struggling to decrease their own pollution, also try to provide developing countries with options (not only concerning electrification) that does not imply usage of fossil fuels.

The amounts of CO_2 depends mainly on the amounts of fuel that is combusted. The amount of generated CO_2 is higher (in weight) than the amount that was combusted. This is because fossil fuels mainly consists (in weight) of carbon and each atom of carbon takes two atoms of oxygen when combusted. All this imply that the idea of filtering is a bit inappropriate. Where should the enormous amounts of CO_2 be disposed? There have however been attempts to dissolve CO_2 in the oceans and in this way reduce the content in the atmosphere (where it has its probable effect of global warming).

NO_x as well as SO_x is transported with air and cause acidification of soil and ground in the area around the power plant. The acidification negatively affects the growing conditions for plants. This will of course affect the people in the area since most people tend to depend on farming etc. in one way or another. The amounts of polluted NO_x depends mainly on the temperature of combustion while the amounts of SO_x depends on sulphur content of the fuel.

A few diesel generators for a small town might not be a problem concerning acidification. But once again, it seems reasonable to avoid habituation of this solution before it becomes a problem (as it did in the western world). Besides, there are a lot of other machines (vehicles for instance) that uses fossil fuel or an area could be extra vulnerable which means that a few extra diesel generators might actually be a problem.

Since the environmental issues probably are paid less interest to (compared to health care, education etc.) in developing countries it can be suspected that the oil that is exported to these countries contains more sulphur compared to the oil that reaches the more environmentally aware western countries. This oil is cheaper and therefore more attractive to those countries that do not care about the content of sulphur.

Oil spill from handling of fuel or lubricants, leakage and overhauling can be substantial. Oil spill of 100 litres for a 24 hour period has been measured in Tanzania from running two generators with an individual output of about 200 kW. The spill should be collected for further treatment, for instance burning or recycling. But it is not always done. In Tanzania the oil spill is most often just stored in holes inside the power plant area.[38]

On a visit at the diesel power plant in Kigoma, Tanzania in July, 1997 we could ourselves see such holes filled with oil. We also saw water, probably cooling water, mixed with oil pouring down in a small stream into Lake Tanganyika.

High sound levels inside the power plants may be a problem for the staff, especially if ear-protection is not used. In a study concerning this in Tanzania it was found that some people spent more than four hours a day unprotected at 100 dB in diesel power plant. This is serious since permanent hearing damage is caused by an exposure of four hours a day at only 85 dB.[39]

Other effects

A system with diesel generators means for most developing countries that fuel has to be import-

38. [22].
39. [22].

ed. Oil products must be bought with hard currency which for many developing countries might be difficult to get. In many countries the cost of this import constitute a major part of their earnings from export. For instance, in Tanzania this percentage equalled 62% in 1985.[40] For such countries would a future oil crisis, like those in the seventies, strike extra hard.

Many countries, not only in the third world, are depending on import of oil to such an extent that it has become part of the national security. For instance during the civil war in Mozambique, there were often Zimbabwean soldiers inside their neighbouring country Mozambique to guard a pipeline that provided Zimbabwe with oil.[41]

Costs in general

The cost of diesel generators per kW depends mainly on the size of the generator. Larger units have a lower price per kW. A Swedish supplier sells a 113 kVA unit for about 27 000 USD and a 59 kVA unit for about 19 000 (see table 3.8). If the power factor is assumed to be equal to one the cost per kW is 240 USD for the larger unit and 320 for the smaller one.

The world market price for diesel was 0.16 USD/L[42] in september 1997. With a density of 0.84 kg/L for diesel this equals 0.23 USD/kg. An assumed high energy efficiency of 35% for a generator implies that 2.85 kWh of calorimetric energy is necessary to produce one kWh of electricity. Since the calorimetric content of diesel is approximately 11.6 kWh/kg the necessary weight of diesel is 0.25 kg and the cost for this is 0.06 USD. This means that the minimum fuel cost for one kWh of electricity with this supply option is 0.06 USD. A more realistic energy efficiency of 25% (corresponding to a fuel consumption of 0.34 kg/kWh) imply a minimum fuel cost of 0.08 USD/kWh.

The real fuel cost is however considerable higher since the cost for transportation is not included and taxes have been neglected. The taxes on petroleum products are very high in many countries. For an example of real fuel cost see figure 3.17, scenario 1.

2.5 GRID EXTENSION

Extending the national grid is the most common method to electrify rural areas. All that is required is a transmission line and a step down transformer that supplies a local distribution network. There must however be enough power in the main grid that supplies the extension.

This is a very reliable supply option since the power is produced by many linked power plants instead of one, which could be the case in an isolated grid.

This can however be a very expensive way to electrify. The load must justify the cost for the transmission lines and for many areas this is not the case. Since many towns or villages can have partly the same transmission line the load for a total area must be considered in order to make this supply option economical viable.

The environmental concerns are very few in setting up the transmission lines. The power however may or may not be produced in a environmental friendly power plant.

It is difficult to state general costs for this supply option, an example is however given in section 3.9.

40. [13], p. 39.
41. [12], p. 9.
42. Swedish Petroleum Institute.

Chapter 3

CASE STUDY: KASULU

As an example of rural electrification in a developing country have we made a case study of the Tanzanian township Kasulu.

3.1 PRESENTATION OF KASULU

Kasulu Township is the administrative centre and largest settlement in Kasulu district which is a part of Kigoma region in the western part of Tanzania. Kasulu township lies about 4° S of the equator and 1200 meters above sea level. The distance to Kigoma is about 100 km and to the Burundi border 50 km (see the map on page II).

Most buildings in the township are one-storey houses.[43] The main construction material is bricks, but there are many houses with simple wood and clay walls. Most houses have iron sheet roofs, but some have thatched roofs. Only buildings in the more wealthy parts of the township are plastered. It is common that the houses have backyards for cooking, vegetable gardens and keeping livestock and poultry, although the latter is frequently walking freely on the streets.

Demography

Kasulu district had 320 000 inhabitants, according to the latest national population census in 1988. The area of the district is about 9 000 square kilometres. The township is one of seven divisions in the district and is divided into seven subdivisions. The number of inhabitants was totally 14 383 in February 1997, according to the division secretary of Kasulu township. Of these 4 639 were children and 2 767 were disabled or elders. According to the same source the number of households were 1 819.[44] A household can consist of up to about twenty members.

Economic activities

In the district about 85% of the people depend on the agricultural sector. Many of the inhabitants of the township also have patches of arable land outside the township. The main cash crops in the district are coffee, tobacco and cotton and the main food crops are maize, beans, banana and cassava.[45] There are no large scale farms and no refining of agricultural products, although the soil is fertile and there are large unexploited areas.

Located close to the border to Burundi and along the main road between Kigoma and Kibondo, Kasulu is a local trade centre and there seems to be a lot of travellers, merchant and NGO employees passing through the town.

Other activities in the district and township are brick making and milling. There are also several small workshops. It has been suggested that timber production and mining could be possible in the district. According to the local administration, an electrification would enable small scale industries, and generally act as an injection to the local economy.

43. Actually there are only two two-storey buildings in Kasulu township.
44. Cf. table 3.2.
45. Kasulu district trade officer, July 1997.

Climate and weather data

There is one dry season from about June to September and one rainy season from October to May. During the dry season there is practically no rainfall at all and the land is very dusty. During the rain season the roads are turned to mud, which makes heavy transports difficult. The temperature varies between approximately 25 °C and 35 °C.

The annual rainfall in Kigoma is approximately 1000 mm per year.[46] We have no good rain data from Kasulu but figures that have been mentioned in the district administration have been considerable higher than 1000 mm per year. According to hearsay there has never been a drought in living memory for this area.

3.2 PRESENT SITUATION CONCERNING ENERGY

Before studying the possible future electricity consumption in Kasulu, it might be interesting to know the current situation.

Present consumption of electricity

There is no public electric supply in Kasulu. The national grid ends in Tabora respectively Mwanza and there has not been set up an isolated system in Kasulu. There are however about 30 petrol or diesel generators of up to 40 kVA each. Most of them are privately owned and are for domestic use or for usage in business activity. Some bars and restaurants have them to provide electric light, cold beverages, music or fans. They are also used by workshop owners for welding and carpentry machines. Many of the generators that are used in a commercial way are also used domestic since the owners tend to have their residence at the same place as their business. Some generators are owned by institutions. For instance the Bishops office owns one to provide electricity for office machines and domestic use in their staff houses.

There are at least two governmental generators. One provides some of the district officials with electricity for domestic use and the hospital when the X-ray machine is needed. The other one is operated by the TTCL office for public wireless communication with the rest of Tanzania. There is a telephone net in Kasulu township but each telephone is powered by individual batteries.

There are two comparatively big existing generators in Kasulu township. These two are both on 170 kVA and manufactured 1989. They were previously owned by Kasulu Teachers College but have recently been given to Kasulu Electricity Consumers Cooperative (KAECO Limited) to generate power to its members. KAECO was formed in February, 1997 and had 189 members in July, the same year.

There are also a few (less than ten) solar systems in Kasulu township. These are used for lighting, radios and refrigeration. Since there of course is no street-lighting in Kasulu township batteries are used in torches by night guards and some of the ordinary citizens that move around after dusk.

Water is provided to the township from a few streams in the adjacent hills. There are taps in many houses and there are also a few public taps in the streets. The pressure in the system is produced by gravity and no pumps are used. The system is from 1975 and works well. The problem is that the system is not dimensioned for the present need of water so the authorities gives different areas of the town ship water on different times of the day. There exists plans to enlarge the system but these do not imply need for electricity; another stream will be used and gravity will produce the pressure.[47]

46. NESTE - Advanced Power Systems Sweden AB.

There are surprisingly many[48] of the residents and others who do not have access to electricity from a diesel generator or solar system that possess electric equipment. The owners could for instance previously had an generator that now has broken down, or perhaps they have moved from an electrified area of Tanzania and brought the equipment hoping that Kasulu would be electrified in the close future.

Consumption of other forms of energy

In Kasulu, as in the rest of Tanzania, charcoal and fire wood are used for cooking. Kerosene are used for lighting in ordinary lamps and in high pressure lamps which give brighter light. A few of the wealthier families also use kerosene for cooking. There are about 20 milling machines in the township and most of them are mechanically powered by diesel engines. Only a few of the vehicles that can be seen on the streets of Kasulu are owned by citizens of Kasulu, most of them are owned by NGOs such as UN organisations active in the area, because of the camps in the adjacent Kibondo district with refugees from Burundi, Zaire and Rwanda.

Previous attempts and future plans to electrify Kasulu

When we came to Kasulu we received a lot of scattered information concerning previous plans and future possibilities to electrify Kasulu town ship. We have encountered the following:

- 1994 TANESCO started to set up a diesel power station in the township but did not get further than bringing some construction material. The project was abandoned after the national election the same year.
- There has been discussions about buying electricity from Burundi, but due to the political situation in Burundi this is no longer of current interest.
- There have been a lot of feasibility studies for hydro power plants in the size a few MW, primary at the lower parts of Malagarasi (see map on page II), but the load in the Kigoma region seems to be to low to justify these projects.
- For the moment, it seems like TANESCO is planning a distribution system for Kasulu, which should be fed by the diesel genset given to KAECO by the Teachers College.

3.3 POWER MARKET SURVEY

Together with Mr. Bosco Selemani, research engineer at TANESCO, we visited Kasulu in July 1997. During our two weeks there, we performed about 50 interviews with possible electric power consumers. We have used these interviews to make two estimations of the load curve for Kasulu township, one high load estimation and one low load estimation (shown in figure 3.1). Hopefully the real load should be somewhere between these estimations.

Assumptions

Of course, a power market survey of this kind is based on a lot of assumptions. The major assumptions we have made are listed below. Further assumptions, that have been made to obtain the individual load curves for the different consumer groups, are found in appendix C.

- Our ambition has not been to estimate the initial load, but the load after a few years when all interested have been connected to the system and when people have bought the electric equipment they want.

47. Interview with Kasulu District Water Engineer, July 1997.
48. In our power market survey we found that about half of the residents without own generator had unused electric equipment.

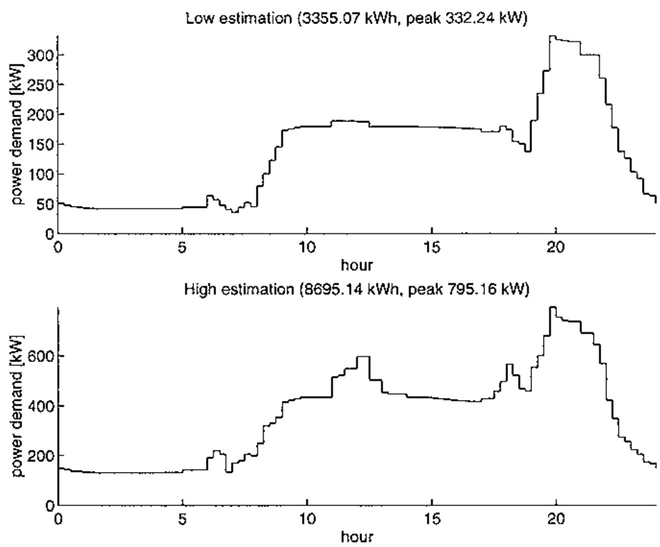

Figure 3.1: Load estimations for Kasulu

- In the high load estimation we have calculated with an energy price of about 100 TSh/kWh. We have also assumed that people are ready to pay more for electric energy than for the energy that they currently are using, and that they can afford to buy extra electric equipment.
- In the low load estimation we have calculated with an energy price of more than 200 TSh/kWh. Furthermore, we have assumed that only rich people (or institutions) will buy more expensive new electric equipment and that most consumers are only interested in electric energy if it reduces their energy costs.
- We have used coincident factors to compensate for the fact that most electric equipment only is used part of the time. This means that our load curves only show the average consumption at a given time, and that some load peaks might not be included. See appendix F for a more detailed discussion of coincident factors.
- Our more or less qualified guesses on the number of consumers in each category that will connect to the electricity supply are shown in table 3.2. For comparison we have included the total quantity of each category as well.

Table 3.2: Consumers in each category

Category	Number of consumers in low load estimation	Number of consumers in high load estimation	Quantity in Kasulu township*	Quantity in Kasulu township†
Residents (large)	100	100		
Residents (medium)	200	300	1819‡	3500**
Residents (small)	300	500		
Bars	10	15	18	10
Restaurants	4	4	Not stated	20††
Guest houses	7	12	7	12

Table 3.2: Consumers in each category

Category	Number of consumers in low load estimation	Number of consumers in high load estimation	Quantity in Kasulu township*	Quantity in Kasulu township†
Shops	30	30	Not stated	325‡‡
Milling machines	7	15	47	20
Primary schools	2	2	4	7
Secondary schools	2	2	2	2
Colleges/Institutions***	4	4	11	4
Garages	Not used	Not used	7	3
Workshops	25	25	107	Not stated
Petrol stations†††	2	3	Not stated	Not stated
Hospitals/Dispensaries‡‡‡	1	1	4	6
Police stations/posts	Not used	Not used	1	1
Post offices	1	1	1	1
Telecommunications	1	1	Not stated	Not stated
Banks	1	1	1	1
Courts/Prisons****	1	1	2	3
Mosques	3	3	3	3
Churches	4	6	8	6
Missions/Charity organisations/NGOs	4	8	10	6
General markets††††	0	0	2	2
Offices	5	7	58	14
Social houses	Not used	Not used	1	2

* Source: Kasulu Division Secretary Mr. Busoro, July 1997. We consider this source as the more reliable.

† Source: Kasulu District administration, July 1997

‡ The dividing of residents in large, medium and small consumers is made by us. See appendix C for more information.

** See previous note.

†† We only saw four restaurants in Kasulu. It is possible that this figure includes small barbecue shops, which we do not consider as restaurants.

‡‡ This figure represents trade permissions, which also includes shops at the markets (which are not likely to connect to the net) and people intending to start a business sometime in the future.

*** The definition of institution is unknown. We have only considered the four colleges we actually visited.

††† The actual number of petrol stations is four, as far as we could see.

‡‡‡ We only consider the Kasulu District Hospital.

****We only consider the prison.

††††The market has been treated as many individual shops. There will be no need for public lighting and other common facilities at the markets, since the markets are only open during the light hours.

• We have used the energy prices shown in table 3.3.

Table 3.3: Energy prices in Kasulu 16/7 1997

Energy source	Price [TSh/L]	Price* [USD/L]
Diesel	453	0.70
Kerosene	340	0.53
Petrol	527	0.82

* Based on the exchange rate 1 USD = 640 TSh.

• An average kerosene lamp consumes about one litre of kerosene per week. This is compared with a 60 W bulb, which when used 21 hours a week, is consuming 1.26 kWh or respectively around 130 TSh/week (high load estimation) and 250 - 300 TSh (low load estimation).

• A kerosene fridge is assumed to consume 3 - 4 litres of kerosene per day. This is compared to an energy consumption of 0.72 kWh for a standard electric fridge.

Sensitivity analysis

Since our load estimations are mostly based on assumption it is important to know which assumptions that are most significant to the result. In table 3.4 the consequence of doubling the load in each category is shown. From this table it is clear that the most important consumers are the residents, milling machines, workshops and colleges. The last category is only important due to the Teachers College, since their pupils represent a large domestic load.

Table 3.4: The sensitivity to errors in number of consumers for the load curve estimations

Category	Impact on low estimation	Impact on high estimation
Residents (large)	Evening load peak increases about 25%.	Evening load peak increases about 20%.
Residents (medium)	Evening load peak increases about 25%.	Evening load peak increases about 22%.
Residents (small)	Evening load peak increases about 22%.	Evening load peak increases about 27%.
Bars	No significant difference.	No significant difference.
Restaurants	No significant difference.	No significant difference.
Guest houses	No significant difference.	No significant difference.

Table 3.4: The sensitivity to errors in number of consumers for the load curve estimations

Category	Impact on low estimation	Impact on high estimation
Shops	No significant difference.	No significant difference.
Milling machines	Increases day load with about 50%.	Increases day load with about 75%.
Primary schools	No significant difference.	No significant difference.
Secondary schools	No significant difference.	No significant difference.
Colleges/Institutions	Evening load peak increases about 15%.	Evening load peak increases about 10%.
Workshops	Increases day load with about 5%.	Increases day load with about 5%.
Petrol stations	No significant difference.	No significant difference.
Hospitals/Dispensaries	No significant difference.	No significant difference.
Post offices	No significant difference.	No significant difference.
Telecommunications	No significant difference.	No significant difference.
Banks	No significant difference.	No significant difference.
Courts/Prisons	No significant difference.	No significant difference.
Mosques	No significant difference.	No significant difference.
Churches	No significant difference.	No significant difference.
Missions/Charity organisations/NGOs	No significant difference.	No significant difference.
Offices	No significant difference.	No significant difference.

3.4 GENERAL REMARKS ABOUT THE SCENARIOS

It should be noted that we are not trying to estimate the *consumers* energy price, but the costs for the producer and distributor. This means that we neglect losses, since in the end it is the consumers that pay the losses. It is of course of interest for the distributor to minimize the losses, but our prime interest is to compare supply options, and as long as the losses are approximately the same size in the different scenarios will they not affect the comparison.

The calculations for the scenarios can be found as Matlab scripts in appendix D.

Most of the scenarios presented here are divided in four subscenarios where we use different loads. In subscenario a and b we use the low estimation and in the subscenarios c and d the high estimation. In subscenario b and d we have assumed that most incandescent bulbs have been replaced with CFLs, which reduces the evening peak so that the load curves in figure 3.5 is obtained.

We have used the method of annuity (explained in for instance [8] pages 14 and 15) and a real interest of 4% in all scenarios. For sensitivity analysis have we also made most calculations with a 7% interest. We have assumed a power factor for the load of 0.95, except in the

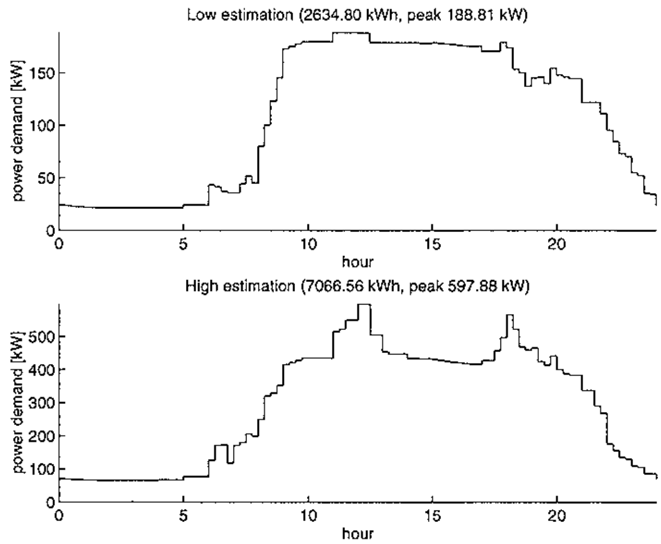

Figure 3.5: Load estimations for Kasulu, when most bulbs are replaced with CFLs

CFL scenarios, where a power factor of 0.7 seem more realistic. Losses in the distribution system are neglected.

We have only made probabilistic simulations for scenario 1, 2 and 4.

Distribution system

Most solutions for electrifying Kasulu require a distribution system. Although we do not intend to plan this system in detail, it is necessary to at least make a rough estimation of the costs for building the distribution system. This estimation can be found in table 3.6. It is based on the following assumptions:

- Prices are taken from tables B.3, B.4 and B.5.
- Milling machines, schools and colleges/institutions, workshops, petrol stations, the hospital and 10% of the residents require three phase connections.
- The location of the substation can be found on the map in figure 3.7. The MV lines follow the roads.
- The low voltage line length is assumed to be 50% longer than the MV net. This is a guess based on the line length for distribution systems in the isolated areas recorded in [13] (table 3-10, p. 81).
- The economic life span of the distribution system is 25 years.
- The maintenance cost is 5% of the investment annually.

3.5 SCENARIO 1: DIESEL GENSETS

The situation concerning diesel power in Kasulu is a bit special since there exists two diesel generators (see section 3.2) available for public electrification. These are rated 170 kVA and are from 1989 but have not been used much since the cost has been too high for the previous owners and present users Kasulu Teachers college. One of them has a defective excitor and has not been repaired since the other one fulfil their needs. The working unit is at the moment used only two hours per day during the periods when school is open.

Assumptions

We have used the following assumptions for the calculations in this scenario:

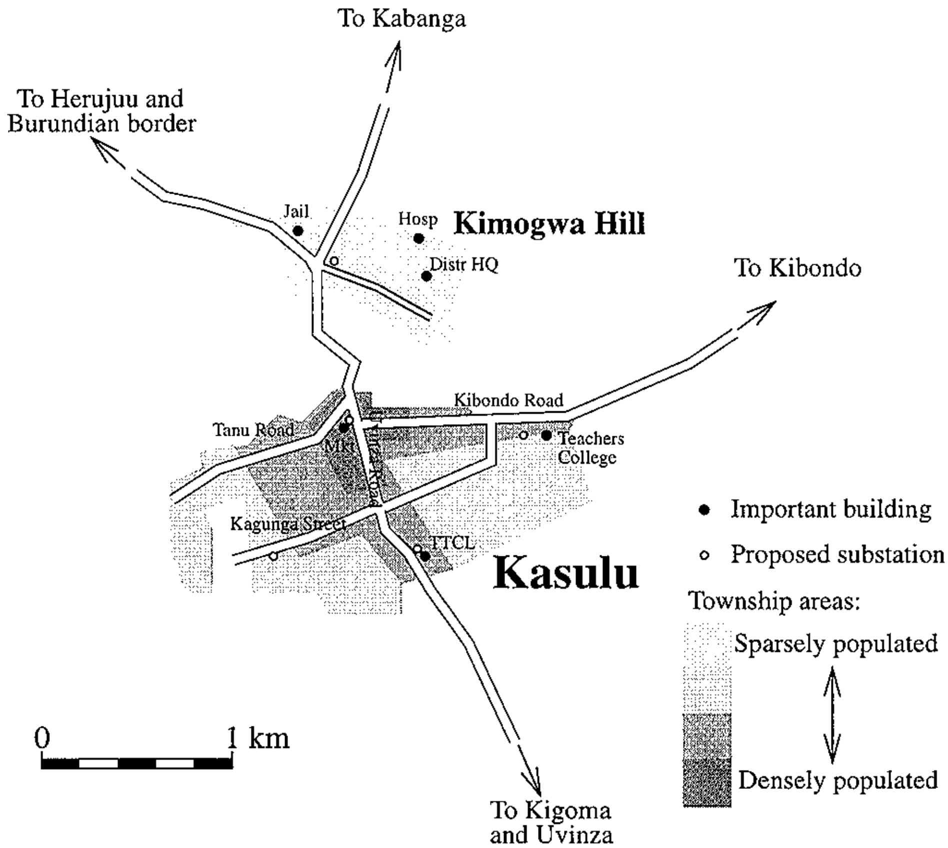

Figure 3.7: Map of Kasulu township.

• For new gensets we have used the prices from table 3.8, to which we have added 23% for transportation costs.[49] The old gensets are assumed to be operational without investments, which means that we neglect the reparation cost for the defective excitor.

• The operation and maintenance costs we have estimated from the cost for fuel consumption[50], to which we have added 25%,[51] which results in a operational cost of 0.37 USD and 0.32 USD respectively. For the existing 170 kVA gensets we have assumed a fuel consumption of 0.35 kg/kWh.

• The life span of diesel gensets varies a lot, but is generally shorter than what could be expected with proper maintenance.[52] We are therefore calculating with an economical life span of seven years for all diesel gensets.

• We have set the availability of diesel gensets to 80%, which is a rather low value, but high compared to the actual performance of many Tanzanian diesel gensets.[53]

Comments

The configuration of the diesel gensets in each subscenario can be found in table 3.9.

We have suggested two solutions respectively for the a) and b) scenarios. The first alterna-

49. We have assumed that the transportation and insurance costs for diesel gensets will be of the same size as the transportation and insurance costs for transmission line equipment in [24]. 15% represents the overseas transport and insurance and 8% the inland transport and insurance.
50. Cf. table 3.8 and table 3.3. The density for diesel is about 0.84 kg/L.
51. The fuel costs accounts for about 80% of the quantifiable cost, according to [13] p. 98.
52. [13] p. 78.
53. [13] p. 77. The Chief Technical Engineer at TANESCO, Mr. M. Katyega suggests that the availability for diesel gensets should be between 70 and 80 per cent.

Table 3.6: Kasulu distribution system

Item	Low load estimation		High load estimation	
	Size	Cost [USD]	Size	Cost [USD]
Town centre substation	100 kVA	4 800	200 kVA	7 700
Kimogwa Hill substation	100 kVA	4 800	200 kVA	7 700
Teachers College substation	100 kVA	4 800	200 kVA	7 700
TTCL substation	100 kVA	4 800	200 kVA	7 700
Kagunga Street substation	100 kVA	4 800	100 kVA	4 800
33 kV lines	4 km	64 000	4 km	64 000
400 V lines	6 km	84 000	6 km	84 000
One phase service line	611 pcs.	244 400	899 pcs.	359 600
One phase meter	611 pcs.	36 660	899 pcs.	53 940
Three phase service line	103 pcs.	72 100	142 pcs.	99 400
Three phase meter	103 pcs.	15 450	142 pcs.	21 300
Σ		540 610		717 840

Table 3.8: Price examples for diesel gensets

Rating [kVA]*	Price†		Fuel consumption [kg/kWh]‡
	[SEK]	[USD]**	
59	143 500	18 900	0.35
113	204 500	26 900	0.35
250	270 000	35 500	0.30
450	486 000	63 950	0.30

* At altitude 1200 m above sea level and cos φ = 0.8 The facility included tropical cooler, automatic synchronising and tank.

† Prices from Martinsson Kraft/Teknik in July and October 1997. VAT excluded.

‡ Our guesses, based on the actual consumptions in Tanzania, recorded in [13], table 3-7 on p. 76.

** Based on the exchange rate 1 USD = 7.60 SEK.

tive means a larger investment (although the difference is in practise negligible), higher operation costs, but better operational performance (i.e. lower LOLP and UE, defined in appendix A, equations A.7 and A.8) than the second. The choice between them has to be done by the local decision makers.

It should be noted that the prices in table 3.3 include taxes. There have been discussions of

Table 3.9: Diesel gensets configuration in scenario 1

Scenario	1st plant	2nd plant	3rd plant	4th plant	5th plant
a (I)	170 kVA (E)	170 kVA (E)	113 kVA (N)	113 kVA (N)	
a (II)	250 kVA (N)	170 kVA (E)	170 kVA (E)		
b (I)	170 kVA (E)	170 kVA (E)	113 kVA (N)	113 kVA (N)	
b (II)	250 kVA (N)	170 kVA (E)	170 kVA (E)		
c	450 kVA (N)	450 kVA (N)	250 kVA (N)	170 kVA (E)	170 kVA (E)
d	450 kVA (N)	450 kVA (N)	250 kVA (N)	170 kVA (E)	170 kVA (E)
(E) - Existing (N) - New					

reducing the taxes on diesel used for rural electrification. Since taxes represent about 60% of the price, this could lead to a major reduction of the operating cost for diesel gensets.

3.6 SCENARIO 2: HYDRO POWER PLANT AND DIESEL GENSETS

We had no possibility to make a complete inventory over the conceivable hydro power sites in Kasulu District. This scenario will only serve as an example to indicate the prices and advantages of hydro power.

Hydro power plant at River Chogo

We made two visits at a site at River Chogo, 14 km along the road north-west of Kasulu, which could be suitable for a mini hydro power scheme. Here it is possible to use a high head and according to the locals there is water in the river all the year around. (See section 2.2 for discussion of flow and head.)

We estimated the flow in Chogo at 1500 m a.s.l. in the end of July, 1997. This was in the middle of the dry season and from what we measured with elementary methods and what the locals said about the flow we believe that the minimum flow during the year is 0.25 m^3/s. This must however be investigated further before setting up a hydro power station.

We do not know how well the area is suited for construction concerning geological conditions etc., but at least we saw that the surface of the area in the vicinity of Chogo is mostly soil.

There were only a few patches of arable land adjacent to the river at the site which indicates that the effects on human activity from a hydro power station should be minimal.

We have made a suggestion (see map in figure G.1) on a scheme which uses a head of 180 m. A minimum flow 0.25 m^3/s gives with equation 2.1 a theoretical minimum capacity of 441 kW. With an overall energy efficiency of 75% (see section 2.2) this gives a minimum capacity of 331 kW.

According to this proposition the length of the canal and the penstock are about 730 m and 400 m respectively.

If the conditions are correct concerning construction it is possible to build a reservoir above the intake (see appendix G for a discussion of the possible reservoir size). If the load during the day exceeds 331 kW it is possible to construct a small reservoir that collects water enough for those hours. This of course means that the installed capacity considering turbines and dimension of penstock has to correspond to this excess. If the demand of electric energy during the day in Kasulu is greater than 331 kW · 24 h = 7944 kWh (losses in distribution are not considered at this point) it is possible to build a bigger reservoir that collects enough water during the rainy season when the flow is expected to be greater than 0.25 m^3/s. The bigger reservoir could also be constructed in order to provide for increasing demand in Kasulu township in the future or to electrify areas like the nearby villages Herujuu or Kabanga.

Transmission line

It is necessary to build a transmission line from Chogo to Kasulu. Using data from table B.3 and assuming that losses cost around 0.15 USD per kWh, the Matlab function `line_design` (presented in appendix B) gives the design criteria shown in figure 3.10. For an average apparent

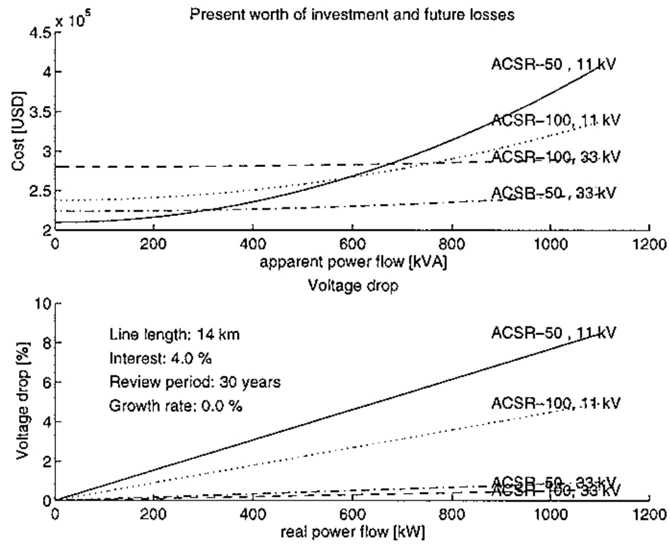

Figure 3.10: Design criteria for transmission line from River Chogo to Kasulu

power flow lower than about 350 kVA (which is the case in the low estimations, cf. figure 3.1 and figure 3.5) an 11 kV transmission line with 50 mm^2 cross area is the best option, but for higher average power flows 33 kV is to prefer. But since a preliminary TANESCO study of a distribution system for Kasulu suggests a 33 kV medium voltage distribution system, it seems like the best option is to use a 33 kV line also in the low load scenarios. Therefore, we assume that the transmission line will cost 224 000 USD.

A transformer to raise the generated power to 33 kV costs about 12 000 USD (scenario 2a and b), 15 000 USD (scenario 2d) and 24 000 USD (scenario 2c) according to table B.4.

Assumptions

We have made the following assumptions for this scenario:

- We assume that the flow is 0.25 m^3/s during 140 days per year and more than that for the rest of the year (see ***Climate and weather data*** on page 18 and the discussion of flow in ***Hydro power plant at River Chogo*** on page 27).
- We assume the overall energy efficiency of the power station to be 75% no matter how much capacity that is installed. This is to limit our calculations.
- We assume that the investment cost for the power station is 6000 USD/kW without a reservoir and 7000 USD/kW with reservoir. In Sweden it is possible to construct mini-hydro

power stations at half that price[54] but the cost in Tanzania is probably higher. According to the Chief Technical Engineer at TANESCO, Mr. Katyega, the price for mini hydro in Tanzania ranges between 2000 and 7000 USD/kW, depending on where the site is located, if the station is with or without reservoir etc. We have chosen the higher values, to be sure not to underestimate the costs for hydro power.

• We assume that the operation and maintenance cost is 0.01 USD per kWh. In Sweden it is less than half of that[55] but we believe it will be higher in Tanzania, and as with the investment cost, we do not want to underestimate the costs for hydro power.

• We assume the economical life length to be 30 years for the power station and the transmission line. In Sweden the life length is expected to be 40 years,[56] but we believe this is too high for an isolated area of Tanzania.

• We assume the availability to be 99%. For comparison, in Sweden the availability in hydro power plants is close to 100%.

• We neglect the losses in the transmission line, which is reasonable since the cost for losses caused by the transmission line will be small compared to the total investment (cf. figure 3.10).

• We assume that the cost for the necessary land is low and included in the investment cost.

Comments

Our suggestion of hydro power plant for the different scenarios can be found in table 3.11. As stated in ***Hydro power plant at River Chogo*** above it might be necessary with seasonal storage of water in a reservoir to satisfy the demand. In other case it is only necessary with a reservoir large enough to hold about one days consumption, as in scenario a and d. In scenario b no reservoir at all is needed, since the peak load is less than the power produced by the minimum water flow. Only in scenario d seasonal saving of water is necessary. The minimum size of the reservoir is obtained through subtracting the energy obtained through the run of the flow from the total hydro generation during the dry season.

Table 3.11: Size of hydro power plant in scenario 2

Scenario	Installed capacity [kW]	Initial investment* [USD]	Minimum reservoir size [kWh]
a	480	3 360 000	3 300
b	330	1 980 000	No reservoir needed
c	930	6 510 000	102 700
d	730	5 110 000	7 050

* Excluding transmission line and transformers.

If it is possible to build a larger reservoir, the extra water could be used to replace the diesel gensets, although in the case of Kasulu the available hydro power is enough to supply the township and the diesel gensets are only used when the hydro power is not available. A larger reservoir could though be necessary if the demand is increasing in the future or to supply the villages near Kasulu.

54. [25], p. 31.
55. [25], p. 32.
56. [25], p. 31.

3.7 SCENARIO 3: PV SYSTEMS

We have not managed to make a scenario with a centralized system together with diesel as back-up that could produce power for the whole town. This is because it has been difficult to find information about such a system concerning layout, sizing, prices, performance etc. It seems like a lot of this information exists in private companies that might not be interested to share them with others. This should be investigated further.

Here we have only considered household systems. This scenario is therefore a bit special, and not directly comparable to the others (see also ***Comments*** on page 33). We have here estimated the cost per kWh for a household system with batteries as backup. We have also estimated an optimal tilt angle and the annual total of the daily insolation corrected for this angle and these results should be applicable for any PV system in Kasulu.

Daily insolation data and optimal tilt angle

We do not have records of daily insolation, hours of sun and length of periods with overcast days from Kasulu. These data as well as the need for electricity are important to know in order to size the system correctly concerning installed capacity in Wp (see section 2.1) and the storage system. The governmental meteorological department in Dar es Salaam reported (July, 1997) that they did not have any meteorological data from Kasulu and there has probably never been any measuring of daily insolation etc. in Kasulu.

We have however data of daily insolation (see section 2.1) from Kigoma at latitude 4.88° S and longitude 29.63° E, some 100 km south-west of Kasulu Township, stated in table 3.12. These data are probably a bit high compared to the case in Kasulu but should be about the same. Kasulu is situated a bit higher and the rainfall is greater which probably means that there are less hours of sun there. There are also rather high mountains around Kasulu Township which probably decreases the daily insolation compared to Kigoma.

In table 3.12 we have also stated the insolation for the two tilt angles 15° towards south and 15° towards north which are the two possible ones for sites this close to the equator (see section 2.1).

Table 3.12: Average daily insolation on a horizontal plane and corrected for a tilt angle of 15°S and 15°N in kWh/m^2 per month in Kigoma, Tanzania

Month	Insolation at 0° *	Correction factors, 15° S†	Correction factors, 15° N	Insolation, 15° S	Insolation, 15° N
January	4.90	1.07	0.87	5.24	4.26
February	5.25	1.03	0.91	5.41	4.78
Mars	5.10	0.98	0.97	5.00	4.94
April	5.10	0.91	1.03	4.64	5.25
May	5.23	0.86	1.08	4.49	5.64
June	5.26	0.83	1.11	4.37	5.83
July	5.54	0.84	1.10	4.65	6.09
August	5.93	0.89	1.06	5.27	6.28

Table 3.12: Average daily insolation on a horizontal plane and corrected for a tilt angle of 15°S and 15°N in kWh/m^2 per month in Kigoma, Tanzania

Month	Insolation at 0° *	Correction factors, 15° S†	Correction factors, 15° N	Insolation, 15° S	Insolation, 15° N
September	5.88	0.94	1.00	5.52	5.88
October	5.81	1.01	0.93	5.86	5.40
November	4.90	1.06	0.88	5.19	4.31
December	4.98	1.08	0.86	5.38	4.28
ANNUAL TOTAL‡	1944			1857	1917

* NESTE Advanced Power Systems Sweden AB.

† The correction factors are for sites at latitudes 0° to 5° south from [17], p. 377.

‡ This is calculated by multiplying each value with corresponding number of days in the month and summing up.

If the cloudiest month are in the winter time as in Kigoma (January and November) the tilt angle for fixed modules in Kasulu should be, according to the rule of thumb (see section 2.1), to the south. However the more accurate method with corrections factors in table 3.12 shows that the mounting should be 15° towards north (since this gives a greater total) and gives a total of 1917 kWh/m^2 and year.

Factors influencing maintenance and performance

Besides what is said in section 2.1 there are a few site specific factors that influence a PV system. For instance Kasulu is extremely dusty during the dry season. According to experiences from Kasulu it is necessary to wash PV modules once a week during this period in order to keep performance high.

Concerning the size of the backup or storage system one of the users of photovoltaic systems in Kasulu stated that the longest period experienced without direct sunlight was only three days.

Since the temperature is often above 25 °C in the sun the actual performance of the modules will in general be lower than the rated in STC (see section 2.1). The life span of batteries will be reduced because of high temperature. This effect can be decreased if the batteries are stored as cool as possible, for instance inside a shed and perhaps in a hole made in the ground.

Costs

To estimate the price for photovoltaic energy in Kasulu we have used a particular household system that is sold commercially in Sweden and modified it to our needs. This system might not exactly fulfil the needs of a consumer in Kasulu but these calculations are made in order to give some idea of how high the costs are for PV electricity. A larger or smaller household system can be expected to result in about the same prize per kWh.

The prices are from a Finnish supplier of household systems sold in packages for domestic use and sized for usage in Sweden. In this package the panel is about 9.20 USD/Wp and considerable higher than the production cost mentioned in section 2.1. However this is a market price for a small system and another supplier sells panels of the same material at the cost of about 8.30 USD/Wp[57] which is in the same order.

The prices[58] are given with VAT excluded and in USD calculated from the rate 1 USD = 7.60 SEK (October 1997). The prizes would of course be a bit lower if a larger order was made.

The package consists of

- 110 Wp panel of mono crystalline silicon, 0.84 m^2
- control unit
- battery of 115 Ah, 12 V, lead acid
- mounting
- some wiring

The energy efficiency η is according to section 2.1 given by

$$\eta \cdot 1000\ \text{W/m}^2 \cdot 0.84\ \text{m}^2 = 110\ \text{W} \tag{3.1}$$

which gives $\eta = 0.13$.

The total prize of this package is 1437 USD. The battery is sold individually for 171 USD and the panel for 1011 USD. According to the supplier the life span of the panel is more than twenty years and the life span of the battery about 5 years.

We assume in the calculations for Kasulu in table 3.13 that:

- $\eta = 0.12$ for the panel, since the temperature is higher than 25 °C (see section 2.1).
- The life length of everything except the batteries is 30 years.
- The life length of batteries is 5 years, since it should be possible to store the batteries below or at least not very high above 25 °C.
- The results from table 3.12 are valid.

We have used the annuity formula to calculate the prize per kWh

$$ann = I \cdot \frac{r}{1-(1+r)^{-n}} \tag{3.2}$$

I is the investment cost in USD, n is the life time in years and r is the real interest which we have taken as 0.04.[59] Since the life span of the batteries differs from the rest we have made two calculations and added the two annuities to get the prize per kWh.

Table 3.13: Annual payment

	Battery	Panel and other BOS components
I (USD)	171	1266
r	0.04	0.04
n (years)	5	30
ann (USD)	38	73

The total annual production from the system is given by the energy efficiency times the annual total of the daily insolation in table 3.12 times the surface of the panel. According to equation 3.3 this equals 193 kWh.

$$0.12 \cdot 1917\ \text{kWh/m}^2 \cdot 0.84\ \text{m}^2 = 193\ \text{kWh} \tag{3.3}$$

57. BP Solar, Dar es Salaam, June 1997. Prices in USD from the rate 1 USD = 640 TSh (July, 1997).
58. NESTE-Advanced Power systems, Price list for consumers, 1997:2.
59. Customary in calculations concerning energy in Sweden, [8] p. 48.

If the batteries are assumed to have a life span of 5 years with a DOD (see section 2.1) of 50% it means that about $0.50 \cdot 12\ V \cdot 115\ Ah = 0.69$ kWh can be discharged each cycle if the battery is fully charged. If the batteries are charged during the day and discharged in the evening one battery should be enough in order to collect all the irradiance during the year. This is because the maximum energy that can be assembled for one day is $0.12 \cdot 6.28\ kWh/m^2 \cdot 0.84\ kWh/m^2 = 0.63$ kWh (see table 3.12). However if only one battery is used there exists no backup for an overcast day and all of the incoming energy on one day more or less has to be used that day to get out the full amount that is produced in the panel. We have therefore made calculations for both one and two batteries in table 3.14.

As indicated above the price for the panel is almost twice the production cost. If a larger order is made it should be possible to get a discount. We have therefore also stated in table 3.14 what the cost per kWh would be if a discount of 20% and 40% on the total cost of the package is made.

Table 3.14: Costs in scenario 3 (I - VI), 4% real interest*

System with:	One battery	One battery, 20%	One battery, 40%	Two batteries	Two batteries, 20%	Two batteries, 40%
Annual cost	111 USD	89 USD	67 USD	149 USD	119 USD	89 USD
Production	193 kWh	193 kWh	193 kWh	193 kWh	193 kWh	193 kWh
Cost per kWh	0.58 USD	0.46 USD	0.35 USD	0.78 USD	0.62 USD	0.47 USD

* See table 3.16 for the results of calculations with a real interest of 7%.

Comments

The average production of electric energy in this package is 193/365 = 0.53 kWh/day and it can be compared with a small resident that in our low load estimation consumes about 1 kWh per day and about 2 kWh per day in our high load estimation (see appendix C, page 68). It should be noted that the package described above does not contain an inverter. If an inverter is used the cost per kWh will probably increase some.

A household system (with or without inverter) can be suitable for consumers that have a daily consumption that is almost equal to the average consumption. These could for instance be residential consumers that have some electric lights, a refrigerator and a fan.

For consumers that have a consumption which for instance consists of a high load appliance that is used once a week this means that there most be enough batteries to store the production from the panel or panels for a whole week. This will make the cost per kWh higher, at least if the life span of the batteries is a fixed number of years, which is not fully true since the life time will be a bit longer for batteries that are less frequently cycled (see section 2.1).

For areas with low population density, where the contribution of a distribution net would be comparatively high in the cost per kWh, and for consumers that have a daily consumption that is almost equal to the energy that is gathered in the panel during that day, a household system is profitable. It will be even more profitable for those consumers that have their load during the sunny hours (if the load does not exceed the output from the panel), since this will decrease the need of batteries.

3.8 SCENARIO 4: WIND POWER PLANT AND DIESEL GENSETS

As stated in section 2.3, wind power cannot be the sole power supply in an isolated system. In this scenario we will use diesel gensets as backup, although hydro power probably is less expensive. The reason for this is merely to illustrate the situation if Kasulu had not been so fortunate as to have hydro power available.

Wind power plant at Kasulu

Kasulu township is located at the bottom of a valley, and there are several neighbouring hills that could be suitable for wind power plants. Since there never has been done any measurements of wind speeds in the Kasulu district is it impossible for us to say where the best sites are. One possibility would be a co-location with a hydro power plant at Chogo, which would mean that the wind and hydro power plant could share a transmission line, but since this scenario treats a wind and diesel system we have calculated with a location four kilometres from Kasulu. For the same reasons as in scenario two we have chosen a 33 kV transmission line with ACSR 50 mm^2 as conductor, which means a cost of 64 000 USD.

Assumptions

Unfortunately no wind data are available from Kasulu district, which means that this scenario has to be based on a lot of assumptions:

- We assume that the wind speed is independent of the load and Rayleigh distributed (see section 2.3).
- We will use two different average wind speeds; 4.0 m/s (alternative I) and 7.0 m/s (alternative II).
- We have used a wind power plant called Vestas V44-600. It is has a rated power of 600 kW and we assume the price 662 000 USD including electric equipment, transport from Denmark to Tanzania and erection of steel tower.[60]
- We have used the lowest air density in table I.1, since the power plant will be located on high altitude (1200 to 1600 m.a.s.l.) and the air is warm. Both these factors lower the air density.
- The manufacturer suggests an availability of almost 100%, but this might be lower in Tanzania, since the maintenance might be neglected. We have no knowledge of actual availability values in developing countries like Tanzania, so we have assumed an availability of 97%.
- The operation and maintenance costs are assumed to be 0.002 USD/kWh. The manufacturer claims that maintenance in Sweden should cost about 0.5 öre/kWh, which equals less than 0.001 USD/kWh. This figure could be higher but would not substantially affect the cost per kWh in this scenario.
- The introduction of wind power in the system will probably reduce the efficiency of the diesel gensets, since diesel gensets operate at their best when they are fully loaded. However, our diesel consumptions in table 3.8 are based on actual, recorded diesel consumptions from systems that are not running during perfect conditions. We therefore neglect the decreased diesel genset efficiency.
- We assume that the cost for the necessary land is negligible.

60. Cost estimation by the manufacturer.

Comments

The first of the assumptions above might be dangerous; if it for instance never is windy during the evening (when the load has a peak) are the diesel gensets suggested for subscenario c) and d) not enough and a configuration like in scenario 1c and 1d would be necessary. However, this problem will only occur when there is no wind and one or more diesel gensets are unavailable, which should be rare occasions.

The configuration of the diesel gensets for each subscenario can be found in table 3.15.

Table 3.15: Diesel gensets configuration in scenario 4

Scenario	1st plant	2nd plant	3rd plant	4th plant
a	250 kVA (N)	170 kVA (E)	170 kVA (E)	
b	250 kVA (N)	170 kVA (E)	170 kVA (E)	
c	450 kVA (N)	450 kVA (N)	170 kVA (E)	170 kVA (E)
d	450 kVA (N)	450 kVA (N)	170 kVA (E)	170 kVA (E)
(E) - Existing (N) - New				

At average wind speed 4.0 m/s the wind power plant is on the limit of being economical. Compare the production cost in scenario 4 (alternative I) with the least expensive of the corresponding diesel scenarios. At an average wind speed of 7.0 m/s the wind power plant is clearly profitable.

3.9 SCENARIO 5: GRID EXTENSION

On a long term basis, this is the best solution, since it represents the most reliable and economical electric supply. Today however, there are many problems with this alternative. Grid extension demands a very large investment and will probably require approval by the Tanzanian government. Furthermore, the demand for electric power is rapidly increasing in Tanzania, and it is not certain that the generation capacity is increased in the same pace, so load shedding in the national grid might be necessary in the future. However when the 180 MW hydro power plant in Kihansi is completed (probably before year 2000) it can be assumed that there then will be enough available power in the national grid.

There are several possibilities to extend the grid to Kasulu (cf. the map on page II):

- From Mwanza via Kibondo to Kasulu and Kigoma.
- From Burundi to Kasulu.
- From Tabora, via Urambo and Uvinza to Kasulu and further on to Kigoma.

The last option is probably the best. Burundi would be an inexpensive alternative, but due to the tense political situation in Burundi is it not possible today or in the closest future. Thus, we will in this scenario only consider the alternative from Tabora.

Cost estimation

It is very hard to calculate an energy cost for this scenario, since the prices will be depending on TANESCO tariffs. The average TANESCO tariff[61] was in July 1997 57 TSh/kWh, which

61. TANESCO uses a differentiated tariff. An example from 1989 can be found in [13], appendix I.

equals nine cents per kWh. However, since TANESCO is making an economical loss, it is likely that the tariffs will be increased in the future. A guess is that the TANESCO average tariff a few years from now will be in the range ten to twenty cents per kWh.

The recently completed 220 kV transmission line from Morogoro to Ubongo cost about 100 000 USD/km.[62] We assume that the above proposed transmission line would cost about the same per kilometre, which means a total investment of 46 million USD. The load in Kasulu would probably represent about 10% of the total load[63] on the line, and it is therefore fair to assume that the distribution company/cooperative in Kasulu should pay 10% of the investment, i.e. 4.6 million USD. We assume that the transmission line will have a economic life span of 25 years and that the maintenance will equal 5% of the initial investment annually.

The cost for building the distribution system has been estimated in ***Distribution system*** on page 24.

3.10 CONCLUSIONS

The results of the scenarios are compiled in table 3.16 and figure 3.17. Since the most common

Table 3.16: Compilation of the scenario results

Load	Initial investment [USD]*	Average production cost with real interest 4%† [USD/kWh]	Average production cost with real interest 7%‡ [USD/kWh]	LOLP [%]	UE [kWh/day]
Scenario 1: Diesel gensets					
Low	I) 606 784 II) 584 275	I) 0.43 II) 0.39	I) 0.44 II) 0.40	I) 2.95 II) 4.93	I) 45.39 II) 69.75
Low (CFL)	I) 606 784 II) 584 275	I) 0.45 II) 0.40	I) 0.46 II) 0.42	I) 2.63 II) 5.30	I) 31.90 II) 62.94
High	918 822	0.36	0.36	2.01	67.85
High (CFL)	918 822	0.37	0.38	2.89	76.57
Scenario 2: Hydro power plant at River Chogo and diesel gensets					
Low	4 136 610	0.23	0.31	0.04	0.37
Low (CFL)	2 756 610	0.21	0.28	0.22	3.09
High	7 475 840	0.16	0.21	0.17	4.63
High (CFL)	6 066 840	0.16	0.22	0.13	2.32

62. According to a TANESCO working paper.
63. This is a guess based on the present electric energy consumption in Kigoma, Kasulu, Uvinza and Urambo.

Table 3.16: Compilation of the scenario results

Load	Initial investment [USD]*	Average production cost with real interest 4%† [USD/kWh]	Average production cost with real interest 7%‡ [USD/kWh]	LOLP [%]	UE [kWh/day]
Scenario 3: PV systems 1 battery (I, II, III) and 2 batteries (IV, V, VI) respectively. None (I, IV), 20% (II, V) and 40% (III, VI) discount respectively.					
Individ-ual house-holds	Investment per household: I) 1437 II) 1150 III) 862 IV) 1608 V) 1286 VI) 965	I) 0.58 II) 0.46 III) 0.35 IV) 0.78 V) 0.62 VI) 0.47	I) 0.74 II) 0.60 III) 0.45 IV) 0.96 V) 0.77 VI) 0.58	LOLP and UE will depend on the battery capacity and how long periods without sun-shine that could be experienced.	
Scenario 4: Wind power plant and diesel gensets Average wind speed 4 m/s (I) and 7 m/s (II) respectively.					
Low	1 310 275	I) 0.38 II) 0.27	I) 0.41 II) 0.30	I) 3.84 II) 2.17	I) 56.12 II) 32.23
Low (CFL)	1 310 275	I) 0.40 II) 0.29	I) 0.43 II) 0.32	I) 4.12 II) 2.25	I) 48.20 II) 26.07
High	1 601 157	I) 0.35 II) 0.28	I) 0.36 II) 0.29	I) 4.34 II) 2.99	I) 167.17 II) 111.41
High (CFL)	1 601 157	I) 0.36 II) 0.28	I) 0.37 II) 0.29	I) 5.44 II) 3.52	I) 177.99 II) 109.18
Scenario 5: Grid extension					
Low	5 140 000**	0.58 to 0.68	0.67 to 0.77	LOLP and UE should be very low, provided that there is enough capacity in the national grid.	
Low (CFL)		0.71 to 0.81	0.83 to 0.93		
High	5 318 000††	0.29 to 0.39	0.33 to 0.43		
High (CFL)		0.34 to 0.44	0.38 to 0.48		

* Including distribution system.
† Including instalments on initial investment.
‡ Also including instalments.
** Estimated share for Kasulu. See chapter 3.9 above.
†† Estimated share for Kasulu.

solution in rural Tanzanian system is diesel gensets, we will use diesels as reference for comparisons.

Economical performance

Obviously hydro power is the least expensive option. The combination of wind power and diesel gensets can compete with a pure diesel gensets solution if the average wind speed is high enough. If the interest rate is low wind power is at the limit of being profitable already at an average wind speed as low as 4 m/s, and the extra cost caused by wind power in the other cases is only a few cents. At an average wind speed of 7 m/s wind power is clearly profitable in all cases. Photo voltaics are only preferable to diesel gensets if the diesel price is high, and the discount for the PV system is large. Grid extension requires a high load, not only in Kasulu but also in the other connected townships,[64] to be competitive to diesel gensets.

As can be seen in figure 3.17 fuel, operation and maintenance is the major part of the production cost for the diesel scenarios. As operation costs for diesel gensets is very dependant on the oil prices on the world market, the production costs might change rapidly in these scenarios. An increase in diesel price, can lead to very high production costs. On the other hand, a decrease in taxes for the diesel fuel would reduce the production cost.

Environmental effects

None of the proposed solutions have a large environmental impact. Diesel gensets represents the, from an environmental view, worst option. Diesel gensets uses fossil fuels, which produce greenhouse gases and acidification. The contribution from a small diesel genset is of course very small compered to the total pollution produced by humans all over the world, but if all rural developing areas should be electrified with fossil fuels, this should be a problem.[65] In the local environment, diesel gensets produce waste oil, that has to be taken care of, and disturbing noise.

Hydro power can cause damage to the local environment, but small scale hydro power, like our proposal of a hydro power plant at River Chogo, would have negligible impact on the land. An eventual reservoir would be small, and would not cover cultivated areas.

Photo voltaics produce neither noise nor pollution, but the batteries contain acid and heavy metals and have to be taken care of. This could though easily be managed by a cooperative.

The environmental impact of wind power or grid extension would merely be aesthetically, although the latter might be depending on power produced in power plants elsewhere that are harmful to the environment. Wind power can cause some noise in the close surroundings, but in this case there are no obstacles to locate the wind power plants in unpopulated areas.

Other effects

Both diesel gensets, hydro power and wind power demand foreign experts and equipment. The diesel gensets have the advantage that there is local knowledge of diesel motors, but for the hydro power and wind power education of operation and maintenance personnel is required. This can however have the advantage that the level of technical knowledge is increased in the area.

Photo voltaics has to be imported and the regulators might be to complicated to be repaired locally.

Diesel gensets, wind power plants and probably photo voltaics can be installed quickly and systems with these supply options can also be expanded fast if the load is increased. If too

64. Since we have assumed that the load in Kasulu represents 10% of the total load along the line in all cases.

65. This is the reason why the Swedish foreign aid agency, SIDA, has recently decided to avoid supporting energy technologies which imply usage of fossil fuels.

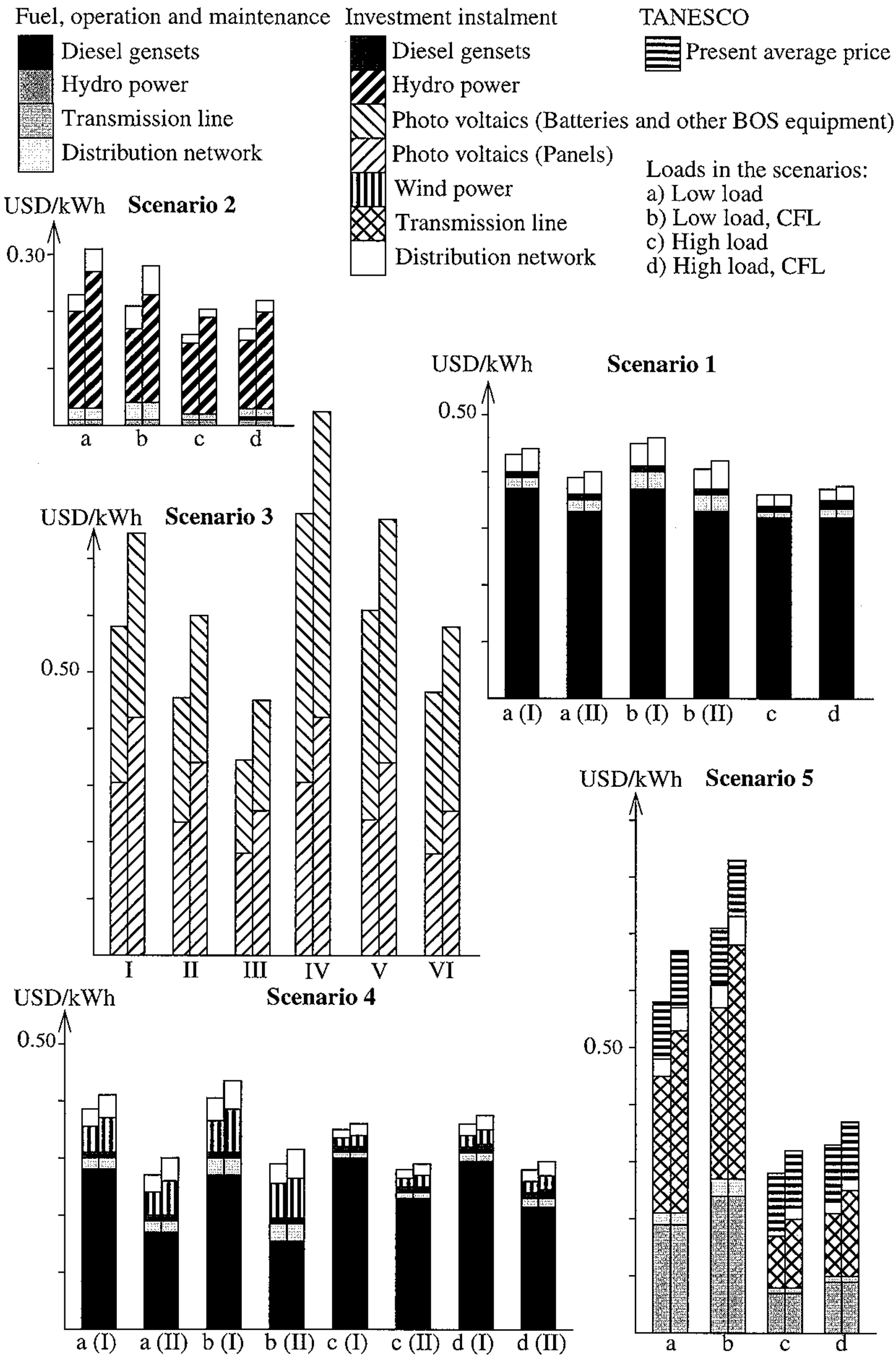

Figure 3.17: Generation and distribution costs per kWh.

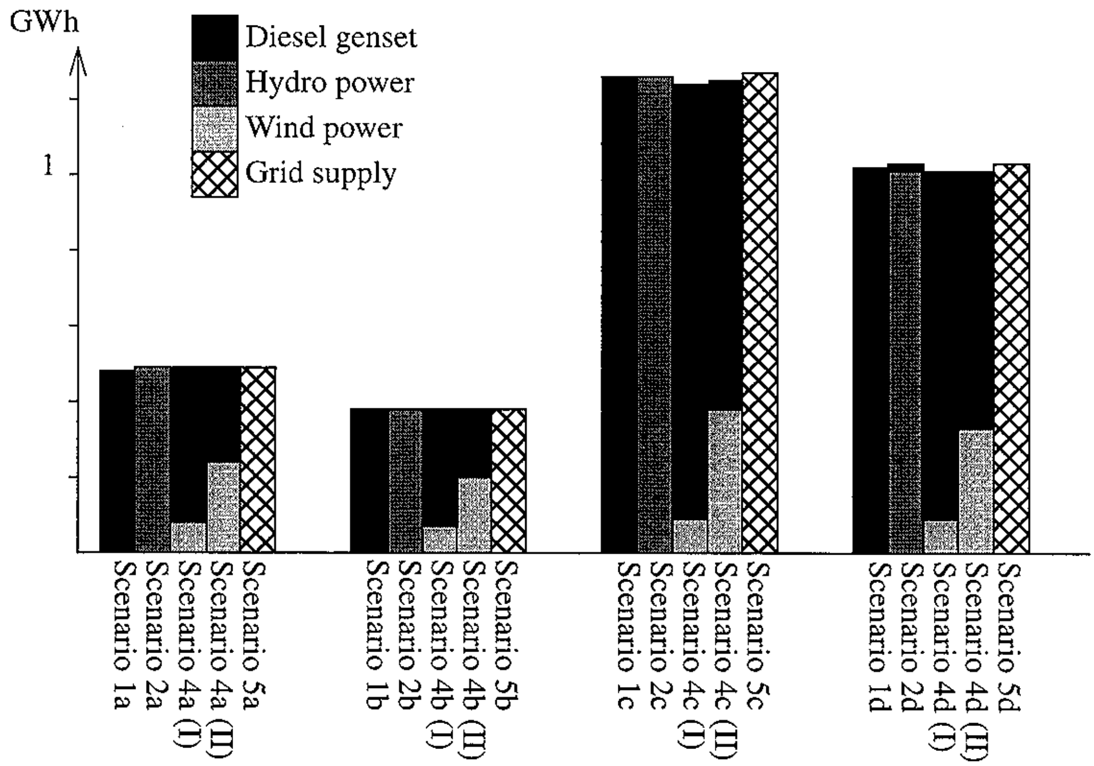

Figure 3.18: Annual generation

much capacity is installed in the system, these plants can easily be dismantled and sold to other places. In the case of diesel gensets, the financial loss due to overcapacity is low, since diesel gensets represent a small investment. Construction of a hydro power plant or a transmission line requires time, but will also produce a lot of work opportunities for the local people.

Wind and hydro power represents long term investments, that will be useful even after an connection to the national grid.

3.11 RECOMMENDATIONS

We would like to make the following recommendations for an electrification project in Kasulu:

- To make a fair estimation of the costs for renewable energy sources it is necessary to have reliable weather data. A weather station measuring rainfall, insolation, sun hours and wind speed should be established immediately.
- An inventory of the streams near Kasulu that are suitable for hydro power should be made as fast as possible. Equipment for measuring the water flow in the most interesting sites (probably including River Chogo) should be installed.
- Our power market survey is based on too many assumption. A more proper estimation of the load has to be made, especially considering the number of customers that want to be connected. Also, the demand in the nearby villages should be examined.
- A distribution network should be designed and constructed, since the least expensive options require a distribution system. In the initial phase of the electrification, the network should be supplied by the existing diesel gensets.
- When the demand in Kasulu exceeds the capacity of the existing diesel gensets[66] and provided that the relations between the prices shown in table 3.16 are correct, we suggest that

the next investment in the Kasulu power system should be a hydro power plant.

• When the load no longer can be supplied from the first hydro power plant, a new power plant based on hydro power, wind power or photovoltaics should be built. The choice will depend on how prices for these sources develop in the future.[67]

On a long term basis, connection to the national grid is the best solution, but it will of course not be a disadvantage for Kasulu to have local energy production when connected to the grid.

• Solar household systems should use as simple technical systems as possible, so that service can be made by a local electrician.

• If KAECO is supported by a foreign development aid, it should be emphasized that aid is most effectively given as beneficial loan. This enables investments in cheap, renewable energy.[68] The aid agency should see to the total costs, not only to the investment. During the past decades, too many diesel gensets have been given to rural villages and townships, even though it later turned out that the receiver could not use them, due to the high operation costs.

66. It might be profitable with a smaller hydro power plant already at a lower load demand. The possibility to construct a hydro power plant in several stages and the necessary load demand when hydro power is profitable needs further studies.

67. The prices for renewable supply options are likely to be reduced in the future. Diesel genset will probably be more and more expensive - unless the fuel taxes are reduced - since their production cost is mainly depending on the price for the diesel fuel.

68. As seen in figure 3.17 are the cost for the renewable options very depending on the real interest.

Chapter 4

METHODOLOGY

This chapter is our suggestion to how a feasibility study for a rural electric power system could be performed. It is based on our experiences from the case study.

4.1 SUPPLY OPTIONS

When investigating possible supply options it is of great importance to have reliable data concerning wind, insolation, rainfall etc., since this information is vital for estimating the generation costs in renewable energy sources like wind power, hydro power and photo voltaics. The first step in a feasibility study should therefore be to establish the necessary measurement stations. Records from at least one year are needed for a good analysis.

When these data are known and the load demand has been determined, the available supply options can be evaluated and compared. We recommend the usage of probabilistic simulations of generation costs (see appendix A), since it not only gives an estimation of the generation costs, but also indicates the reliability of the system.

At least the following factors should be evaluated for each option:

- **Production cost.** This should include instalments on the investments, fuel costs and O&M costs.
- **Environmental impact.** Even when planning a small scale power plant it is necessary to consider the environmental effects. It might be worth to choose a solution with slightly higher generation cost if the environmental profits are large enough.
- **Other effects.** Which other factors will be affected by the different supply options? For instance, how will the local economy be involved? Are there large financial risks connected with an option?

4.2 POWER MARKET SURVEY

To be able to choose the size of the power plants is it necessary to determine the demand. A power market survey can be performed in many ways, for instance with interviews of several possible consumers (like we did) or estimations based on experiences of demand from other, already electrified, areas.

Important factors

As the sensitivity analysis in section 3.3 points out, there are some categories which have a larger impact on the load demand than other. Generally, residents and light industries should be studied with special care.[69] It is fairly easy to estimate the demand for each residential, but it is hard to determine their number, since it might depend on the price how many residents that will connect to a public electricity supply. Light industries on the other hand are more easy to count,

69. In Kasulu, the College and Institution category had a large impact on the load curve, but this was caused by only one large college, which hosted a lot of residents.

but their electricity consumption might vary a lot.

The most important aspect of the power market survey - especially if it is performed by someone with no local knowledge - is to carefully record all assumptions made. Too often feasibility reports only include a phrase like "... the demand in X-town is estimated to Y MW.." with no specification of the conditions when this estimation is valid. This means that the estimation is worthless after a few years, when nobody knows if some important factor have been changed. It also means that it is impossible to use the estimation for comparison with not yet electrified areas.

Results of the power market survey

A power market survey should at least result in an estimation of peak and lowest demand, although it is preferable to estimate the load curve when possible, since this enables probabilistic simulations.

Furthermore, these facts should be determined by the survey:

- **Energy price dependency.** It is important to have an estimation on how the demand depends on the energy price. This is a delicate issue, since people might be offended when asked about how much they can afford to pay for electricity. It might be preferable to compare how energy consumption is varying with the price in other areas.
- **Future growth rate.** Some kind of forecast of the future growth of the demand can be used when planning the distribution system.
- **Customers demand.** The customers demand on voltage and frequency stability as well as reliability has to be known when choosing a supply source. When planning the distribution system it is necessary to know how many customers that require three phase supply and how many that are satisfied with one phase supply.
- **Customer geographical distribution.** This is also necessary information for planning the distribution system.

4.3 DISTRIBUTION SYSTEM

The distribution system has to be planned together with the supply options, since a badly located, but inexpensive, power plant, might be less profitable than a more expensive but centrally located power plant. The planning of the distribution system have not been treated in this report (more than briefly in appendix B), but we want to emphasize some of the findings from [2]:

- **Symmetric load.** A three-phase system operates at its best when the load is distributed symmetrically over the phases, since this will reduce the losses due to currents in the neutral conductor. As mentioned above, not all customers have a need for a three-phase supply. However, these customers should be distributed as equally as possible over the phases.

  Load shedding is often practised in isolated rural systems, due to lack of capacity or failure in the generators. This is of course most easily avoided through installing enough generator capacity and correct maintenance, but if load shedding still must be practised it is desirable that there is a possibility to disconnect all three phases of a part of the system instead of just disconnecting one phase.
- **Transformer capacity.** The MV/LV transformers in the system should be equally loaded. There is no point in overloading one transformer and not fully use another. To avoid this situation is it advisable to locate the transformers so that customers can be shifted from one transformer to a neighbouring transformer, or to introduce spare transformers like in figure 4.1. The spare transformer T_3 can be used to unload the transformers T_1 and T_2 when the load increase (in the future or if one of them fails).

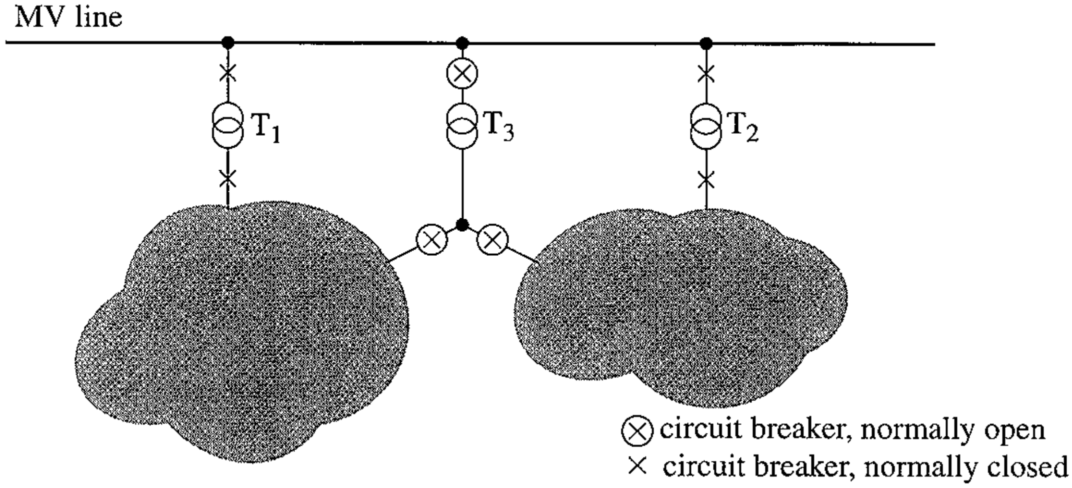

Figure 4.1: System with spare transformer

• **Conductor area.** Conductors with larger area have less resistance and thus lower losses. The choice between several conductors can be made through weighting the investment cost for larger area against the value of lower losses. Compare with the formulas presented in section B.1.

• **Geographical distribution.** It is recommended that the individual low voltage networks do not extend more than 500 m.[70]

70. [23], p. 60.

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[21] I. Vorwerk, "Electric energy effiency in Urambo power system (part two)". Master thesis work at KTH 1996.

[22] E. Westling & P. Liljevik, "Evaluation of environmental pollution from TANESCO diesel power plants". Master thesis work at KTH 1991.

[23] "Dimensionering av landsbygdsnät" (Design of rural power systems). Svenska Elverksföreningen 1985 (in Swedish).

[24] "Draft Feasability Study Report. Malagarasi Hydro Power Project Kigoma. Volume 4." Norconsult 1983.

[25] "Omställning av energisystemet" (Changeover of the power system). SOU 1995:140, Stockholm 1995 (in Swedish).

Appendix A

PROBABILISTIC SIMULATIONS

When analysing the scenarios in chapter 3 we have used a method called probabilistic simulation of production costs. In this appendix we will give a brief summary of this method. For a more penetrating discussion on the subject refer to for instance [20] or similar literature.

Normalized load duration curves

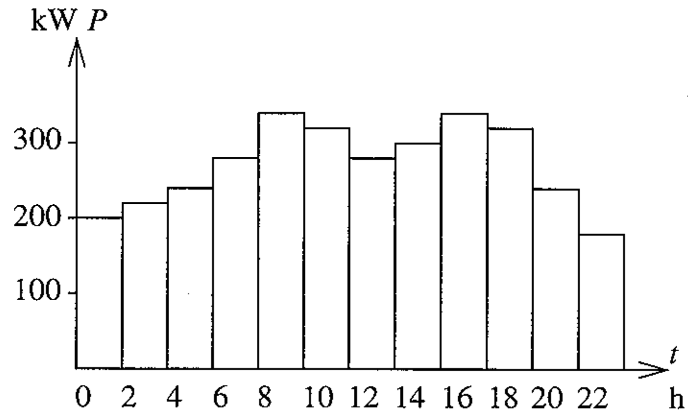


Figure A.1: Example of a load curve

A figure showing how the load of a system varies with time is called a load curve. More interesting for system planning purposes is the *load duration curve*, which is defined as

$$LDC_R(k) = \text{Load demand which is exceeded during } k \text{ hours} \tag{A.1}$$

The load duration curve is easily obtained from the load curve through sorting the values of the load curve in descending order, as in figure A.2.

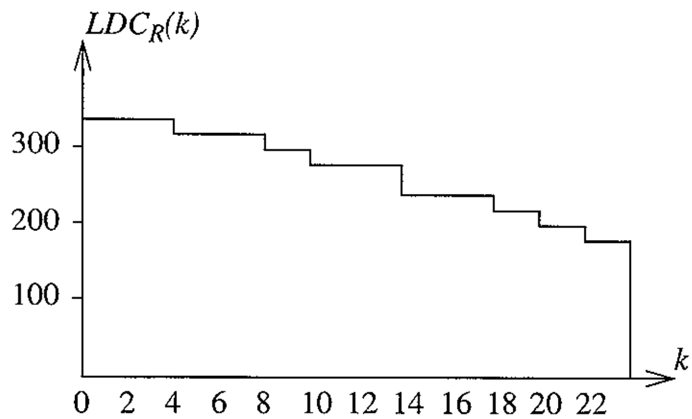


Figure A.2: Load duration curve corresponding to the load curve in figure A.1

The index R indicates that this is the real load duration curve, in contrast to the *inverted load duration curve*, where the axis have changed places. The inverted load duration curve is denoted $F_{LDC}(x)$.

The *normalized load duration curve* is obtained from the inverted load duration curve through dividing with studied time period, *T*. Thus, the normalized load duration curve, $F(x)$, represents the probability that the load x is exceeded. The normalized load duration curve corresponding to the load curve in figure A.1 is shown in figure A.3.

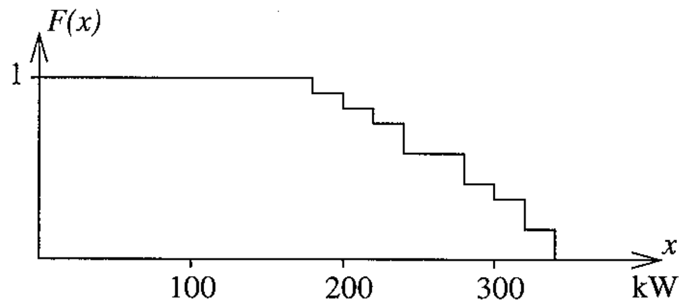


Figure A.3: The normalized load duration curve of the load in figure A.1

Impact of not 100% available power plants

The theory in this subsection is only valid under the assumption that the probability of failure in a power plant is independent of the load and the state of other power plants in the system.

The loss of a power plant due to failure can be seen as an increase of the load that have to be produced in the remaining power plants. Consider the system shown in figure A.4a, there we

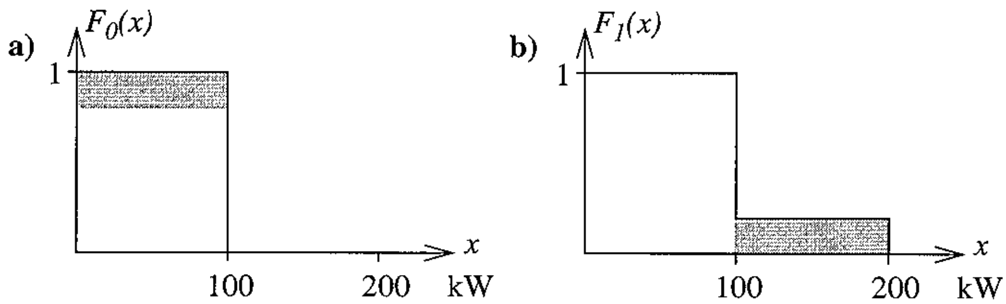


Figure A.4: System supplied with a 100 kW-generator with availability 80%.
a) Normalized load duration curve for the system
b) Equivalent load duration curve for the system

always have a demand of 100 kW. The system is supplied from a 100 kW-generator with availability[71] of 80%. This means that 20% of the demanded energy (the shadowed part in the figure) will not be supplied. However, this system is equivalent to a system supplied by a 100 kW-generator with 100% availability, but with a load that has a probability of increasing from the original load. The probability for this increase is the same as the probability for failure in the 100 kW-generator and the size of the increase is 100 kW. This way, the unserved energy in the system is unchanged, which can clearly be seen if the shadowed parts of figure A.4a and A.4b are compared. The load duration curve in figure A.4b is called an *equivalent load duration curve* and can be obtained with the convolution equation

71. Availability is defined as the probability that a power plant is available for power production at a given moment.

$$F_1(x) = p_1 F_0(x) + q_1 F_0(x - \hat{P}_1) \quad \text{(A.2)}$$

where

$F_0(x)$ = original normalized load duration curve

$F_1(x)$ = equivalent load duration curve with one power plant

p_1 = availability for the power plant

q_1 = unavailability for the power plant (i.e. forced outage rate)

$\hat{P}_1$ = maximum power output of the power plant.

The equation A.2 can be generalized to

$$F_k(x) = p_k F_{k-1}(x) + q_k F_{k-1}(x - \hat{P}_k) \quad \text{(A.3)}$$

which gives the equivalent load duration curve with k power plants.

Impact of the order of power plants

The order in which the power plants are added to the equivalent load duration curve using equation A.3 is significant, since the first added plant ($k = 1$) will experience the largest load and thus be used more frequently. The plant in the next position ($k = 2$) will only be used when the first plant is not sufficient to cover the load, either because the first power plant is not operating or because the load is larger than the installed power of the first plant. The third plant is only used when the entire generation in the first two power plants is not enough, etc.

This means that since lower positioned power plants will be used more frequently than the higher positioned, the least expensive plants (i.e. the plants with the lowest generation costs) should be added first.

Impact of wind power plants

The convolution equation A.3 is valid for power plants that either has the installed capacity available or is not available at all, which is an appropriate model for hydro power plants and diesel gensets. For wind power this is not a sufficient model, since the produced power in a wind power plant is varying with the wind speed, as described in section 2.3.

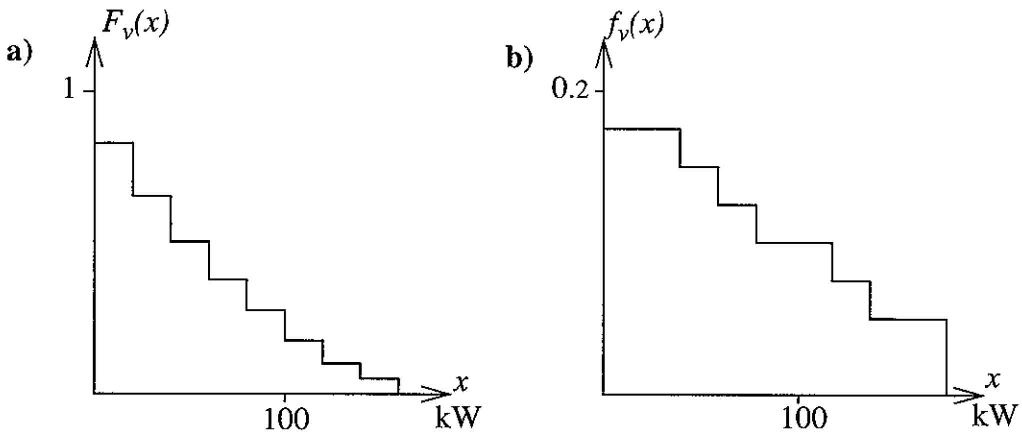


Figure A.5: Example of a 160 kW wind power plant
a) Normalized duration curve for the available power of a wind power plant
b) Frequency function for the available power production in the same wind power plant

The power generation in a wind power plant can be described with a normalized duration curve, which is obtained through combining the distribution curve of the wind speed (see figure 2.2) and the power function[72] of the wind power plant. An example of a normalized duration curve, divided in 20 kW-segments is shown in figure A.5a. From the normalized duration curve, a frequency function for the power generation can be obtained. The frequency function is here[73] defined by:

$f_v(x)$ = the probability that the generation is in the segment x (A.4)

The relation between the normalized duration curve and the frequency function is given by

$$f_v(x) = F_v(x - P_{segment}) - F_v(x) \qquad \text{(A.5)}$$

where

$P_{segment}$ = the length of the segments

Equation A.5 should be interpreted that since $F_v(x - P_{segment})$ is the probability that the generation exceeds $(x - P_{segment})$ and $F_v(x)$ is the probability that the generation exceeds x, the difference between them must be the probability that the generation belongs to the interval $(x - P_{segment}, x)$.

When knowing the probability for each generation level, it is easy to calculate the probability for each level of production outage. This is used in a multi-state model of the wind power plant. The model has N states, each occurring with the probability p_i, $i = 1, \ldots, N$. For each state there is a loss of production x_i, $i = 1, \ldots, N$. If the two-state model in the previous section should be described this way, we would have $N = 2$, $p_1 = p_k$, $x_1 = 0$, $p_2 = q_k$ and $x_2 = \hat{P}_k$. Thus, equation A.3 could be generalized to

$$F_k(x) = \sum_{i=1}^{N} p_i F_{k-1}(x - x_i) \qquad \text{(A.6)}$$

Loss Of Load Probability and Unserved Energy

On the basis of the equivalent load duration curve it is possible to calculate some values describing the system performance, the Loss Of Load Probability and the Unserved Energy. It is also possible to calculate the expected energy generation in each power plant.

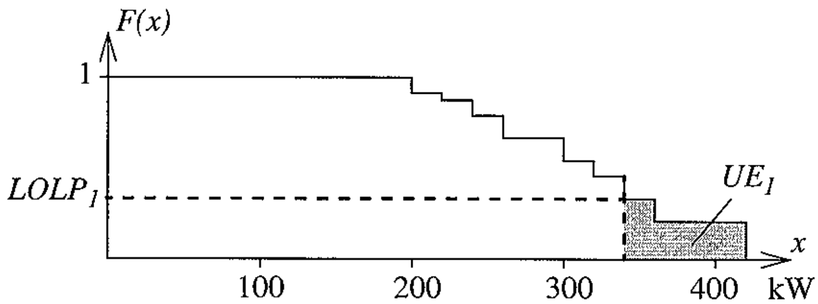


Figure A.6: Equivalent load duration curve of the LDC in figure A.3. One power plant with $p = 0.8$ and $\hat{P}_1 = 340$ kW

The Loss Of Load Probability (abbreviated LOLP) is the probability that the available supply is not enough to match the demand, which means that customers have to be disconnected.[74] The LOLP can be obtained from the equivalent load duration curve. Only if the

72. The power function states the power generation as a function of the wind speed.
73. The equations A.4 and A.5 are designed for duration curves divided in segments.

equivalent load is exceeding the total installed power with k power plants, X_k, some load has to be disconnected (since we assume that all power plants are 100% available in the equivalent load duration curve). The probability of the load exceeding X_k is $F_k(X_k)$ (cf. figure A.6). Thus the LOLP with k power plants is given by

$$LOLP_k = F_k(X_{k\cdot}) \tag{A.7}$$

LOLP indicates how often the demand is not satisfied. It might however also be interesting to know how much load that is lost. This is called the Unserved Energy (UE) and is defined as the energy that could not be delivered due to loss of production. The UE can also be obtained from the equivalent load duration curve. The power that cannot be delivered is the equivalent load that is higher than the installed power, i.e.

$$UE_k = T\int_{\overline{X}_k}^{\infty} F_k(x)dx \tag{A.8}$$

With UE the energy production in each power plant can be calculated. Since UE_k is the energy not supplied with k power plants and UE_{k-1} is the energy not supplied with k - 1 power plants, the difference has to be produced in the k:th power plant, and therefore the energy supplied by power plant k can be calculated by

$$W_k = UE_{k-1} - UE_k \tag{A.9}$$

Impact of dispatchable hydro power

In this section we will briefly show how hydro power plants with reservoirs should be treated. In the model, these power plants can be divided into a base plant (using the flow of the run) with installed capacity $\hat{P}_{HB}$, and a dispatchable plant (using the water in the reservoir) with installed capacity $\hat{P}_{HD}$. Since there is a limited amount of water in the reservoir, the possible energy generation from the dispatchable plant is limited. Our objective is now to choose when to use the reservoir, and make this choice so that the total operating cost[75] for the system is minimized.

Consider a system with dispatchable hydro power and K diesel gensets.[76] The base hydro power is used as first power plant (see ***Impact of the order of power plants*** on page 49), since it would be a waste to spill water and use more expensive diesel gensets instead. To obtain the correct position for the dispatchable hydro power plant we try to place it in the last position, after the diesel gensets. Now the energy generation in each power plant is calculated with equation A.9 and if the movable generation cost λ_k is known for each power plant the total variable generation cost is given by

$$C_{t1} = \sum_{k=1}^{K+2} \lambda_k W_k \tag{A.10}$$

If the dispatchable hydro power now changes place with the K:th diesel genset, the generation in the dispatchable hydro power plant will increase and the generation in the diesel genset will decrease, which means that the total cost is reduced since the operation cost is less for hydro power. The generation in the other plants are not affected and the total generation in the system has remained the same. This will always be the case when two power plants following

74. This is called load shedding.

75. With operation generation costs we mean costs that are directly proportional to the generation in the plant, i.e. no capital costs or other fixed yearly costs.

76. The diesel gensets are only used as examples. The model is valid for any combination of hydro power and other power plants presupposed that the other plants have a operation cost not less than the operation cost for the hydro power.

each other switches position.[77] Thus, all diesel gensets will only have two possible generation levels; one if they are used before the dispatchable hydro power and one if they are used after. This means that all possible generation levels can be calculated from two equivalent load duration curves; one with the dispatchable hydro power used directly after the base hydro power and one with the dispatchable hydro power used as last power plant.

Now the total generation cost can be calculated with equation A.10 for each position of the dispatchable hydro power. This can be shown as a function of the hydro power generation, as in figure A.7. Only the break points of the partially continuous function is obtained, but the total operation cost for any level of available hydro energy can be calculated with linear interpolation.

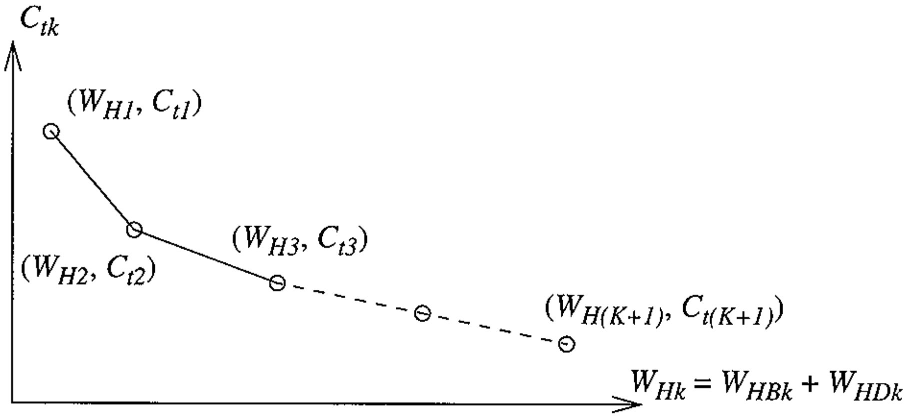


Figure A.7: Total movable cost as a function of available hydro energy.
C_{t1} is the total movable cost when the dispatchable water has the highest position,
C_{t2} is the total movable cost when the dispatchable water has been switched once, etc.

77. This is easily shown. It is obvious that the previous power plants are not effected by the switch. Now consider the load duration curve when n convolutions have been performed. Let us add two more power plants with availability $p_1 = \alpha$ and $p_2 = \gamma$, unavailability $q_1 = \beta$ and $q_2 = \delta$, and installed power $\hat{P}_1 = \Pi$ and $\hat{P}_2 = \pi$. The equivalent load duration curve with these two power plants is obtained with two convolutions with equation A.3:

$$F_{n+1}(x) = \alpha F_n(x) + \beta F_n(x - \Pi)$$

$$F_{n+2}(x) = \gamma F_{n+1}(x) + \delta F_{n+1}(x - \pi) =$$

$$= \gamma(\alpha F_n(x) + \beta F_n(x - \Pi)) + \delta(\alpha F_n(x - \pi) + \beta F_n(x - \Pi - \pi))$$

If the power plants switches places we obtain

$$F^*_{n+1}(x) = \gamma F_n(x) + \delta F_n(x - \pi)$$

$$F^*_{n+2}(x) = \alpha F^*_{n+1}(x) + \beta F^*_{n+1}(x - \Pi) =$$

$$= \alpha(\gamma F_n(x) + \delta F_n(x - \pi)) + \beta(\gamma F_n(x - \Pi) + \delta F_n(x - \pi - \Pi)) = F_{n+2}(x)$$

This means that the equivalent load duration curve has remained unchanged and the *(n + 3)*:th power plant will be placed at the same power level in both cases, and therefore the generation in the higher positioned power plants will be unchanged.

Appendix B

TRANSMISSION AND DISTRIBUTION

The objective of this appendix is to describe how the costs for transmission lines and distribution networks could be estimated.

B.1 HIGH AND MEDIUM VOLTAGE LINES

MV lines uses voltages in the range 1 kV to 40 kV. If the voltage is higher the line is considered a HV line. The higher voltages are used for transmission over long distances, and the MV lines are used for transmission over shorter distances and for distribution, either from a HV line or from a local power plant, to the LV networks.

Voltage drop

An important constraint when choosing conductor dimensions for the MV network is which voltage drops that are acceptable. TANESCO usually accepts voltage drops less than 5%.

Conductors with a length less than 100 km is usually modelled as in figure B.1, there U_s is

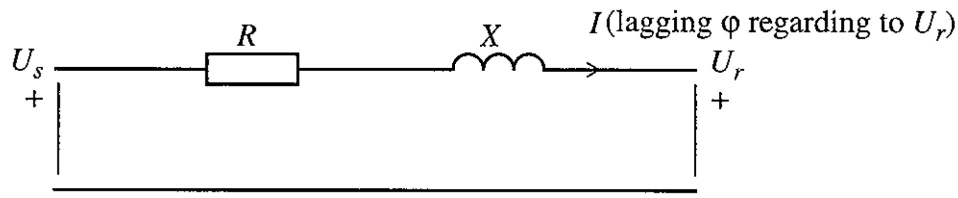


Figure B.1: Model of a MV line

the sending-end phase voltage and U_r is the receiving-end phase voltage. The phasor diagram for this line is shown in figure B.2.

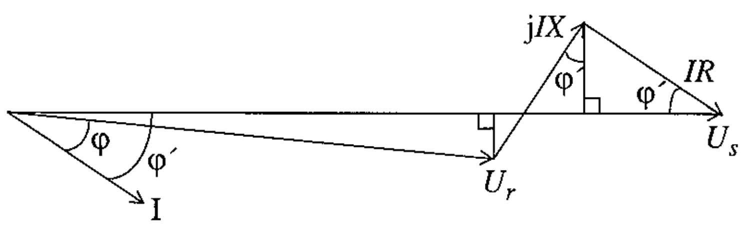


Figure B.2: Phasor diagram for the MV line in figure B.1

When the distribution system is operating normally the angle between U_s and U_r is negligible,[78] i.e. $\varphi \approx \varphi'$, which gives

78. [15], p. 38.

$$U_s \approx U_r + IR\cos\varphi + IX\sin\varphi \tag{B.1}$$

From this expression the voltage drop U_d is easily calculated by

$$U_d = U_s - U_r = IR\cos\varphi + IX\sin\varphi \tag{B.2}$$

In single phase calculations the resistance and reactance of the return path must be included in R and X. For three-phase systems the line-line voltage drop is given by

$$U_d = \sqrt{3}(IR\cos\varphi + IX\sin\varphi) \tag{B.3}$$

The real three-phase power on the line is

$$P = \sqrt{3}UI\cos\varphi \tag{B.4}$$

where U is the line-line voltage.

This gives that equation B.3 can be rewritten as

$$U_d = \frac{P}{U}(R + X\tan\varphi) \tag{B.5}$$

Losses

The losses on a transmission line is depending on the conductor dimensions and the voltage of the transmission. Given the apparent power transmitted on a line, S_L, and ignoring the voltage drop on the line (which as stated above should be only a few per cent) is it easy to calculate the losses:

$$P_{loss} = 3I_L^2R_L = \left\{I_L = \frac{S_L}{\sqrt{3}U}\right\} = \frac{S_L^2}{U^2}R_L \tag{B.6}$$

where

S_L = apparent power flow on the line

I_L = line current

R_L = line resistance

U = system voltage

From equation B.6 it is clear that the losses can be decreased either by increasing the system voltage, decreasing the load or decreasing the line resistance. The conductor dimensions (which determines the line resistance) and the system voltage are chosen when designing the line.

Choosing larger conductor dimensions or a higher voltage leads to a more expensive investment (cf. table B.3), and it is not certain that the future savings due to lower losses will compensate that. On the other hand, even if the losses are small at the current load, it might be more profitable investing in a system with higher voltages and/or larger conductor dimensions, if the load is expected to grow rapidly in the future.

In order to compare different combinations of voltage and conductor dimensions it is possible to calculate the present worth of the investment cost through

$$C = C_{line} + C_{loss}P_{loss}\gamma_1\frac{\gamma_1^T - 1}{\gamma_1 - 1} \tag{B.7}$$

where

$$\gamma_1 = \frac{\left(1 + \frac{r}{100}\right)^2}{1 + \frac{i}{100}} \tag{B.8}$$

and

C = present worth of the investment cost

C_{line} = investment cost depending on choice of conductor

C_{loss} = cost for losses in $/W per year

P_{loss} = losses on the line (given by equation B.6)

r = annual growth rate in per cent

i = interest rate in per cent

T = review period in years

For a further explanation of the expression γ_1, defined in equation B.8, see [15], p. 92.

Designing a line

The Matlab function `line_design` shown below can be used when choosing conductor dimensions and voltage levels for transmission lines or MV networks. It plots in separate figures the voltage drop (calculated with equation B.5) and the present worth of the total costs (calculated with equation B.7) as a function of the active power flow on the line.

```
% line_design plots some graphs that can be useful when dimensioning a
% transmission line or MV network
% Arguments:
%  C - Row vector containing the cost per km for each conductor that should
%      be considered
%  U - Row vector containing the voltage in kV for each conductor that should
%      be considered
%  Z - Row vector containing the impedance in Ohm per km for each conductor
%      that should be considerd
%  S - Matrix containing strings with the name of each conductor. Row i should
%      contain the name of the i:th conductor in the C-, U- and Z-vectors.
%      Note that Matlab requires all strings to be of the same length.
%       Example: Z = [0.27 0.54];
%                S = ['ACSR-50 '; 'ACSR-100'];
%  Cl - Cost for losses in economic units per W per year
%  L - length of line in km
%  i - interest in per cent
%  r - growth rate of the line loading in per cent
%  T - review period in years
%  Smax - The maximum power flow of the line to be considered
%  cosfi - power factor of the load
%  ecu - String containing the name of the economic unit used
%
function line_design(C,U,Z,S,Cl,L,i,r,T,Smax,cosfi,ecu)

clf
subplot(2,1,1),hold on
title('Present worth of investment and future losses')

R = real(Z);
X = imag(Z);
style = ['- '; ': '; '-.'; '--'];

Ctot = zeros(Smax+1,length(C));
for n = 1:length(C)
  Ctot(:,n) = C(n)*L*ones(Smax+1,1);
end
```

```
drops = zeros(size(Ctot));
for p = 0:Smax
  for n = 1:length(C)
     Ploss = (p/U(n))^2*R(n)*L;
     gamma1 = ((1 + r/100)^2)/(1 + i/100);                    % See Lakervi, Holmes, p. 92
     Ctot(p+1,n) = Ctot(p+1,n) + Cl*Ploss*gamma1*(gamma1^T -1)/(gamma1 - 1);
     drops(p+1,n) = p/(U(n))^2*L*(R(n) + X(n)*tan(acos(cosfi)))/10;
  end
end
s = 1; xvals = 0:Smax;
for n = 1:length(C)
  plot(xvals,Ctot(:,n),style(s,:));
  txt = sprintf('%s, %d kV', S(n,:), U(n));
  text(Smax*0.8,Ctot(Smax,n)*1.01,txt);
  s = s + 1;
  if s > 4
    s = 1;
  end
end
xlabel('apparent power flow [kVA]'), ylabel(sprintf('Cost [%s]', ecu))

subplot(2,1,2),hold on
title('Voltage drop');

s = 1; xvals = 0:Smax;
maxdrop = 0; mindrop = Inf;
for n = 1:length(C)
  plot(xvals,drops(:,n),style(s,:));
  txt = sprintf('%s, %d kV', S(n,:), U(n));
  text(Smax*0.8,drops(Smax,n)*1.01,txt);
  if drops(1,n) < mindrop
    mindrop = drops(1,n);
  end
  if drops(Smax,n) > maxdrop
    maxdrop = drops(Smax,n);
  end
  s = s + 1;
  if s > 4
    s = 1;
  end
end
rowheight = (maxdrop - mindrop)/7;
currline = maxdrop;
txt = sprintf('Line length: %d km', L);
text(Smax/10,currline,txt);
currline = currline - rowheight;
txt = sprintf('Interest: %.1f %%', i);
text(Smax/10,currline,txt);
currline = currline - rowheight;
txt = sprintf('Review period: %.d years', T);
text(Smax/10,currline,txt);
currline = currline - rowheight;
txt = sprintf('Growth rate: %.1f %%', r);
text(Smax/10,currline,txt);
xlabel('real power flow [kW]'), ylabel('Voltage drop [%]')
hold off
```

B.2 COST ESTIMATIONS

Planning the location of the MV/LV substations and the routing of the LV lines is a very complex task. For the calculations in this report we only want to make a rough estimation of the cost for the distribution system, so that we approximately can see how large part the distribution system contributes with to the total investment.

Table B.3: Price examples for high and medium voltage lines

Voltage [kV]	Conductor	r* [Ω/km]	x† [Ω/km]	Price [$/km]‡
0.4	AAC-PVC 50 mm^2			14 000
0.4	AAC-PVC 100 mm^2			15 000
11	ACSR 50 mm^2	0.543	0.372	15 000
11	ACSR 100 mm^2	0.273	0.350	17 000
33	ACSR 50 mm^2	0.543	0.372	16 000
33	ACSR 100 mm^2	0.273	0.350	20 000
66	ACSR 150 mm^2			38 500
132	ACSR 150 mm^2			60 000

* Source: [1], p. 16.
† Source: [1], p. 17.
‡ Source: Working paper from TANESCO Department for Distribution and Commercial Service, August 1997.

Table B.4: Price examples for transformers*

Voltages [kV]	Apparent power [kVA]	Price [TSh]	Price [USD]†
11/0.400	50	2 304 250	3 600
11/0.400	100	2 985 125	4 700
11/0.400	200	4 774 000	7 500
11/0.400	315	5 466 500	8 500
33/0.400	100	3 043 625	4 800
33/0.400	200	4 954 625	7 700
33/0.400	500	7 686 000	12 000
33/0.400	800	9 585 875	15 000
33/11	500	9 280 375	14 500
33/11	1000	15 276 625	23 900

* Source: ABB Tanelec Ltd, July 1997.
† Based on the exchange rate 1 USD = 640 TSh.

Proposal of quick estimation methodology

• Select how many and how large substations that are needed and select suitable sites for them. The exact location of each substation is irrelevant, it is enough to determine the location with a precision of 100 to 200 m.

Table B.5: Price examples for customer connections*

Item	Price [TSh]	Price [USD]†
One phase service line	252 600	400
One phase meter	37 000	60
Three phase service line	450 000	700
Three phase meter	97 000	150

* Source: Working paper from TANESCO, October 1997.

† Based on the exchange rate 1 USD = 640 TSh.

• Estimate the length of the MV network. The terrain has to be considered, but it is not important to make a solid appraisal of the ground conditions at this stage. In Tanzania, most MV and LV lines follow existing roads.

• Choose voltage and conductor dimensions for the MV network.

• Estimate the length of the LV networks. This is most easily done by comparison with similar areas elsewhere. If this is impossible, assume that the LV line length is 50% to 100% longer than the MV lines.

• Determine how many consumers that will need three phase supply and how many that are satisfied with one phase. The unit cost for service lines and meters can be found in table B.5.

Appendix C

LOAD CURVES FOR TYPICAL KASULU CONSUMERS

In this appendix the result of our interviews with possible electric power consumers is presented in the form of Matlab scripts. For each category of consumers two "standard" load curves are estimated; one low estimation and one high.

We have frequently used the conception of coincident factors. The definition of coincident factors can be found in appendix F.

In the Matlab code the following conventions are used (for an explanation of the special Matlab functions used, please refer to appendix E):

- When stating the demanded power with `add_demand` is the demand calculated with

  number of items · power of each item · coincident factor

  unless the number of items is one, in which case the number of items is omitted.

  Sometimes the demand is given by

  (power of one item + power of another item) · coincident factor

- Names are given to the load curves of the individual consumers in this manner:

  `residents5low`

  The first part is the category (in this case residents), the number is the number of the interview[79] and the last part is either `low` or `high`, depending on which estimate it is.

Standard loads

Some common standard loads have been defined. These are then used in the consumer scripts. The following assumptions should be noted:

- Load curves for fans and lighting have been "smoothed" at the beginning and end, so that not for instance all bulbs in Kasulu are switched on exactly seven p.m.
- In Kasulu it is light outside between approximately seven a.m. to seven p.m. all around the year. We therefore assume that security lights are used between around seven p.m. to seven a.m.
- We have assumed that people start using their fans when it starts getting warm around nine a.m. Likewise, they do not turn the fans off at sunset, but a few hours later, except for offices, since these are closing around three p.m.
- In guesthouses we have assumed that most guests only stay in their room (and use the fan) during the evening.
- Air conditioning is assumed to be left on all the day.
- The coincident factor for ironing is based on the assumption that people iron about two hours every week.
- For heaters we have assumed that warm water is needed between six a.m. and eleven p.m. The coincident factor of 0.05 is based on the fact that it is usual that the heaters only are

79. Some interviews concerned more than one consumer, but always in different categories. For instance, when we have interviewed a shopkeeper, we might have asked questions about his household too.

switched on when warm water is actually needed.

- Although we have not defined any standard computers, typewriters, duplicators, copiers or TV and video sets (since the operating hours are varying a lot) we have made the same assumption of power and coincident factors (see table C.1). These assumptions are based more or less on guesses.

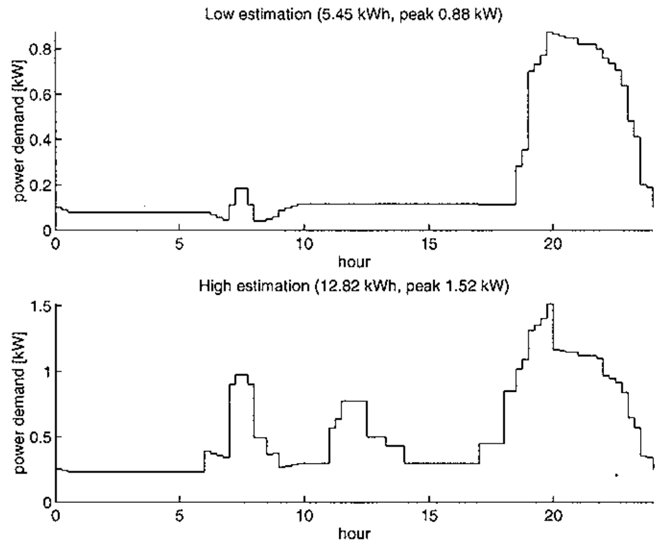
Table C.1: Assumptions for office equipment

Equipment	Rated power [W]	Coincident factor [%]
Computer	250	20
Copier	1500	10
Duplicating machine	200	5
Typewriter	100	10
TV	100	80
Video	20	80

```
residentialFan = newLC(0);
residentialFan = add_demand(0.010,8.5,20.5,residentialFan);
residentialFan = add_demand(0.010,8.75,20.25,residentialFan);
residentialFan = add_demand(0.010,9,20,residentialFan);
residentialFan = add_demand(0.010,9.25,19.75,residentialFan);
residentialFan = add_demand(0.010,9.5,19.5,residentialFan);
residentialFan = add_demand(0.010,9.75,19.25,residentialFan);

officeFan = newLC(0);
officeFan = add_demand(0.010,8.5,16.5,officeFan);
officeFan = add_demand(0.010,8.75,16.25,officeFan);
officeFan = add_demand(0.010,9,16,officeFan);
officeFan = add_demand(0.010,9.25,15.75,officeFan);
officeFan = add_demand(0.010,9.5,15.5,officeFan);
officeFan = add_demand(0.010,9.75,15.25,officeFan);

guesthouseFan = newLC(0);
guesthouseFan = add_demand(0.075*0.1,9,22,guesthouseFan);
guesthouseFan = add_demand(0.075*0.2,17,21.75,guesthouseFan);
guesthouseFan = add_demand(0.075*0.2,17.5,21.5,guesthouseFan);

AC = newLC(0.5);

fridge = newLC(0.1*0.3);

iron = newLC(0);
iron = add_demand(1*0.024,9,21,iron);

heater = newLC(0);
heater = add_demand(4.5*0.05,6,23,heater);


% Some standard load curves for 60W bulbs:

bulb19to22 = newLC(0);
bulb19to22 = add_demand(0.06*0.2,19,22.5,bulb19to22);
bulb19to22 = add_demand(0.06*0.2,19.25,22.25,bulb19to22);
bulb19to22 = add_demand(0.06*0.2,19.5,22,bulb19to22);
bulb19to22 = add_demand(0.06*0.2,19.75,21.75,bulb19to22);

bulb19to23 = newLC(0);
```

```
bulb19to23 = add_demand(0.06*0.2,19,23.5,bulb19to23);
bulb19to23 = add_demand(0.06*0.2,19.25,23.25,bulb19to23);
bulb19to23 = add_demand(0.06*0.2,19.5,23,bulb19to23);
bulb19to23 = add_demand(0.06*0.2,19.75,22.75,bulb19to23);

bulb19to24 = newLC(0);
bulb19to24 = add_demand(0.06*0.2,19,24,bulb19to24);
bulb19to24 = add_demand(0.06*0.2,0,0.5,bulb19to24);
bulb19to24 = add_demand(0.06*0.2,19.25,24,bulb19to24);
bulb19to24 = add_demand(0.06*0.2,0,0.25,bulb19to24);
bulb19to24 = add_demand(0.06*0.2,19.5,24,bulb19to24);
bulb19to24 = add_demand(0.06*0.2,19.75,23.75,bulb19to24);

bulb19to1 = newLC(0);
bulb19to1 = add_demand(0.06*0.2,19,24,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,0,1.5,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,19.25,24,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,0,1.25,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,19.5,24,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,0,1,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,19.75,24,bulb19to1);
bulb19to1 = add_demand(0.06*0.2,0,0.75,bulb19to1);

% Some standard load curves for security lights:

bulbsecurity60 = newLC(0);
bulbsecurity60 = add_demand(0.06*0.25,0,7,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,19,24,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,0,6.75,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,19.25,24,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,0,6.5,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,19.5,24,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,0,6.25,bulbsecurity60);
bulbsecurity60 = add_demand(0.06*0.25,19.75,24,bulbsecurity60);

bulbsecurity100 = newLC(0);
bulbsecurity100 = add_demand(0.1*0.25,0,7,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,19,24,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,0,6.75,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,19.25,24,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,0,6.5,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,19.5,24,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,0,6.25,bulbsecurity100);
bulbsecurity100 = add_demand(0.1*0.25,19.75,24,bulbsecurity100);

% Some standard load curves for tube lights:

tube19to22 = newLC(0);
tube19to22 = add_demand(0.04*0.2,19,22.5,tube19to22);
tube19to22 = add_demand(0.04*0.2,19.25,22.25,tube19to22);
tube19to22 = add_demand(0.04*0.2,19.5,22,tube19to22);
tube19to22 = add_demand(0.04*0.2,19.75,21.75,tube19to22);
```

Residents (large consumers)



The division of residential consumers in the categories large, medium and small is made by us, and is based on our impressions of the interviewed persons capability to buy new electric equipment and pay connection fees and running costs.

The residents classified as large are comparatively wealthy people, who already have a lot of electric equipment, maybe even an own generator, and will have no problem to buy more equipment.

We have made the following assumptions concerning some special loads:

- Electric cooking seems very expensive compared to cooking with charcoal (which costs 2000 TSh/bag) or fire wood (which is either collected by the members in the household or bought very cheap). Some wealthy people might though afford to use electric cooking. For those customers we have used the coincident factor 0.75. The rest of the cookers are considered to be used only occasionally, and have therefore a coincident factor of 0.2.
- The energy consumption of the juice extractor in interviews 15 and 37 is based on our guess, since it is unclear what equipment that was meant
- The washing machine in interview 37 is assumed to be a small washing machine and used about three hours every week.

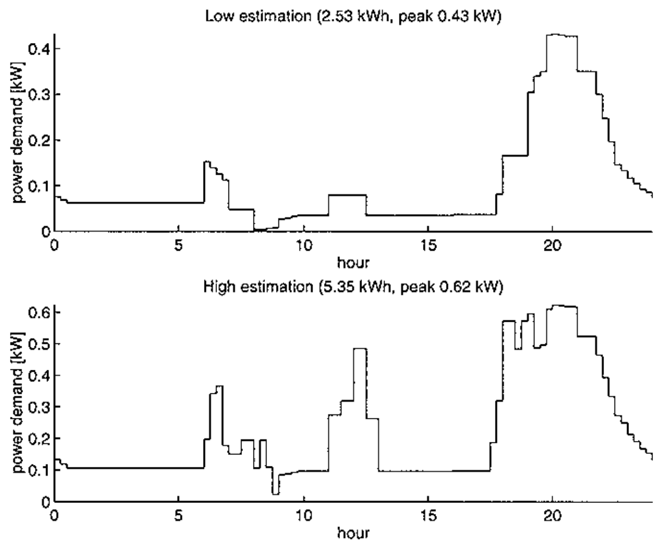
```
resident3low = newLC(0);
resident3low = add_demand(6*0.040*0.8,19,23,resident3low);      % Bulbs
resident3low = add_demand(1*0.040*0.8,19,23,resident3low);      % Tube lights
resident3low = resident3low + residentialFan;                   % Fan
resident3low = resident3low + fridge;                           % Fridge

resident3high = add_demand(2*0.75,6,7,resident3low);            % Cooker
resident3high = add_demand(2*0.75,11,12,resident3high);         % Cooker
resident3high = add_demand(2*0.75,18,20,resident3high);         % Cooker
resident3high = add_demand(1*0.05,8,18,resident3high);          % Carpentry
                                                                %  machines
resident3high = resident3high + AC;                             % Air
                                                                %  conditioning

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident5low = newLC(0);
resident5low = add_demand(7*0.1*0.8,19,24,resident5low);        % Bulbs
resident5low = add_demand(6*0.04*0.8,19,24,resident5low);       % Tube lights
resident5low = add_demand(0.120*0.8,19,22,resident5low);        % TV & video
resident5low = resident5low + fridge;                           % Fridge

resident5high = resident5low;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident6low = newLC(0);
resident6low = resident6low + 15*bulb19to23;                % Bulbs
resident6low = add_demand(0.120*0.8,19,22,resident6low);    % TV & video
resident6low = resident6low + fridge;                        % Fridge
resident6low = add_demand(0.015*0.07,7,23,resident6low);    % Radio

resident6high = resident6low + AC;                           % Air
                                                             %  conditioning

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident8low = newLC(0);
resident8low = resident8low + 15*bulb19to23;                % Bulbs
resident8low = add_demand(0.1*0.8,19,23,resident8low);      % Bulb
resident8low = add_demand(3*0.04*0.8,19,23,resident8low);   % Tube lights
resident8low = add_demand(0.085*0.1,10,23,resident8low);    % Music system
resident8low = resident8low + residentialFan;                % Fan
resident8low = add_demand(0.115*0.8,19,23,resident8low);    % TV, video &
                                                             % satelite rec.
resident8low = resident8low + fridge;                        % Fridge

resident8high = resident8low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident9low = newLC(0);
resident9low = add_demand(16*0.06*0.8,18.5,23.5,resident9low);  % Bulbs
resident9low = add_demand(6*0.04*0.8,18.5,23.5,resident9low);   % Tube lights
resident9low = add_demand(0.015*0.1,7,19,resident9low);     % Radio
resident9low = resident9low + 2*residentialFan;              % Fans
resident9low = add_demand(0.1*0.8,18.5,23,resident9low);    % TV
resident9low = resident9low + fridge;                        % Fridge
resident9low = resident9low + iron;                          % Iron

resident9high = add_demand(4.5*0.2,7,8,resident9low);       % Cooker
resident9high = add_demand(4.5*0.2,17,18,resident9high);    % Cooker
resident9high = resident9high + heater;                      % Heater

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident15low = newLC(0);
resident15low = resident15low + 17*bulb19to23;              % Bulbs
resident15low = add_demand(0.015*0.5,8,22,resident15low);   % Radio
resident15low = resident15low + residentialFan;              % Fan
resident15low = resident15low + fridge;                      % Fridge
resident15low = resident15low + iron;                        % Iron

resident15high = add_demand(0.12*0.5,8,23,resident15low);   % TV & video
resident15high = add_demand(2*0.4,7,8,resident15high);      % Kettle
resident15high = add_demand(2*0.4,17,18,resident15high);    % Kettle
resident15high = add_demand(1*0.05,8,19,resident15high);    % Juice
                                                             %  extractor

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident28low = newLC(0);
resident28low = resident28low + 20*bulb19to22;              % Bulbs
resident28low = add_demand(0.015*0.1,9,21,resident28low);   % Radio
resident28low = resident28low + 2*residentialFan;            % Fans
resident28low = resident28low + iron;                        % Iron
resident28low = resident28low + fridge;                      % Fridge

resident28high = add_demand(0.105*0.8,19,23,resident28low);      % TV
resident28high = add_demand(2*0.75,7,8.5,resident28high);        % Cooker
resident28high = add_demand(2*0.75,11.5,12.5,resident28high);    % Cooker
resident28high = add_demand(2*0.75,18,19,resident28high);        % Cooker
```

```
resident28high = resident28high + AC;                     % Air
                                                          %  conditioning

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident37low = newLC(0);
resident37low = add_demand(13*0.06*0.8,19,23.5,resident37low);   % Bulbs
resident37low = resident37low + 2*bulbsecurity60;                 % Bulbs
resident37low = resident37low + residentialFan;                   % Fan
resident37low = add_demand(0.12*0.8,19,22.5,resident37low);       % TV & video
resident37low = add_demand(2*0.4,7.25,7.75,resident37low);        % Kettle
resident37low = add_demand(2*0.4,18.75,19.25,resident37low);      % Kettle
resident37low = resident37low + fridge;                           % Fridge
resident37low = add_demand(1*0.075,9,21,resident37low);           % Iron
resident37low = add_demand(1*0.05,7,21,resident37low);            % Juice
                                                                  %  extractor
resident37low = add_demand(0.5*0.05,7,21,resident37low);          % Mixer

resident37high = add_demand(2*0.75,7,8,resident37low);            % Cooker
resident37high = add_demand(2*0.75,11,12.5,resident37high);       % Cooker
resident37high = add_demand(2*0.75,18,20,resident37high);         % Cooker
resident37high = add_demand(2.2*0.04,8,18,resident37high);        % Washing
                                                                  %  machine

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident40low = newLC(0);
resident40low = resident40low + bulb19to23;                       % Bulb
resident40low = resident40low + 2*bulbsecurity100;                % Bulbs
resident40low = add_demand(10*0.04*0.8,19,23,resident40low);      % Tube lights
resident40low = add_demand(0.015*0.1,8,23,resident40low);         % Radio
resident40low = resident40low + residentialFan;                   % Fan
resident40low = add_demand(0.120*0.8,19.5,24,resident40low);      % TV & video
resident40low = resident40low + fridge;                           % Fridge
resident40low = resident40low + iron;                             % Iron
resident40low = add_demand(0.06*0.5,7,17,resident40low);          % Sewing
                                                                  %  machine

resident40high = resident40low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident44low = newLC(0);
resident44low = resident44low + 15*bulb19to23;                    % Bulbs
resident44low = resident44low + 2*bulbsecurity60;                 % Bulbs
resident44low = add_demand(3*0.015*0.1,19,24,resident44low);      % Radio sets
resident44low = resident44low + residentialFan;                   % Fan
resident44low = add_demand(2*0.4,7,8,resident44low);              % Kettle
resident44low = add_demand(2*0.4,18.5,19.5,resident44low);        % Kettle
resident44low = resident44low + fridge;                           % Fridge
resident44low = resident44low + iron;                             % Iron

resident44high = resident44low + 5*bulb19to23;                    % Bulbs
resident44high = resident44high + 3*bulbsecurity60;               % Bulbs
resident44high = add_demand(1*0.75,7,8,resident44high);           % Cooker
resident44high = add_demand(1*0.75,11.25,13.25,resident44high);   % Cooker
resident44high = add_demand(1*0.75,18,20,resident44high);         % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident52low = newLC(0);
resident52low = resident52low + 10*bulb19to24;                    % Bulbs
resident52low = resident52low + bulbsecurity60;                   % Bulb
resident52low = add_demand(0.04*1,0,7,resident52low);             % Tube light
resident52low = add_demand(0.04*1,19,24,resident52low);           % Tube light
resident52low = add_demand(0.015*0.1,9,21,resident52low);         % Radio
resident52low = add_demand(0.12*0.5,19,23,resident52low);         % TV & video
resident52low = resident52low + fridge;                           % Fridge
resident52low = resident52low + iron;                             % Iron
```

```
resident52high = add_demand(2*0.75,7,9,resident52low);              % Cooker
resident52high = add_demand(2*0.75,12,14,resident52high);           % Cooker
resident52high = add_demand(2*0.5,18,22,resident52high);            % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

LargeResidentsLow = (resident3low + resident5low + resident6low + resident8low + resident9low +
resident15low + resident28low + resident37low + resident40low + resident44low +
resident52low)/11;

LargeResidentsHigh = (resident3high + resident5high + resident6high + resident8high +
resident9high + resident15high + resident28high + resident37high + resident40high +
resident44high + resident52high)/11;

if p==1
  LCplot2(LargeResidentsLow,LargeResidentsHigh);
  print -deps LargeResidents.eps
end
```

Residents (medium consumers)



The division of residential consumers in the categories large, medium and small is made by us, and is based on our impressions of the interviewed persons capability to buy new electric equipment and pay connection fees and running costs.

The people we have classified as medium consumers have no own generator, but they might still have some (unused) electric equipment and they are likely to afford to buy some more equipment when connected to the net.

The following assumptions have been made for medium consumers:

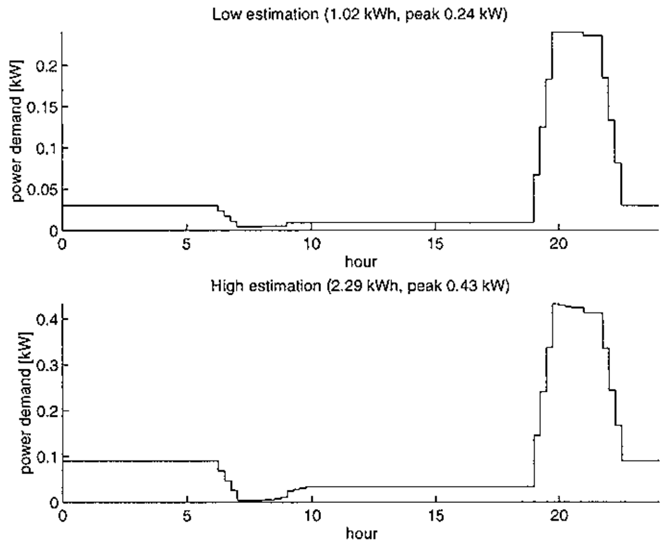
- Cookers are used only occasionally, which usually means a coincident factor of 0.4 or 0.2, depending on how the interviewed person described his or hers needs. For kettles we have assumed a coincident factor of 0.4.
- The sewing machine in interview 38 will be used commercially, but we have assumed that she will not have customers all the day and therefore chosen the coincident factor 0.3.

```
resident23low = newLC(0);
resident23low = add_demand(8*0.06*0.8,19,21,resident23low);         % Bulbs
resident23low = add_demand(0.015*0.1,8,20,resident23low);           % Radio
resident23low = add_demand(2*0.4,6,7,resident23low);                % Cooker
resident23low = add_demand(2*0.4,18,19.5,resident23low);            % Cooker
resident23low = resident23low + iron;                               % Iron
```

```
resident23high = resident23low + bulbsecurity100;                  % Bulbs
resident23high = add_demand(8*0.075*0.5,9,19.5,resident23high);   % Fans
resident23high = resident23high + fridge;                          % Fridge
resident23high = add_demand(0.1*0.8,21,23,resident23high);         % TV

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident24low = newLC(0);
resident24low = add_demand(8*0.04*0.5,19.5,21,resident24low);     % Tube lights
resident24low = add_demand(0.015*0.1,9,20,resident24low);          % Radio
resident24low = resident24low + residentialFan;                    % Fan

resident24high = add_demand(0.1*0.8,19,21,resident24low);          % TV
resident24high = resident24high + iron;                            % Iron

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident26low = newLC(0);
resident26low = resident26low + 9*bulb19to22;                      % Bulbs
resident26low = add_demand(0.015*1,8,20,resident26low);            % Radio

resident26high = add_demand(0.1*0.8,19,21,resident26low);          % TV
resident26high = add_demand(2*0.4,8.25,8.75,resident26high);       % Kettle
resident26high = add_demand(2*0.4,18.75,19.25,resident26high);     % Kettle
resident26high = resident26high + fridge;                          % Fridge
resident26high = resident26high + iron;                            % Iron

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident27low = newLC(0);
resident27low = resident27low + 11*bulb19to22;                     % Bulbs
resident27low = add_demand(0.015*1,9.5,19,resident27low);          % Radio

resident27high = resident27low + residentialFan;                   % Fan
resident27high = resident27high + fridge;                          % Fridge
resident27high = resident27high + iron;                            % Iron

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident30low = newLC(0);
resident30low = resident30low + 5*bulb19to24;                      % Bulbs
resident30low = resident30low + bulbsecurity60;                    % Bulb
resident30low = add_demand(0.015*0.1,8,20,resident30low);          % Radio
resident30low = resident30low + residentialFan;                    % Fan
resident30low = resident30low + iron;                              % Iron

resident30high = resident30low + 5*bulb19to24;                     % Bulbs
resident30high = resident30high + bulbsecurity60;                  % Bulb

% TV:
resident30low = add_demand(0.1*0.4,20,24,resident30low);
resident30high = add_demand(0.1*0.8,20,24,resident30high);

% Cooker:
resident30low = add_demand(2*0.2,7,8,resident30low);
resident30low = add_demand(2*0.2,11,12.5,resident30low);
resident30low = add_demand(2*0.2,17.75,19.25,resident30low);
resident30high = add_demand(2*0.4,7,8,resident30high);
resident30high = add_demand(2*0.4,11,12.5,resident30high);
resident30high = add_demand(2*0.4,17.75,19.25,resident30high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident31low = newLC(0);
resident31low = resident31low + 12*bulb19to22;                     % Bulbs
resident31low = resident31low + 4*bulbsecurity60;                  % Bulbs
resident31low = add_demand(0.015*0.1,9,21,resident31low);          % Radio
resident31low = resident31low + iron;                              % Iron
```

```
resident31high = add_demand(0.1*0.8,20,22,resident31low);          % TV
resident31high = add_demand(2*0.4,7.5,8.5,resident31high);         % Cooker
resident31high = add_demand(2*0.4,11,12.5,resident31high);         % Cooker
resident31high = add_demand(2*0.4,17.5,18.5,resident31high);       % Cooker
resident31high = resident31high + fridge;                          % Fridge

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident33low = newLC(0);
resident33low = resident33low + 6*bulb19to22;                      % Bulbs
resident33low = resident33low + 2*bulbsecurity60;                  % Bulbs
resident33low = add_demand(0.015*1,19,22,resident33low);           % Radio
resident33low = resident33low + iron;                              % Iron

resident33high = resident33low + 7*bulb19to22;                     % Bulbs
resident33high = resident33high + bulbsecurity60;                  % Bulbs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident38low = newLC(0);
resident38low = resident38low + 4*bulb19to23;                      % Bulbs
resident38low = resident38low + bulbsecurity60;                    % Bulb
resident38low = add_demand(0.015*1,6,8,resident38low);             % Radio
resident38low = add_demand(0.015*1,16,18,resident38low);           % Radio
resident38low = add_demand(0.015*1,20,23,resident38low);           % Radio
resident38low = resident38low + iron;                              % Iron
resident38low = add_demand(0.06*0.3,7,18,resident38low);           % Sewing
                                                                   %  machine

resident38high = resident38low + 4*bulb19to23;                     % Bulbs
resident38high = resident38high + bulbsecurity60;                  % Bulb
resident38high = add_demand(2*0.75,6.25,6.75,resident38high);      % Cooker
resident38high = add_demand(2*0.75,12,13,resident38high);          % Cooker
resident38high = add_demand(2*0.75,18,19,resident38high);          % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident49low = newLC(0);
resident49low = resident49low + 5*bulb19to23;                      % Bulbs
resident49low = add_demand(0.04*0.8,19,23,resident49low);          % Tube light
resident49low = add_demand(2*0.04*1,0,7,resident49low);            % Tube lights
resident49low = add_demand(2*0.04*1,19,24,resident49low);          % Tube lights
resident49low = add_demand(0.015*0.1,9,21,resident49low);          % Radio
resident49low = resident49low + iron;                              % Iron

resident49high = resident49low + 4*bulb19to23;                     % Bulbs
resident49high = add_demand(2*0.2,6.5,7.5,resident49high);         % Cooker
resident49high = add_demand(2*0.2,11.5,12.5,resident49high);       % Cooker
resident49high = add_demand(2*0.2,17.75,19.25,resident49high);     % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

MediumResidentsLow = (resident23low + resident24low + resident26low + resident27low +
resident30low + resident31low + resident33low + resident38low + resident49low)/9;

MediumResidentsHigh = (resident23high + resident24high + resident26high + resident27high +
resident30high + resident31high + resident33high + resident38high + resident49high)/9;

if p==1
  LCplot2(MediumResidentsLow,MediumResidentsHigh);
  print -deps MediumResidents.eps
end
```

Residents (small consumers)



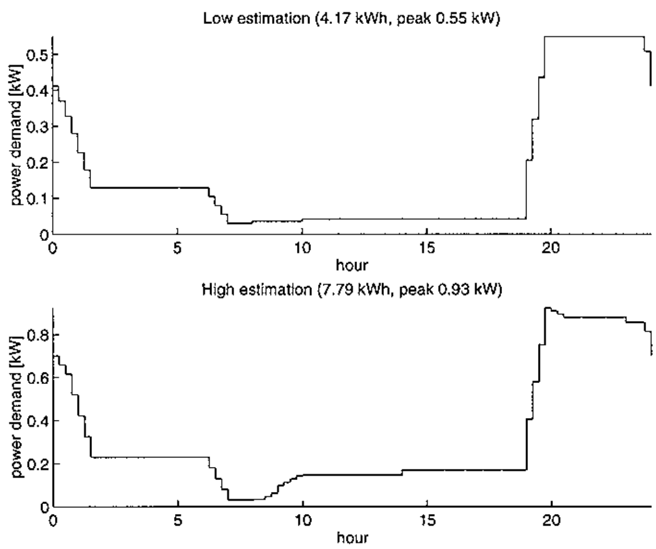
The division of residential consumers in the categories large, medium and small is made by us, and is based on our impressions of the interviewed persons capability to buy new electric equipment and pay connection fees and running costs.

The small consumers are the people who are not likely to afford to pay more for electric energy than they pay for kerosene today.

```
resident32low = newLC(0);
resident32low = resident32low + 5*bulb19to22;                % Bulbs
resident32low = resident32low + bulbsecurity60;              % Bulbs

resident32high = resident32low + 5*bulb19to22;               % Bulbs
resident32high = resident32high + bulbsecurity60;            % Bulbs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident34low = newLC(0);
resident34low = resident34low + 4*bulb19to22;                % Bulbs
resident34low = add_demand(0.015*0.1,8,19,resident34low);    % Radio

resident34high = resident34low + bulbsecurity60;             % Bulb

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident36low = newLC(0);
resident36low = resident36low + 3*bulb19to22;                % Bulbs
resident36low = add_demand(0.015*0.1,8,22,resident36low);    % Radio

resident36high = resident36low + 3*bulb19to22;               % Bulbs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident39low = newLC(0);
resident39low = resident39low + 5*bulb19to22;                % Bulbs
resident39low = resident39low + fridge;                      % Fridge
resident39low = resident39low + iron;                        % Iron

resident39high = resident39low + residentialFan;             % Fan
resident39high = resident39high + bulb19to22;                % Bulb
resident39high = resident39high + 2*bulbsecurity60;          % Bulbs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident41low = newLC(0);
resident41low = resident41low + 4*bulb19to22;                % Bulbs
```

```
resident41low = resident41low + bulbsecurity60;                % Bulb
resident41low = add_demand(0.015*0.1,9,20,resident41low);     % Radio

resident41high = resident41low + 4*bulb19to22;                 % Bulbs
resident41high = resident41high + bulbsecurity60;              % Bulb
resident41high = add_demand(0.12*0.8,19,22,resident41high);   % TV & Video

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident43low = newLC(0);
resident43low = resident43low + 6*bulb19to22;                  % Bulbs
resident43low = resident43low + bulbsecurity60;                % Bulb
resident43low = add_demand(0.015*0.4,9,21,resident43low);     % Radio

resident43high = resident43low + iron;                         % Iron

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

resident51low = newLC(0);
resident51low = resident51low + 3*bulb19to22;                  % Bulbs
resident51low = add_demand(0.015*0.1,8,21,resident51low);     % Radio

resident51high = resident51low + 2*bulb19to22;                 % Bulbs
resident51high = resident51high + 2*bulbsecurity60;            % Bulbs
resident51high = resident51high + residentialFan;              % Fan
resident51high = resident51high + iron;                        % Iron

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SmallResidentsLow = (resident32low + resident34low + resident36low + resident39low +
resident41low + resident43low + resident51low)/7;

SmallResidentsHigh = (resident32high + resident34high + resident36high + resident39high +
resident41high + resident43high + resident51high)/7;

if p==1
  LCplot2(SmallResidentsLow,SmallResidentsHigh);
  print -deps SmallResidents.eps
end
```

Bars

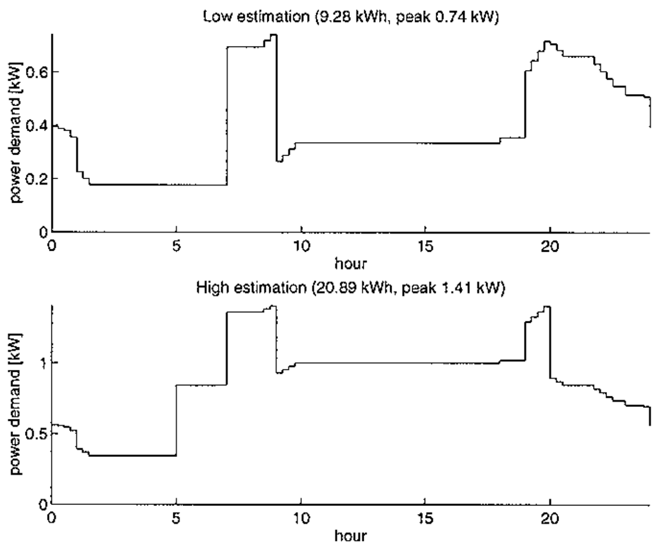


These two interviews seem to be good samples of bars.

```
bar16low = newLC(0);
bar16low = bar16low + 8*bulb19to1;                             % Bulbs
bar16low = bar16low + 2*bulbsecurity100;                       % Bulbs
bar16low = bar16low + fridge;                                  % Fridge
```

```
bar16high = bar16low + 8*bulb19to1;                        % Bulbs
bar16high = bar16high + 2*bulbsecurity100;                 % Bulbs
bar16high = add_demand(0.1*0.4,9,24,bar16high);            % TV
bar16high = bar16high + residentialFan;                    % Fan

% Radio:
bar16low = add_demand(0.015*0.8,8,24,bar16low);
bar16low = add_demand(0.015*0.8,0,1,bar16low);
bar16high = add_demand(0.015*0.4,8,24,bar16high);
bar16high = add_demand(0.015*0.4,0,1,bar16high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

bar19low = newLC(0);
bar19low = bar19low + 7*bulb19to24;                        % Bulbs
bar19low = add_demand(3*0.04*0.8,19,24,bar19low);          % Tube lights
bar19low = bar19low + fridge;                              % Fridge

bar19high = add_demand(0.12*0.4,14,23,bar19low);           % TV & video
bar19high = bar19high + 2*residentialFan;                  % Fans

% Radio:
bar19low = add_demand(0.015*0.8,10,24,bar19low);
bar19high = add_demand(0.015*0.4,10,24,bar19high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

BarsLow = (bar16low + bar19low)/2;

BarsHigh = (bar16high + bar19high)/2;

if p==1
  LCplot2(BarsLow,BarsHigh);
  print -deps Bars.eps
end
```

Restaurants



It should be noted that the restaurants category does not include restaurants in guesthouses. These are instead included in the load curve for guesthouses.

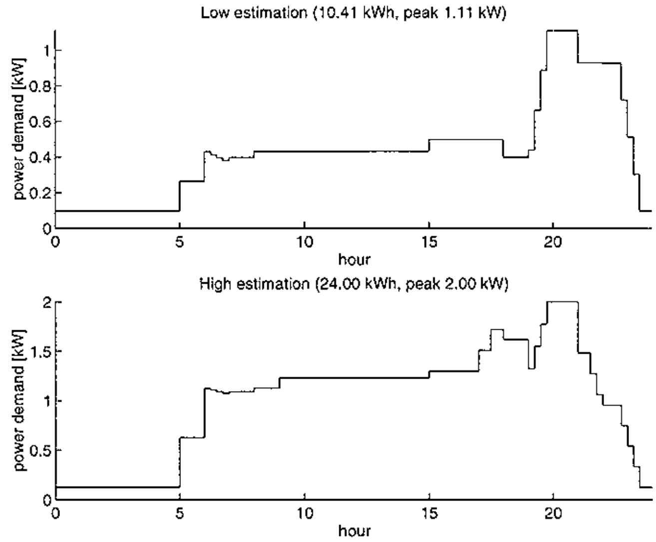
The following assumptions have been made:

- We have assumed that restaurants investing in a electric cooker also will use them as much as possible, and we have therefore chosen the coincident factor 0.75 for the cookers.
- The energy consumption for the juice extractors and mixer in interview 37 is based on our

guesses.

```
restaurant5low = newLC(0);
restaurant5low = restaurant5low + 6*bulb19to1;                % Bulbs
restaurant5low = add_demand(10*0.04*0.8,0,1,restaurant5low);   % Tube lights
restaurant5low = add_demand(10*0.04*0.8,19,24,restaurant5low); % Tube lights
restaurant5low = restaurant5low + 4*residentialFan;            % Fans
restaurant5low = add_demand(0.12*0.5,18,24,restaurant5low);    % TV & video
restaurant5low = restaurant5low + 2*newLC(0.235);              % Fridges

restaurant5high = restaurant5low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

restaurant6low = newLC(0);
restaurant6low = restaurant6low + 2*bulb19to24;                % Bulbs
restaurant6low = add_demand(8*0.04*0.8,19,24,restaurant6low);  % Tube lights
restaurant6low = restaurant6low + 2*residentialFan;            % Fans
restaurant6low = add_demand(0.120*0.8,20,23,restaurant6low);   % TV & video
restaurant6low = restaurant6low + fridge;                      % Fridge

restaurant6high = add_demand(2*0.04*0.8,19,24,restaurant6low); % Tube lights
restaurant6high = restaurant6high + AC;                        % Air
                                                               %  conditioning
restaurant6high = add_demand(2*0.75,5,20,restaurant6high);     % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

restaurant37low = newLC(0);
restaurant37low = restaurant37low + 7*bulb19to22;              % Bulbs
restaurant37low = restaurant37low + residentialFan;            % Fan
restaurant37low = add_demand(2*0.75,7,9,restaurant37low);      % Cooker
restaurant37low = restaurant37low + fridge;                    % Fridge
restaurant37low = add_demand(1*0.05,7,20,restaurant37low);     % Juice
                                                               %  extractor
restaurant37low = add_demand(0.06*0.1,7,20,restaurant37low);   % Juice mixer

restaurant37high = restaurant37low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

RestaurantsLow = (restaurant5low + restaurant6low + restaurant37low)/3;

RestaurantsHigh = (restaurant5high + restaurant6high + restaurant37high)/3;

if p==1
  LCplot2(RestaurantsLow,RestaurantsHigh);
  print -deps Restaurants.eps
end
```

Guesthouses

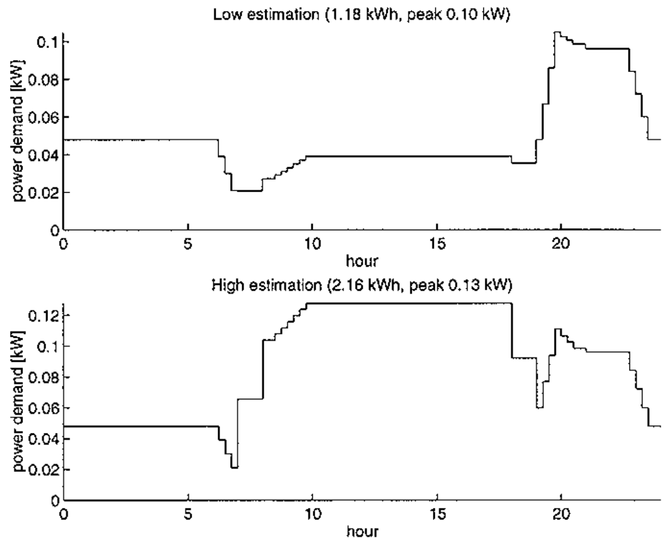


We only made two interviews with guesthouse owners and it seems like we visited two comparatively large guesthouses. One of them already had a restaurant in his guesthouse and the other one was intending to start one as soon as electricity is available. However, the most common guesthouses in Tanzania do not run restaurants. To compensate for this bad luck in choice of samples, we have included our estimation of the electric energy consumption for a small guesthouse. This estimation is based on a guesthouse in Kasulu where we stayed for a week.

```
guesthouse4low = newLC(0);
guesthouse4low = guesthouse4low + 17*bulb19to23;                  % Bulbs
guesthouse4low = add_demand(17*0.06*0.05,7,19,guesthouse4low);    % Bulbs
guesthouse4low = guesthouse4low + bulbsecurity100;                % Bulb
guesthouse4low = add_demand(0.015*0.1,9,22,guesthouse4low);       % Radio
guesthouse4low = guesthouse4low + fridge;                         % Fridge
guesthouse4low = add_demand(1*0.05,7,21,guesthouse4low);          % Iron

guesthouse4high = guesthouse4low + 10*guesthouseFan;              % Fans

% Cooker:
guesthouse4low = add_demand(2*0.25,6,19,guesthouse4low);
guesthouse4high = add_demand(2*0.75,6,19,guesthouse4high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

guesthouse17low = newLC(0);
guesthouse17low = guesthouse17low + 22*bulb19to23;                % Bulbs
guesthouse17low = add_demand(1*0.2,15,18,guesthouse17low);        % Iron
guesthouse17low = guesthouse17low + 2*fridge;                     % Fridges

guesthouse17high = guesthouse17low + 22*guesthouseFan;            % Fans
guesthouse17high = guesthouse17high + 2*fridge;                   % Fridges

% Cooker:
guesthouse17low = add_demand(2*0.25,5,21,guesthouse17low);
guesthouse17high = add_demand(2*0.75,5,21,guesthouse17high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% IMPORTANT NOTICE: This guesthouse is not based on an interview, but on
%                   our impressions what equipment a small guesthouse
%                   would buy.

guesthouse53low = newLC(0);
guesthouse53low = guesthouse53low + 13*bulb19to23;                % Bulbs
guesthouse53low = guesthouse53low + bulbsecurity100;              % Bulb
```

```
guesthouse53low = add_demand(1*0.1,8,18,guesthouse53low);         % Iron
guesthouse53low = add_demand(0.015*0.2,7,21,guesthouse53low);     % Radio

guesthouse53high = guesthouse53low + 10*guesthouseFan;            % Fans
guesthouse53high = guesthouse53high + fridge;                     % Fridge

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

GuesthousesLow = (guesthouse4low + guesthouse17low + guesthouse53low)/3;

GuesthousesHigh = (guesthouse4high + guesthouse17high + guesthouse53high)/3;

if p==1
  LCplot2(GuesthousesLow,GuesthousesHigh);
  print -deps Guesthouses.eps
end
```

Shops



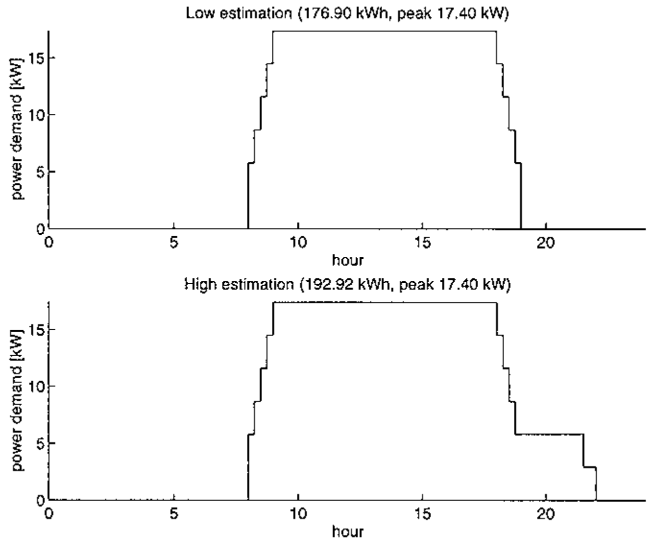
Shops represents a very diversified group of customers, since a shop can be anything from a two square metres large wooden shed to a medium size bookshop. We have made the following assumptions concerning the load profile for shops:

- The smallest shop (the two square metres kind) are not likely to be electrified, since they do not fulfil the TANESCO requirement of iron sheet roof. Furthermore, if electrified, their load would only be something like a bulb used evenings only. We have therefore ignored the small shops.
- There will be no large market for the copier in the bookshop (interview 18), so we have set the coincident factor to 0.1.
- The enlarger machine in the photo shop (interview 52) will not be used during long periods. We have assumed a coincident factor of 0.01.
- The sewing machines in interview 7 are currently powered by manual labour, but they are prepared for electric power. We have assumed that in the low estimation, they will only afford to use one electric sewing machine and in the high estimation all four sewing machines are assumed to be electrified. The coincident factor is set to 0.5, since they use the sewing machines during all the open hours.
- The music system is on during all open hours and have therefore a coincident factor of 1.

```
shop7low = newLC(0);
shop7low = add_demand(0.04*0.05,7,20,shop7low);             % Tube light
shop7low = add_demand(0.015*0.8,7,19,shop7low);             % Radio
```

```
shop7low = add_demand(0.06*0.5,7,19,shop7low);                 % Sewing
                                                               %  machine

shop7high = shop7low + residentialFan;                         % Fan
shop7high = add_demand(1*0.1,7,19,shop7high);                  % Iron
shop7high = add_demand(3*0.06*0.5,7,19,shop7high);             % Sewing
                                                               %  machines

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

shop15low = newLC(0);
shop15low = shop15low + 5*bulb19to23;                          % Bulbs
shop15low = shop15low + residentialFan;                        % Fan
shop15low = shop15low + 2*fridge;                              % Fridges

shop15high = shop15low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

shop18low = newLC(0);
shop18low = add_demand(4*0.06*0.05,8,21,shop18low);            % Bulbs
shop18low = shop18low + 3*bulbsecurity60;                      % Bulbs
shop18low = add_demand(0.015*0.1,8,19,shop18low);              % Radio

shop18high = add_demand(1.5*0.1,8,18,shop18low);               % Copier
shop18high = add_demand(0.2*0.05,8,18,shop18high);             % Duplicater

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

shop46low = newLC(0);

shop46high = add_demand(0.06*0.05,7,19,shop46low);             % Bulb
shop46high = add_demand(0.03*1,7,19,shop46high);               % Music system

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

shop52low = newLC(0);
shop52low = add_demand(0.06*0.05,8,18,shop52low);              % Bulb
shop52low = add_demand(1.5*0.01,8,18,shop52low);               % Enlarger
                                                               %  machine

shop52high = shop52low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

ShopsLow = (shop7low + shop15low + shop18low + shop46low + shop52low)/5;

ShopsHigh = (shop7high + shop15high + shop18high + shop46high + shop52high)/5;

if p==1
  LCplot2(ShopsLow,ShopsHigh);
  print -deps Shops.eps
end
```

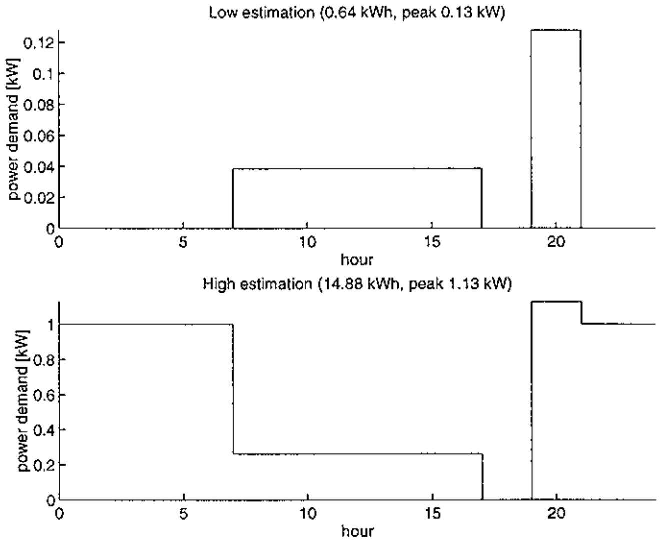
Milling machines



Although we only visited one milling machine, we believe that this machine was rather typical in rated power. It is possible that this machine had more customers than an average machine (the operator told as that he was milling during 60 - 80% of the day). To compensate for this, we have chosen a coincident factor of 0.6 during day time. In the high load estimation, we have assumed that he has so many customers that he will have to work some evenings every week.

```
milling2low = newLC(0);
milling2low = add_demand(29*0.2,8,19,milling2low);               % Milling
                                                                 %  machine
milling2low = add_demand(29*0.1,8.25,18.75,milling2low);         % Milling
                                                                 %  machine
milling2low = add_demand(29*0.1,8.5,18.5,milling2low);           % Milling
                                                                 %  machine
milling2low = add_demand(29*0.1,8.75,18.25,milling2low);         % Milling
                                                                 %  machine
milling2low = add_demand(29*0.1,9,18,milling2low);               % Milling
                                                                 %  machine


milling2high = add_demand(2*0.06*0.2,19,22,milling2low);         % Bulbs
milling2high = add_demand(29*0.1,19,22,milling2high);            % Milling
                                                                 %  machine
milling2high = add_demand(29*0.1,19,21.5,milling2high);          % Milling
                                                                 %  machine

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

MillingMachinesLow = milling2low;

MillingMachinesHigh = milling2high;

if p==1
  LCplot2(MillingMachinesLow,MillingMachinesHigh);
  print -deps MillingMachines.eps
end
```

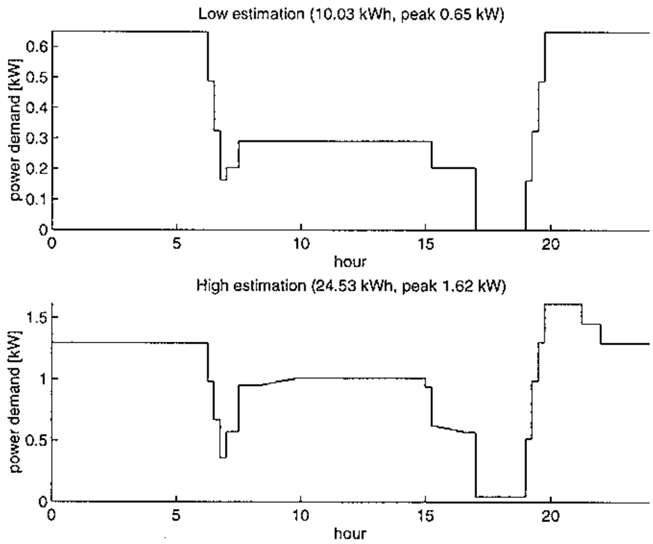
Primary schools



Unfortunately, we only visited one primary school and it seems like it was a rather large one. The school has about 1200 pupils, which should be compared with the total number of children in Kasulu (about 4500, see ***Demography*** on page 17). But since the load is very small in the low estimation and the major part of the load in the high estimation is security lighting, we still consider this as a fair sample of the load curve for a primary school.

```
school35low = newLC(0);
school35low = add_demand(46*0.04*0.01,7,17,school35low);        % Tube lights
school35low = add_demand(4*0.04*0.8,19,21,school35low);         % Tube lights
school35low = add_demand(0.2*0.05,7,17,school35low);            % Duplicating
                                                                 %  machine
school35low = add_demand(0.1*0.1,7,17,school35low);             % Typewriter

school35high = add_demand(4*0.25*1,0,7,school35low);            % Mercury light
school35high = add_demand(4*0.25*1,19,24,school35high);         % Mercury light
school35high = add_demand(0.12*0.2,7,17,school35high);          % TV & video
school35high = add_demand(2*2*0.05,7,17,school35high);          % Cookers

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

PrimarySchoolsLow = school35low;

PrimarySchoolsHigh = school35high;

if p==1
  LCplot2(PrimarySchoolsLow,PrimarySchoolsHigh);
  print -deps PrimarySchools.eps
end
```

Secondary schools



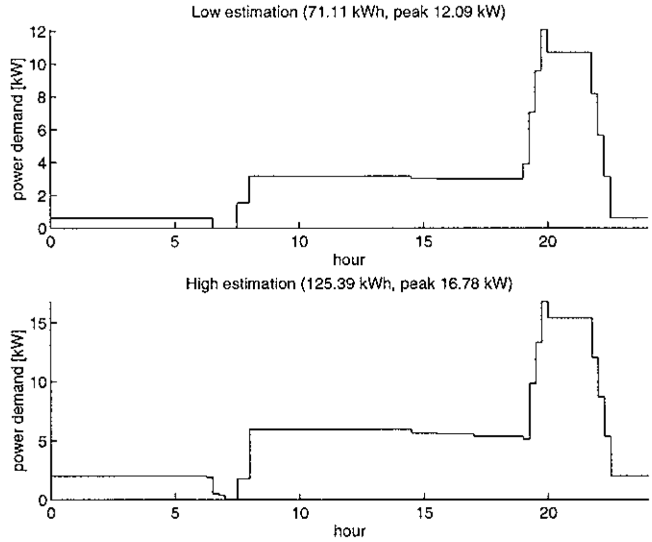
This should be a good estimation of the load curve for secondary schools in Kasulu, since we have visited both of them. The following assumptions should be noted:

- The cookers are used for domestic sciences. We have assumed that this means that they only will be used occasionally and therefore we have chosen the coincident factor 0.1.
- The carpentry machines will be used only occasionally, so the coincident factor is set to 0.05.

```
school11low = newLC(0);
school11low = school11low + 8*bulbsecurity100;                   % Bulbs
school11low = add_demand(52*0.04*0.1,7,17,school11low);          % Tube lights
school11low = add_demand(2*0.1,7,17,school11low);                % Cooker

school11high = school11low + 7*bulbsecurity100;                  % Bulbs
school11high = add_demand(48*0.04*0.1,7,17,school11high);        % Tube lights
school11high = add_demand(8*0.04*1,19,22,school11high);          % Tube lights
school11high = add_demand(2*0.1,7,17,school11high);              % Cooker
school11high = school11high + 2*fridge;                          % Fridges
school11high = add_demand(1.5*0.1,7,17,school11high);            % Copier
school11high = add_demand(2*1*0.05,7,17,school11high);           % Carpentry
                                                                 %  machines

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

school14low = newLC(0);
school14low = school14low + 5*bulbsecurity100;                   % Bulbs
school14low = add_demand(87*0.04*0.05,7.5,15.25,school14low);    % Tube lights

school14high = school14low + 5*bulbsecurity100;                  % Bulbs
school14high = add_demand(109*0.04*0.1,7.5,15.25,school14high);  % Tube lights
school14high = add_demand(8*0.04*1,19.25,21.25,school14high);    % Tube lights
school14high = add_demand(0.015*0.1,7,16,school14high);          % Radio
school14high = school14high + 2*officeFan;                       % Fans
school14high = school14high + fridge;                            % Fridge
school14high = add_demand(1.5*0.1,7.5,15,school14high);          % Copier

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

SecondarySchoolsLow = (school11low + school14low)/2;

SecondarySchoolsHigh = (school11high + school14high)/2;

if p==1
  LCplot2(SecondarySchoolsLow,SecondarySchoolsHigh);
  print -deps SecondarySchools.eps
```

```
end
```

Colleges/Institutions



We made interviews at all four colleges in Kasulu, so we consider this estimation rather reliable. There are huge differences between the colleges, so the average load curve above does not say much. The largest consumer is the Teachers College (interview 10), which today has two 170 kVA diesel gensets.

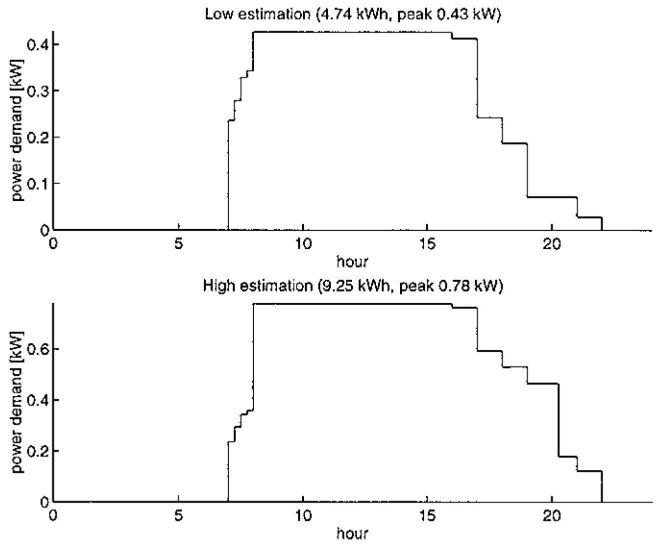
We have made these assumptions:

- Although the colleges will try to use their milling machines commercially, we have assumed that they will not attract as many customers as the Milling machine category, and therefore we have chosen a lower coincident factor (0.3 compared to 0.6 for Milling machines). For Teachers College we have in the low estimation set the coincident factor to 0.1, since they told us that they at least will use the milling machine for their own needs.
- The cookers at Teachers College are used for domestic sciences. Please refer to the assumptions for Secondary schools.
- Carpentry machines, concrete mixers and welding sets are assumed to be used only occasionally, but we believe that carpentry machines (including drills) will be used more frequently. We have set the coincident factors to 0.15 and 0.05 respectively.
- Sewing machines are running for longer periods, but since these will be used for education we have assumed a low coincident factor, 0.2 to be precise.

```
college10low = newLC(0);
college10low = add_demand(50*0.06*0.1,8,19,college10low);      % Bulbs
college10low = college10low + 720*bulb19to22;                  % Bulbs
college10low = add_demand(340*0.04*0.1,8,19,college10low);     % Tube lights
college10low = college10low + 60*tube19to22;                   % Tube lights
college10low = add_demand(10*0.25*1,0,6.5,college10low);       % Mercury light
college10low = add_demand(10*0.25*1,19.25,24,college10low);    % Mercury light
college10low = add_demand((0.56 + 4)*0.1,8,19,college10low);   % Carpentry
                                                               %  machines

college10high = add_demand(20*0.06*0.1,8,19,college10low);     % Bulbs
college10high = college10high + 240*bulb19to22;                % Bulbs
college10high = add_demand(110*0.04*0.1,8,19,college10high);   % Tube lights
college10high = college10high + 20*tube19to22;                 % Tube lights
college10high = add_demand(10*0.25*1,0,6.5,college10high);     % Mercury light
college10high = add_demand(10*0.25*1,19.25,24,college10high);  % Mercury light
college10high = add_demand(0.12*0.3,8,17,college10high);       % TV & video
college10high = add_demand(2*4*0.1,8,17,college10high);        % Cookers
```

```
% Milling & husking machines:
college10low = add_demand(2*22*0.1,8,19,college10low);
college10high = add_demand(2*22*0.3,8,19,college10high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

college12low = newLC(0);
college12low = add_demand(9*0.06*0.1,7.5,14.5,college12low);      % Bulbs
college12low = college12low + 23*bulb19to22;                      % Bulbs
college12low = add_demand(25*0.04*0.1,7.5,14.5,college12low);     % Tube lights
college12low = college12low + 25*tube19to22;                      % Tube lights
college12low = add_demand(18.5*0.3,7.5,20,college12low);          % Milling
                                                                  %  machine
college12low = add_demand(3*1*0.15,7.5,14.5,college12low);        % Carpentry
                                                                  %  machines

college12high = college12low + 20*bulbsecurity100;                % Bulbs
college12high = add_demand(25*0.04*0.1,7.5,14.5,college12high);   % Tube lights
college12high = college12high + 25*tube19to22;                    % Tube lights
college12high = add_demand(0.375*0.05,7.5,14.5,college12high);    % Concrete
                                                                  %  mixer
college12high = add_demand(2*1*0.15,7.5,14.5,college12high);      % Drills
college12high = add_demand(6*0.05,7.5,14.5,college12high);        % Welding
                                                                  %  set

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

college21low = newLC(0);

college21high = add_demand(6*0.06*0.2,8,15.5,college21low);       % Sewing
                                                                  %  machines
college21high = add_demand(0.2*0.05,8,15.5,college21high);        % Duplicating
                                                                  %  machine

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

college25low = newLC(0);
college25low = college25low + 40*bulb19to22;                      % Bulb
college25low = add_demand(0.12*0.08,20,24,college25low);          % TV & video
college25low = add_demand(0.2*0.05,7,15.5,college25low);          % Duplicating
                                                                  %  machine
college25low = add_demand(0.1*0.1,7,15.5,college25low);           % Typewriter

college25high = college25low + 8*tube19to22;                      % Tube lights
college25high = add_demand(4*0.25*1,0,7,college25high);           % Mercury light
college25high = add_demand(4*0.25*1,19,24,college25high);         % Mercury light
college25high = college25high + fridge;                           % Fridge
college25high = add_demand(1.5*0.1,7,15.5,college25high);         % Copier

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

CollegesLow = (college10low + college12low + college21low + college25low)/4;

CollegesHigh = (college10high + college12high + college21high + college25high)/4;

if p==1
  LCplot2(CollegesLow,CollegesHigh);
  print -deps Colleges.eps
end
```

Workshops



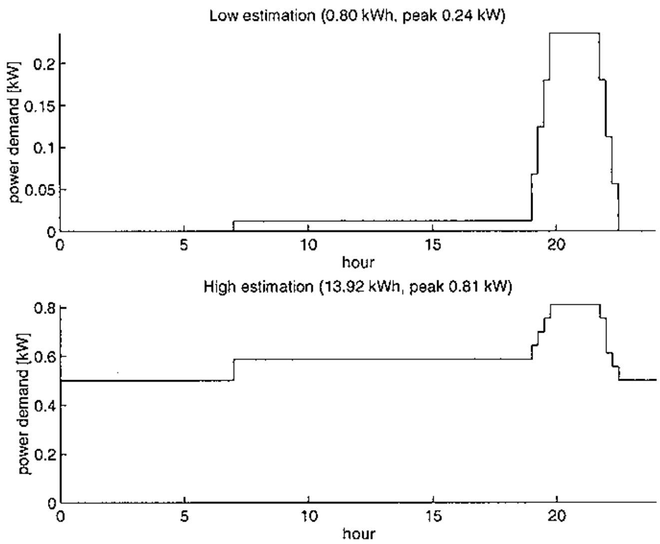
Workshops include all kinds of light industrial activities. We have made the following assumptions for workshops:

- Most of the equipment is used only occasionally, so we have chosen a standard coincident factor of 0.05. The coincident factor might be higher if we got the impression that some particular workshop will have a lot of customers.
- Battery chargers are used in longer periods and have therefore a standard coincident factor of 0.2.
- The milling machine in the high estimation for workshop 28 is assumed to not be the primary source of income for the workshop and the coincident factor is therefore set to 0.4 (compared to 0.6 for the Milling machine category).

```
workshop5low = newLC(0);
workshop5low = add_demand(1*0.05,7,19,workshop5low);           % Grinder
workshop5low = add_demand(2.2*0.05,7,19,workshop5low);         % Compressor
workshop5low = add_demand(6*0.05,7,19,workshop5low);           % Welding set

workshop5high = workshop5low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop23low = newLC(0);

% Wood plainer & drill
workshop23low = add_demand((0.5 + 0.5)*0.2,8,22,workshop23low);
workshop23high = add_demand((0.5 + 0.5)*0.3,8,22,workshop23low);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop28low = newLC(0);
workshop28low = add_demand(1*0.05,7.25,21,workshop28low);      % Grinder
workshop28low = add_demand(1*0.2,7.25,21,workshop28low);       % Battery
                                                               %  charger
workshop28low = add_demand(1*0.05,7.25,21,workshop28low);      % Drill

workshop28high = add_demand(20*0.1,7.25,21,workshop28low);     % Milling
                                                               %  machine
workshop28high = add_demand(20*0.1,7.5,20.75,workshop28low);   % Milling
                                                               %  machine
workshop28high = add_demand(20*0.1,7.75,20.5,workshop28low);   % Milling
                                                               %  machine
workshop28high = add_demand(20*0.1,8,20.25,workshop28low);     % Milling
                                                               %  machine
```

```
workshop28high = add_demand(2*0.05,7.25,21,workshop28high);        % Welding set

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop36low = newLC(0);
workshop36low = add_demand(1*0.2,7.5,19,workshop36low);             % Grinder
workshop36low = add_demand(1*0.05,7.5,19,workshop36low);            % Drill
workshop36low = add_demand(2*0.05,7.5,19,workshop36low);            % Welding set

workshop36high = add_demand(1*0.2,19,22,workshop36low);             % Grinder
workshop36high = add_demand(1*0.05,19,22,workshop36high);           % Drill
workshop36high = add_demand(2*0.05,19,22,workshop36high);           % Welding set

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop40low = newLC(0);
workshop40low = add_demand(1*0.05,7.75,16,workshop40low);           % Grinder
workshop40low = add_demand(1*0.05,7.75,16,workshop40low);           % Drill

workshop40high = workshop40low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop50low = newLC(0);
workshop50low = add_demand(6*0.1,7,17,workshop50low);               % Welding set
workshop50low = add_demand(1.5*0.05,7,17,workshop50low);            % Drill
workshop50low = add_demand(1*0.2,7,17,workshop50low);               % Battery
                                                                    %  charger
workshop50low = add_demand(1.8*0.1,7,17,workshop50low);             % Compressor
workshop50low = add_demand(2.8*0.05,7,17,workshop50low);            % Grinder

workshop50high = workshop50low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

workshop52low = newLC(0);
workshop52low = add_demand(1*0.05,8,18,workshop52low);              % Sawing
                                                                    %  machine
workshop52low = add_demand(1.8*0.05,8,18,workshop52low);            % Welding set
workshop52low = add_demand(1*0.2,8,18,workshop52low);               % Battery
                                                                    %  charger
workshop52low = add_demand(1*0.05,8,18,workshop52low);              % Grinder

workshop52high = add_demand(1*0.05,8,18,workshop52low);             % Carpentry
                                                                    %  machine

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

WorkshopsLow = (workshop5low + workshop23low + workshop28low + workshop36low + workshop40low +
workshop50low + workshop52low)/7;

WorkshopsHigh = (workshop5high + workshop23high + workshop28high + workshop36high +
workshop40high + workshop50high + workshop52high)/7;

if p==1
  LCplot2(WorkshopsLow,WorkshopsHigh);
  print -deps Workshops.eps
end
```

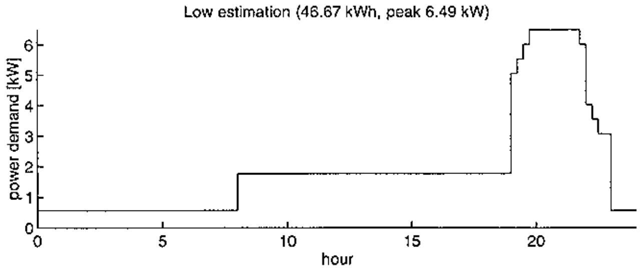
Petrol stations

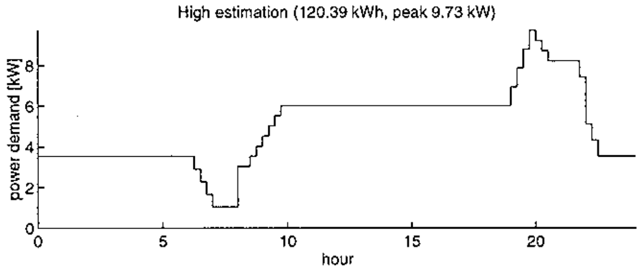


Unfortunately we only visited one petrol station, so this load curve estimation is of course very unsure. The coincident factor for the petrol pumps is based on the fact that this particular petrol station sells 1000 L to 3000 L petrol each day.

```
petrol1low = newLC(0);
petrol1low = petrol1low + 2*bulb19to22;                   % Bulbs
petrol1low = petrol1low + 4*tube19to22;                   % Tube lights
petrol1low = add_demand(2*0.3*0.02,7,22,petrol1low);      % Petrol pumps

petrol1high = petrol1low + AC;                            % Air
                                                          %  conditioning
petrol1high = add_demand(1.5*0.05,7,22,petrol1high);      % Copier

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

PetrolStationsLow = petrol1low;

PetrolStationsHigh = petrol1high;

if p==1
  LCplot2(PetrolStationsLow,PetrolStationsHigh);
  print -deps PetrolStations.eps
end
```

Hospital





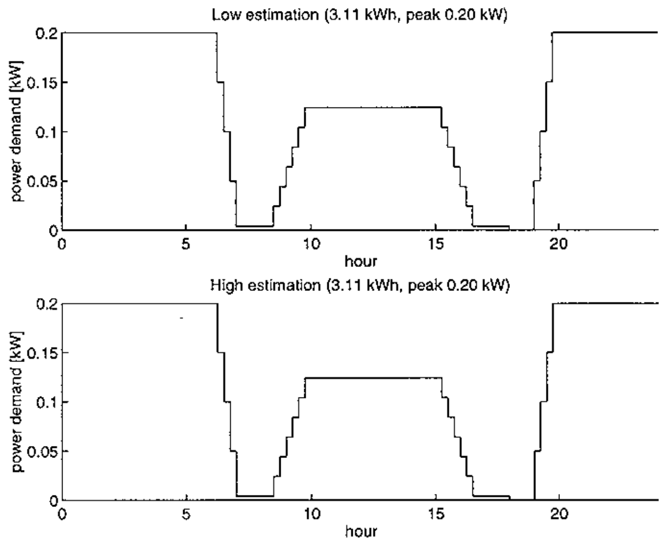
There is only one hospital in Kasulu. The following assumptions should be noted:

- The operation theatre is used about ten hours every day.
- The hospital was undergoing rehabilitation during our visit, so it was impossible to get the correct number of lights and fans that is going to be installed. The numbers used below is based on our guesses of the need for lights and fans for twelve buildings with about 100 to 130 patients.
- The assumptions of wattage and coincident factors for the X-ray machine, developing machine, autoclaves and sterilizing equipment is based on information from swedish suppliers of medical equipment. We have also compared with the wattage of the equipment in the hospital in Urambo (see [1], p. 39).

```
hospital45low = newLC(0);
hospital45low = add_demand(50*0.06*0.5,19,22,hospital45low);      % Bulbs
hospital45low = add_demand(3*0.1*0.4,0,24,hospital45low);         % Bulbs
                                                                  %  (operation
                                                                  %  theatre)
hospital45low = hospital45low + 60*tube19to22;                    % Tube lights
hospital45low = add_demand(10*0.04*0.4,0,24,hospital45low);       % Tube lights
                                                                  %  (operation
                                                                  %  theatre)
hospital45low = hospital45low + 7*fridge;                         % Fridges
hospital45low = add_demand(0.17*0.2,0,24,hospital45low);          % Suction
                                                                  %  machine

hospital45high = hospital45low + 40*tube19to22;                   % Tube lights
hospital45high = hospital45high + 50*residentialFan;              % Fans
hospital45high = hospital45high + AC;                             % Air
                                                                  %  conditioning

% Security lights:
hospital45low = add_demand(25*0.1*1,19,23,hospital45low);
hospital45high = hospital45high + 25*bulbsecurity100;

% X-ray machine:
hospital45low = add_demand(15*0.0001,0,24,hospital45low);
hospital45high = add_demand(15*0.0004,0,24,hospital45high);

% Developing machine;
hospital45low = add_demand(1.5*0.01,0,24,hospital45low);
hospital45low = add_demand(1.5*0.02,0,24,hospital45low);

% Autoclaver:
```

```
hospital45low = add_demand(2*40*0.01,8,19,hospital45low);
hospital45high = add_demand(2*40*0.015,8,19,hospital45high);

% Sterilizing equipment:
hospital45low = add_demand(8*1*0.05,8,19,hospital45low);
hospital45high = add_demand(8*1*0.1,8,19,hospital45high);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

HospitalsLow = hospital45low;

HospitalsHigh = hospital45high;

if p==1
  LCplot2(HospitalsLow,HospitalsHigh);
  print -deps Hospitals.eps
end
```

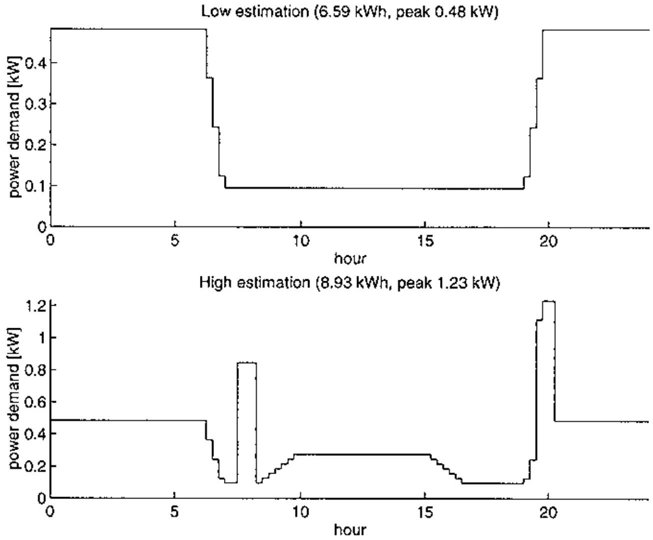
Post office



A new building for the post office is being constructed in Kasulu. The load curves above refers to this new building.

```
post47low = newLC(0);
post47low = add_demand(7*0.06*0.01,7,18,post47low);           % Bulbs
post47low = post47low + 2*bulbsecurity100;                     % Bulbs
post47low = post47low + 2*officeFan;                           % Fans

post47high = post47low;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

PostOfficesLow = post47low;

PostOfficesHigh = post47high;

if p==1
  LCplot2(PostOfficesLow,PostOfficesHigh);
  print -deps PostOffices.eps
end
```

Telecommunications

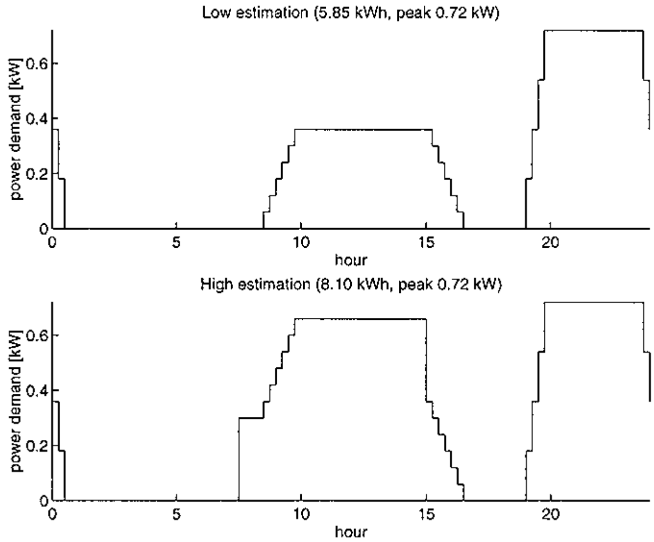


This is the TTCL (Tanzania Telecommunications Company Ltd.) Kasulu branch. They have an own generator, which is used to power the radio link and some security lights.

The wattage and coincident factor for the telefax machine is based on a guess.

```
telecom48low = newLC(0);
telecom48low = telecom48low + 8*bulbsecurity60;                      % Bulbs
telecom48low = add_demand(10*0.04*0.01,0,7,telecom48low);            % Tube lights
telecom48low = add_demand(10*0.04*0.2,7,19,telecom48low);            % Tube lights
telecom48low = add_demand(10*0.04*0.01,19,24,telecom48low);          % Tube lights
telecom48low = add_demand(0.3*0.05,7,19,telecom48low);               % Telefax

telecom48high = telecom48low + 3*officeFan;                          % Fans
telecom48high = add_demand(1*0.75,7.5,8.25,telecom48high);           % Cooker
telecom48high = add_demand(1*0.75,19.5,20.25,telecom48high);         % Cooker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

TelecomLow = telecom48low;

TelecomHigh = telecom48high;

if p==1
  LCplot2(TelecomLow,TelecomHigh);
  print -deps Telecom.eps
end
```

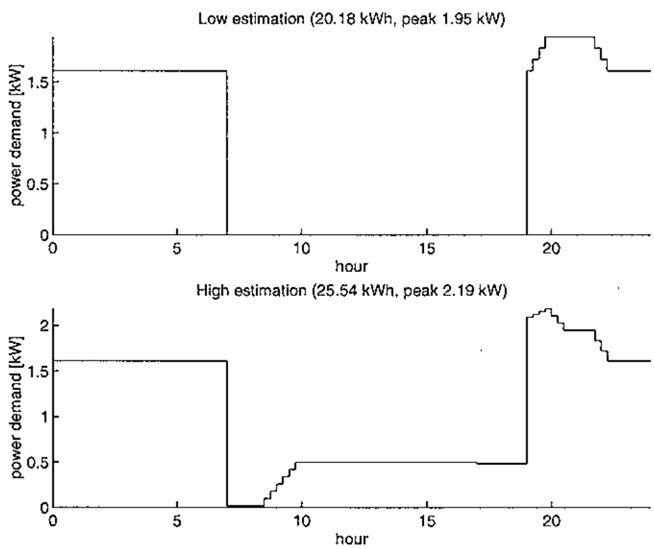
Bank



There is only one bank in Kasulu, so the estimations above ought to be good.

```
bank8low = newLC(0);
bank8low = bank8low + 15*bulb19to24;                              % Bulbs
bank8low = bank8low + 6*officeFan;                                % Fans

bank8high = add_demand(2*1.5*0.1,7.5,15,bank8low);                % Copiers

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

BanksLow = bank8low;

BanksHigh = bank8high;

if p==1
  LCplot2(BanksLow,BanksHigh);
  print -deps Banks.eps
end
```

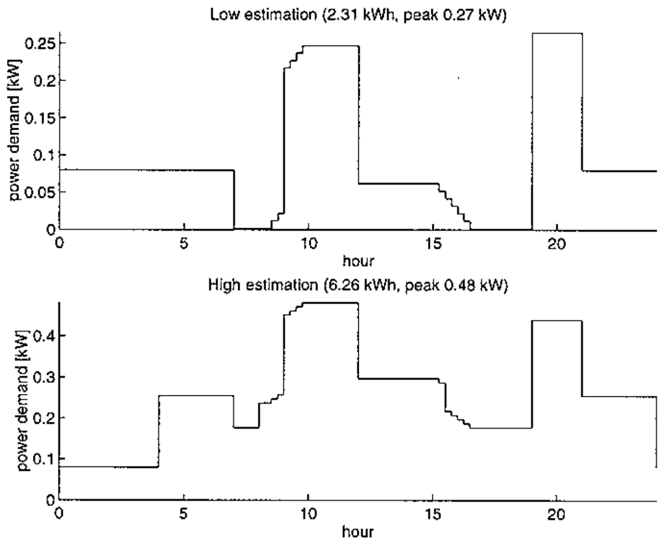
Prison



There is only one prison in Kasulu, so the estimations above ought to be good.

```
prison22low = newLC(0);
prison22low = prison22low + 14*tube19to22;                     % Tube lights
prison22low = add_demand(14*0.04*0.2,0,7,prison22low);         % Tube lights
prison22low = add_demand(14*0.04*0.2,22.5,24,prison22low);     % Tube lights
prison22low = add_demand(6*0.25*1,0,7,prison22low);            % Mercury light
prison22low = add_demand(6*0.25*1,19,24,prison22low);          % Mercury light

prison22high = prison22low + 8*residentialFan;                 % Fans
prison22high = add_demand(0.2*0.05,7,17,prison22high);         % Duplicate
                                                               %  machine
prison22high = add_demand(0.1*0.1,7,17,prison22high);          % Typewriter

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

PrisonsLow = prison22low;

PrisonsHigh = prison22high;

if p==1
  LCplot2(PrisonsLow,PrisonsHigh);
  print -deps Prisons.eps
end
```

Churches



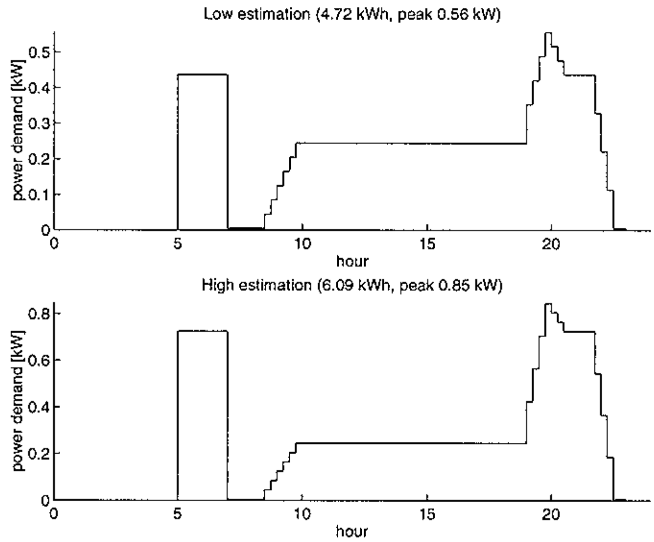
The economic situation seemed to be quite different between the churches in Kasulu. Unfortunately we only had time to visit one church, so we can only hope that it is representative. We have made the following assumptions:

- The rated power of the audio system is guessed by us. The coincident factor is based on that the audio system is used on sundays and occasionally in the evening.
- The rated power and coincident factor for the water pump is based on a wild guess, since we had no opportunity to have a closer look at it.

```
church49low = newLC(0);
church49low = add_demand(5*0.04*0.01,7,19,church49low);        % Tube lights
church49low = add_demand(2*0.04*1,0,7,church49low);            % Tube lights
church49low = add_demand(2*0.04*1,19,24,church49low);          % Tube lights
church49low = add_demand(0.1*0.05,9,12,church49low);           % Audio system
church49low = add_demand(0.1*0.05,19,21,church49low);          % Audio system
church49low = add_demand(3*0.075*0.8,9,12,church49low);        % Fans
church49low = add_demand(3*0.075*0.8,19,21,church49low);       % Fans
church49low = church49low + officeFan;                         % Fan

church49high = add_demand(3.5*0.05,4,24,church49low);          % Water pump
church49high = add_demand(0.25*0.2,8,15.5,church49high);       % Computer
```

```
church49high = add_demand(0.1*0.1,8,15.5,church49high);          % Typewriter

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

ChurchesLow = church49low;

ChurchesHigh = church49high;

if p==1
  LCplot2(ChurchesLow,ChurchesHigh);
  print -deps Churches.eps
end
```

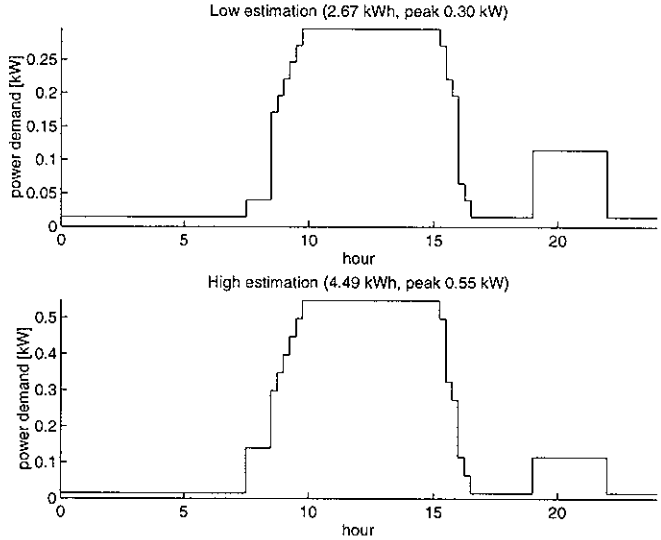
Mosques



All mosques we have seen have made a rather wealthy impression, so we think the mosque we visited is representative. The wattage of the loudspeaker is based on a guess.

```
mosque51low = newLC(0);
mosque51low = mosque51low + 9*bulb19to22;                        % Bulbs
mosque51low = add_demand(9*0.06*0.8,5,7,mosque51low);            % Bulbs
mosque51low = mosque51low + 4*residentialFan;                    % Fans
mosque51low = add_demand(0.05*0.1,5,23,mosque51low);             % Loudspeaker

mosque51high = mosque51low + 6*bulb19to22;                       % Bulbs
mosque51high = add_demand(6*0.06*0.8,5,7,mosque51high);          % Bulbs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

MosquesLow = mosque51low;

MosquesHigh = mosque51high;

if p==1
  LCplot2(MosquesLow,MosquesHigh);
  print -deps Mosques.eps
end
```

Missions, charity organisations and other NGOs

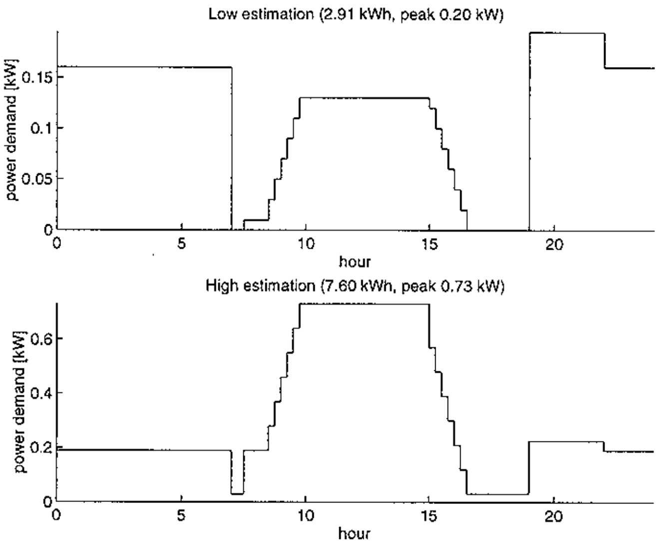


This category is to diversified to be described with only two samples, but we had no time to visit more of them.

The carpentry machines in interview 13 are assumed to be used only occasionally (cf. with workshops).

```
ngo13low = newLC(0);
ngo13low = add_demand(10*0.06*0.2,19,22,ngo13low);          % Bulbs
ngo13low = add_demand(10*0.04*0.2,19,22,ngo13low);          % Tube lights
ngo13low = ngo13low + 5*officeFan;                          % Fans
ngo13low = ngo13low + fridge;                               % Fridge
ngo13low = add_demand(1*0.05,7.5,15.5,ngo13low);            % Carpentry
                                                            %  machines

ngo13high = ngo13low + 5*officeFan;                         % Fans
ngo13high = add_demand(1.5*0.1,7.5,15.5,ngo13high);         % Copier
ngo13high = add_demand(0.25*0.2,7.5,15.5,ngo13high);        % Computer

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

ngo20low = newLC(0);
ngo20low = add_demand(8*0.036*0.01,8.5,16,ngo20low);        % Tube lights
ngo20low = add_demand(1.5*0.1,8.5,16,ngo20low);             % Copier
ngo20low = add_demand(0.1*0.1,8.5,16,ngo20low);             % Typewriter
ngo20low = add_demand(0.25*0.2,8.5,16,ngo20low);            % Computer

ngo20high = add_demand(8*0.036*0.01,8.5,16,ngo20low);       % Tube lights

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

NGOLow = (ngo13low + ngo20low)/2;

NGOHigh = (ngo13high + ngo20high)/2;

if p==1
  LCplot2(NGOLow,NGOHigh);
  print -deps NGO.eps
end
```

Offices



The only office we visited had seven employees. We do not know if this is representative.

The loud speaker is used for public meetings outdoors, and we assume that it will be used sparsely.

```
office29low = newLC(0);
office29low = add_demand(9*0.06*0.05,19,22,office29low);      % Bulbs
office29low = add_demand(4*0.04*0.05,19,22,office29low);      % Tube lights
office29low = add_demand(4*0.04*1,0,7,office29low);           % Tube lights
office29low = add_demand(4*0.04*1,19,24,office29low);         % Tube lights
office29low = office29low + 2*officeFan;                      % Fans
office29low = add_demand(0.2*0.05,7.5,15,office29low);        % Duplicate
                                                              %  machine

office29high = office29low + 7*officeFan;                     % Fans
office29high = office29high + fridge;                         % Fridge
office29high = add_demand(1.5*0.1,7.5,15,office29high);       % Copier
office29high = add_demand(0.1*0.01,11,22,office29high);       % Loudspeaker

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

OfficesLow = office29low;

OfficesHigh = office29high;

if p==1
  LCplot2(OfficesLow,OfficesHigh);
  print -deps Offices.eps
end
```

Appendix D

MATLAB SCRIPTS FOR SCENARIOS

In this appendix the Matlab scripts that we have used for our scenario calculations are presented. The Matlab functions for handling load curves and load duration curves are described in appendix E.

KasuluConsumers.m

This script just defines the number of consumers in each category, i.e. the information in table 3.2.

```
% Set number of consumers for low and high estimation:
noLargeResidentsLow = 100;                noLargeResidentsHigh = 100;
noMediumResidentsLow = 200;               noMediumResidentsHigh = 300;
noSmallResidentsLow = 300;                noSmallResidentsHigh = 500;
noBarsLow = 10;                           noBarsHigh = 15;
noRestaurantsLow = 4;                     noRestaurantsHigh = 4;
noGuesthousesLow = 7;                     noGuesthousesHigh = 12;
noShopsLow = 30;                          noShopsHigh = 30;
noMillingMachinesLow = 7;                 noMillingMachinesHigh = 15;
noPrimarySchoolsLow = 2;                  noPrimarySchoolsHigh = 2;
noSecondarySchoolsLow = 2;                noSecondarySchoolsHigh = 2;
noCollegesLow = 4;                        noCollegesHigh = 4;
noWorkshopsLow = 25;                      noWorkshopsHigh = 25;
noPetrolStationsLow = 2;                  noPetrolStationsHigh = 3;
noHospitalsLow = 1;                       noHospitalsHigh = 1;
noPostOfficesLow = 1;                     noPostOfficesHigh = 1;
noTelecomLow = 1;                         noTelecomHigh = 1;
noBanksLow = 1;                           noBanksHigh = 1;
noPrisonsLow = 1;                         noPrisonsHigh = 1;
noChurchesLow = 4;                        noChurchesHigh = 6;
noMosquesLow = 3;                         noMosquesHigh = 3;
noNGOLow = 4;                             noNGOHigh = 8;
noOfficesLow = 10;                        noOfficesHigh = 14;
```

KasuluLoadCurves.m

Here the two estimated load curves are calculated:

```
% Define standard load curves:
LargeResidents
MediumResidents
SmallResidents
Bars
Restaurants
Guesthouses
Shops
MillingMachines
PrimarySchools
SecondarySchools
Colleges
Workshops
PetrolStations
Hospitals
PostOffices
Telecom
Banks
```

```
Prisons
Churches
Mosques
NGO
Offices

LowLoad = noLargeResidentsLow*LargeResidentsLow + noMediumResidentsLow*MediumResidentsLow +
noSmallResidentsLow*SmallResidentsLow + noBarsLow*BarsLow + noRestaurantsLow*RestaurantsLow +
noGuesthousesLow*GuesthousesLow + noShopsLow*ShopsLow + noMillingMachinesLow*MillingMachinesLow
+ noPrimarySchoolsLow*PrimarySchoolsLow + noSecondarySchoolsLow*SecondarySchoolsLow + noCol-
legesLow*CollegesLow + noWorkshopsLow*WorkshopsLow + noPetrolStationsLow*PetrolStationsLow +
noHospitalsLow*HospitalsLow + noPostOfficesLow*PostOfficesLow + noTelecomLow*TelecomLow +
noBanksLow*BanksLow + noPrisonsLow*PrisonsLow + noChurchesLow*ChurchesLow + noMosques-
Low*MosquesLow + noNGOLow*NGOLow + noOfficesLow*OfficesLow;

HighLoad = noLargeResidentsHigh*LargeResidentsHigh + noMediumResidentsHigh*MediumResidentsHigh
+ noSmallResidentsHigh*SmallResidentsHigh + noBarsHigh*BarsHigh + noRestaurantsHigh*Restaurant-
sHigh + noGuesthousesHigh*GuesthousesHigh + noShopsHigh*ShopsHigh + noMillingMachinesHigh*Mill-
ingMachinesHigh + noPrimarySchoolsHigh*PrimarySchoolsHigh +
noSecondarySchoolsHigh*SecondarySchoolsHigh + noCollegesHigh*CollegesHigh + noWorkshop-
sHigh*WorkshopsHigh + noPetrolStationsHigh*PetrolStationsHigh + noHospitalsHigh*HospitalsHigh +
noPostOfficesHigh*PostOfficesHigh + noTelecomHigh*TelecomHigh + noBanksHigh*BanksHigh + noPris-
onsHigh*PrisonsHigh + noChurchesHigh*ChurchesHigh + noMosquesHigh*MosquesHigh + noNGOHigh*NGO-
High + noOfficesHigh*OfficesHigh;
```

KasuluPowerMarket.m

This is the start-up script to obtain load curves for a system with incandescent bulbs.

```
% Set number of consumers for low and high estimation:
KasuluConsumers

% Define standard loads:
standardloads

% Select if load curves should be stored in files (p=0 no, p=1 yes):
p = 0;

% Define standard load curves:
KasuluLoadCurves

LCplot2(LowLoad,HighLoad)
if p==1
  print -deps KasuluPowerMarket.eps
end
```

CFLloads.m

This script is equivalent to the previous one, but gives the load curves when most bulbs have been replaced by CFLs.

```
% Set number of consumers for low and high estimation:
KasuluConsumers

% Select if load curves should be stored in a file (store=0 no, store=1 yes):
store = 0;

% Define standard loads:
standardloads

% Redefine bulbs:
bulb19to22 = bulb19to22 / 4;
bulb19to23 = bulb19to23 / 4;
bulb19to24 = bulb19to24 / 4;
bulb19to1 = bulb19to1 / 4;
bulbsecurity60 = bulbsecurity60 / 4;
```

```
bulbsecurity100 = bulbsecurity100 / 4;

% Define standard load curves:
p = 0;
KasuluLoadCurves

LCplot2(LowLoad,HighLoad)
if store==1
  print -deps CFLloads.eps
end
```

scenario_parameters.m

Some important parameters used in all scenarios has been collected in this file, so that it is simpler to change them.

```
T = 24;                                 % Review period of load curves
                                        %  [hours]
interest = 4;                           % Real interest
segment = 1;                            % Length of segments in
                                        %  load duration curve
pf = 0.95;                              % Power factor
DistrCostLow = 540610;                  % Cost for the distribution
DistrCostHigh = 717840;                 %  system
```

wind_parameters.m

The wind data used in scenario 4 is defined in a separate file, so that they can be modified more easily.

```
global avail vco alpha

% All wind speeds in m/s

% Assumed average wind speed:
vm = 4;

% Data for Vestas V44-600
vci = 4.5;                              % Wind speed for cut in
vr = 19;                                % Wind speed for rated power
vco = 20;                               % Wind speed for cut off
Pr = 600;                               % Rated power [kW]
avail = 0.97;                           % Availability of power plant

% Calculate parameter for Rayleigh distribution:
alpha = 2*vm/sqrt(pi);

% Calculate probabilities for generation losses (for usage with ELDC).
Psegment_wind = 10;                     % Segment length (in kW) for
                                        % the generation losses
max = floor(Pr/Psegment_wind);
x = 0:Psegment_wind:Pr;
Fv = powdistrfunc(x);
pwind = zeros(1,max);
Pwind = Pr - x(1:max);
for i = 2:max
  pwind(i) = Fv(i)-Fv(i+1);
end
% Round the probability vector:
pwind = round(pwind*1000)/1000;
pwind(1) = 1 - sum(pwind);
```

powdistrfunc.m

This function calculates values of the power duration curve for the wind power plant and is used in the `wind_parameters` script. It uses a slightly modified version of equation 3.20 in [19].

```
function out = powdistrfunc(in)
global avail vco alpha
out = avail*(exp(-(invpowfuncV44_600(in)/alpha).^2) - exp(-(vco/alpha)^2)*ones(size(in)));
```

invposfuncV44_600.m

This function calculates the wind speed necessary to produce a certain power in a Vestas V44-600 power plant. It is used in `powdistrfucn`. The wind speed is calculated using linear interpolation between the known points (from table I.1) on the wind speed - power curve.

```
% Inverted power function for Vestas wind power plant V44-600
% Calculates necessary wind speed [m/s] to achieve the power P [kW] at air
% density 1.06 kg/m3

function v = invpowfuncV44_600(P)
if P > 600
  error('V44-600 cannot produce more than 600 kW')
end
if P < 0
  error('It is impossible to produce negative power')
end
powfunc = [-24.7 24.7 65.2 115 176 246 320 393 461 517 557 581 593 598 599 600];
i = 1;
while powfunc(i) < P
 i = i + 1;
end
P = P - powfunc(i-1);
Pdiff = powfunc(i) - powfunc(i-1);
v = i + 2 + P/Pdiff;
```

Scenario1a.m

This scenario is called alternative I) in table 3.16.

```
% Scenario 1a:
% Diesel gensets and low load

figure(1)
KasuluPowerMarket
scenario_parameters

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 113 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 113*pf], 113*pf);

% Diesel genset, 113 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 113*pf], 113*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
```

```
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(1) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(1));
c(2) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(2));
c(3) = energy_cost(26900*1.23,interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(26900*1.23,interest, 7, 0, 0.37, 365*Wprod(4));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.37 0.37 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow, 0, 365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                           % Total daily demand
c                                                 % Cost per kWh for each unit
ctot                                              % Total daily production cost
caverage = ctot/Wprodtot + d + t                  % Average cost per kWh
```

Scenario1aII.m

This scenario is called alternative II) in table 3.16.

```
% Scenario 1a (alternative II):
% Diesel gensets and low load

figure(1)
KasuluPowerMarket
scenario_parameters

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(3) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(3));
c(2) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(2));
c(1) = energy_cost(35500*1.23, interest, 7, 0, 0.32, 365*Wprod(1));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.32 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot
```

```
% Cost for distribution (investment and operation % maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                     % Total daily demand
c                                           % Cost per kWh for each unit
ctot                                        % Total daily production cost
caverage = ctot/Wprodtot + d + t            % Average cost per kWh
```

Scenario1b.m

This scenario is called alternative I) in table 3.16.

```
% Scenario 1b:
% Diesel gensets and low load, CFLs used for lighting

figure(1)
CFLloads
scenario_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 113 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 113*pf], 113*pf);

% Diesel genset, 113 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 113*pf], 113*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(1) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(1));
c(2) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(2));
c(3) = energy_cost(26900*1.23,interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(26900*1.23,interest, 7, 0, 0.37, 365*Wprod(4));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.37 0.37 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);
```

```
% Display results:
Wdemand                                          % Total daily demand
c                                                % Cost per kWh for each unit
ctot                                             % Total daily production cost
caverage = ctot/Wprodtot + d + t                 % Average cost per kWh
```

Scenario1bII.m

This scenario is called alternative II) in table 3.16.

```
% Scenario 1b: (alternative II)
% Diesel gensets and low load, CFLs used for lighting

figure(1)
CFLloads
scenario_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(3) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(3));
c(2) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(2));
c(1) = energy_cost(35500*1.23,interest, 7, 0, 0.32, 365*Wprod(1));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.32 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot

% Cost for distribution (investment and operation % maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                          % Total daily demand
c                                                % Cost per kWh for each unit
ctot                                             % Total daily production cost
caverage = ctot/Wprodtot + d + t                 % Average cost per kWh
```

Scenario1c.m

```
% Scenario 1c:
% Diesel gensets and high load
```

```
figure(1)
KasuluPowerMarket
scenario_parameters

figure(2)
ldc = LC2LDC(HighLoad,segment);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(1) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(1));
c(2) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(35500*1.23,interest, 7, 0, 0.32, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
c(5) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(5));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.32 0.32 0.32 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(24000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                   % Total daily demand
c                                         % Cost per kWh for each unit
ctot                                      % Total daily production cost
caverage = ctot/Wprodtot + d + t          % Average cost per kWh
```

Scenario1d.m

```
% Scenario 1d:
% Diesel gensets and high load, CFLs used for lighting

figure(1)
CFLloads
scenario_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(HighLoad,segment);
```

```
% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
c(1) = energy_cost(63950*1.23, interest, 7, 0, 0.32, 365*Wprod(1));
c(2) = energy_cost(63950*1.23, interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(35500*1.23, interest, 7, 0, 0.32, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
c(5) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(5));
ctot = c*Wprod';

% Operation and maintenance cost for the diesel:
opmaverage = [0.32 0.32 0.32 0.37 0.37]*Wprod'/Wprodtot

% Average diesel cost:
diesaver = ctot/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(24000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                      % Total daily demand
c                                            % Cost per kWh for each unit
ctot                                         % Total daily production cost
caverage = ctot/Wprodtot + d + t             % Average cost per kWh
```

Scenario2a.m

```
% Scenario 2a:
% Hydro power + diesel gensets. Low load

figure(1)
KasuluPowerMarket
scenario_parameters

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Hydro power (Base), 330 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 330], 330);

% Hydro power (Dispatchable), 150 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 150], 150);
```

```
% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wdemand = energy_demand(ldc, T);
Whydro = Wprod(1) + Wprod(2);
Wdiesel = Wprod(3) + Wprod(4);
Wprodtot = sum(Wprod);
c = zeros(1,3);
hydro_price = (330+150)*7000 + 224000 + 12000;          % Plant + transm. line + trsfr
c(1) = energy_cost(hydro_price, interest, 30, 0, 0.01, 365*Whydro);
c(3) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(4));

ctot = c(1)*Whydro + c(3)*Wprod(3) + c(4)*Wprod(4);

% Cost for hydro power (investment and operation & maintenance):
hinv = energy_cost(hydro_price, interest, 30, 0, 0, 365*Whydro)*Whydro/Wprodtot
hopm = 0.01*Whydro/Wprodtot

% Operation & maintenance cost for diesel gensets:
dgopm = 0.37*Wdiesel/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                  % Total daily demand
c                                        % Cost per kWh for each unit
ctot                                     % Total daily production cost
caverage = ctot/Wprodtot + d + t         % Average cost per kWh
W_H_dry = Whydro*140                     % Hydro power generation
                                         % from reservoir
                                         % during dry season [kWh]
reservoir_needed = W_H_dry - 330*24*140  % Minimum size for reservoir
```

Scenario2b.m

```
% Scenario 2b:
% Hydro power + diesel gensets. Low load with CFLs

figure(1)
CFLloads
scenario_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Hydro power (Base), 330 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 330], 330);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);
```

```
% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
Whydro = Wprod(1);
Wdiesel = Wprod(2) + Wprod(3);
c = zeros(1,3);
hydro_price = 330*6000 + 224000 + 12000;                          % Plant + transm. line + trsfr
c(1) = energy_cost(hydro_price, interest, 30, 0, 0.01, 365*Whydro);
c(2) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(2));
c(3) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(3));

ctot = c*Wprod';

% Cost for hydro power (investment and operation & maintenance):
hinv = energy_cost(hydro_price, interest, 30, 0, 0, 365*Whydro)*Whydro/Wprodtot
hopm = 0.01*Whydro/Wprodtot

% Operation & maintenance cost for diesel gensets:
dgopm = 0.37*Wdiesel/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                                           % Total daily demand
c                                                                 % Cost per kWh for each unit
ctot                                                              % Total daily production cost
caverage = ctot/Wprodtot + d + t                                  % Average cost per kWh
W_H_dry = Whydro*140                                              % Hydro power generation
                                                                  % from reservoir
                                                                  % during dry season [kWh]
reservoir_needed = W_H_dry - 330*24*140                           % Minimum size for reservoir
```

Scenario2c.m

```
% Scenario 2c:
% Hydro power + diesel gensets. High load

figure(1)
KasuluPowerMarket
scenario_parameters

figure(2)
ldc = LC2LDC(HighLoad,segment);

% Hydro power (Base), 330 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 330], 330);

% Hydro power (Dispatchable), 600 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 600], 600);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
```

```
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
Whydro = Wprod(1) + Wprod(2);
Wdiesel = Wprod(3) + Wprod(4);
c = zeros(1,3);
hydro_price = (330+600)*7000 + 224000 + 24000;          % Plant + transm. line + trsfr
c(1) = energy_cost(hydro_price, interest, 30, 0, 0.01, 365*Whydro);
c(3) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(4));

ctot = c(1)*Whydro + c(3)*Wprod(3) + c(4)*Wprod(4);

% Cost for hydro power (investment and operation & maintenance):
hinv = energy_cost(hydro_price, interest, 30, 0, 0, 365*Whydro)*Whydro/Wprodtot
hopm = 0.01*Whydro/Wprodtot

% Operation & maintenance cost for diesel gensets:
dgopm = 0.37*Wdiesel/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                   % Total daily demand
c                                         % Cost per kWh for each unit
ctot                                      % Total daily production cost
caverage = ctot/Wprodtot + d + t          % Average cost per kWh
W_H_dry = Whydro*140                      % Hydro power generation
                                          % from reservoir
                                          % during dry season [kWh]
reservoir_needed = W_H_dry - 330*24*140   % Minimum size for reservoir
```

Scenario2d.m

```
% Scenario 2d:
% Hydro power + diesel gensets. High load with CFLs

figure(1)
CFLloads
scenario_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(HighLoad,segment);

% Hydro power (Base), 330 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 330], 330);

% Hydro power (Dispatchable), 400 kW, 99% availability
ldc = ELDC(ldc, [0.99 0.01], [0 400], 400);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
```

```
Wdemand = energy_demand(ldc, T);
Whydro = Wprod(1) + Wprod(2);
Wdiesel = Wprod(3) + Wprod(4);
c = zeros(1,3);
hydro_price = (330+400)*7000 + 224000 + 15000;                % Plant + transm. line + trsfr
c(1) = energy_cost(hydro_price, interest, 30, 0, 0.01, 365*Whydro);
c(3) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(0, interest, 7, 0, 0.37, 365*Wprod(4));

ctot = c(1)*Whydro + c(3)*Wprod(3) + c(4)*Wprod(4);

% Cost for hydro power (investment and operation & maintenance):
hinv = energy_cost(hydro_price, interest, 30, 0, 0, 365*Whydro)*Whydro/Wprodtot
hopm = 0.01*Whydro/Wprodtot

% Operation & maintenance cost for diesel gensets:
dgopm = 0.37*Wdiesel/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh,0,365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                                      % Total daily demand
c                                                            % Cost per kWh for each unit
ctot                                                         % Total daily production cost
caverage = ctot/Wprodtot + d + t                             % Average cost per kWh
W_H_dry = Whydro*140                                         % Hydro power generation
                                                             % from reservoir
                                                             % during dry season [kWh]
reservoir_needed = W_H_dry - 330*24*140                      % Minimum size for reservoir
```

Scenario3.m

```
% Scenario 3:
% Household PV systems

interest = 4;

battery_price = 171;
panel_price = 1011;
other_price = 255;
Wannual = 193;

battery = zeros(1,1);
panel = zeros(1,1);
other = zeros(1,1);
battery(1) = energy_cost(battery_price,interest, 5, 0, 0, Wannual);
battery(2) = energy_cost(battery_price*0.8,interest, 5, 0, 0, Wannual);
battery(3) = energy_cost(battery_price*0.6,interest, 5, 0, 0, Wannual);
battery(4) = energy_cost(2*battery_price,interest, 5, 0, 0, Wannual);
battery(5) = energy_cost(2*battery_price*0.8,interest, 5, 0, 0, Wannual);
battery(6) = energy_cost(2*battery_price*0.6,interest, 5, 0, 0, Wannual);
panel(1) = energy_cost(panel_price,interest, 30, 0, 0, Wannual);
panel(2) = energy_cost(panel_price*0.8,interest, 30, 0, 0, Wannual);
panel(3) = energy_cost(panel_price*0.6,interest, 30, 0, 0, Wannual);
panel(4) = energy_cost(panel_price,interest, 30, 0, 0, Wannual);
panel(5) = energy_cost(panel_price*0.8,interest, 30, 0, 0, Wannual);
panel(6) = energy_cost(panel_price*0.6,interest, 30, 0, 0, Wannual);
other(1) = energy_cost(other_price,interest, 30, 0, 0, Wannual);
other(2) = energy_cost(other_price*0.8,interest, 30, 0, 0, Wannual);
other(3) = energy_cost(other_price*0.6,interest, 30, 0, 0, Wannual);
other(4) = energy_cost(other_price,interest, 30, 0, 0, Wannual);
```

```
other(5) = energy_cost(other_price*0.8,interest, 30, 0, 0, Wannual);
other(6) = energy_cost(other_price*0.6,interest, 30, 0, 0, Wannual);

% Display results:
battery
panel
other
c = battery + panel + other
```

Scenario4a.m

```
% Scenario4a:
% Wind power + diesel gensets. Low load

figure(1)
KasuluPowerMarket
scenario_parameters
wind_parameters

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Wind power 600 kW, 97% availability
ldc = ELDC(ldc, pwind, Pwind, Pr);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
wind_price = 662000+64000;
c(1) = energy_cost(wind_price,interest, 20, 0, 0.002, 365*Wprod(1));
c(2) = energy_cost(35500*1.23, interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
ctot = c*Wprod';

% Cost for wind power (investmend and operation & maintenance):
winv = energy_cost(wind_price,interest, 20, 0, 0, 365*Wprod(1))*Wprod(1)/Wprodtot
wopm = 0.002*Wprod(1)/Wprodtot

% Cost for diesel gensets (investment and operation & maintenance):
dginv = energy_cost(35500*1.23, interest, 7, 0, 0, 365*Wprod(2))*sum(Wprod(2:4))/Wprodtot
dgopm = [0.32 0.37 0.37]*Wprod(2:4)'/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow, 0, 365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                                 % Total daily demand
c                                                       % Cost per kWh for each unit
```

```
ctot                                                    % Total daily production cost
caverage = ctot/Wprodtot + d + t                        % Average cost per kWh
```

Scenario4b.m

```
% Scenario4b:
% Wind power + diesel gensets. Low load with CFLs

figure(1)
CFLloads
scenario_parameters
wind_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(LowLoad,segment);

% Wind power 600 kW, 97% availability
ldc = ELDC(ldc, pwind, Pwind, Pr);

% Diesel genset, 250 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 250*pf], 250*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
wind_price = 662000+64000;
c(1) = energy_cost(wind_price,interest, 20, 0, 0.002, 365*Wprod(1));
c(2) = energy_cost(35500*1.23, interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
ctot = c*Wprod';

% Cost for wind power (investmend and operation & maintenance):
winv = energy_cost(wind_price,interest, 20, 0, 0, 365*Wprod(1))*Wprod(1)/Wprodtot
wopm = 0.002*Wprod(1)/Wprodtot

% Cost for diesel gensets (investment and operation & maintenance):
dginv = energy_cost(35500*1.23, interest, 7, 0, 0, 365*Wprod(2))*sum(Wprod(2:4))/Wprodtot
dgopm = [0.32 0.37 0.37]*Wprod(2:4)'/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostLow,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostLow, 0, 365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                                 % Total daily demand
c                                                       % Cost per kWh for each unit
ctot                                                    % Total daily production cost
caverage = ctot/Wprodtot + d + t                        % Average cost per kWh
```

Scenario4c.m

```
% Scenario4c:
% Wind power + diesel gensets. High load

figure(1)
KasuluPowerMarket
scenario_parameters
wind_parameters

figure(2)
ldc = LC2LDC(HighLoad,segment);

% Wind power 600 kW, 97% availability
ldc = ELDC(ldc, pwind, Pwind, Pr);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
wind_price = 662000 + 64000;
c(1) = energy_cost(wind_price,interest, 20, 0, 0.002, 365*Wprod(1));
c(2) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
c(5) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(5));
ctot = c*Wprod';

% Cost for wind power (investmend and operation & maintenance):
winv = energy_cost(wind_price,interest, 20, 0, 0, 365*Wprod(1))*Wprod(1)/Wprodtot
wopm = 0.002*Wprod(1)/Wprodtot

% Cost for diesel gensets (investment and operation & maintenance):
diesel_price = (63950 + 63950)*1.23;
dginv = energy_cost(diesel_price, interest, 7, 0, 0, 365*sum(Wprod(2:3)))*sum(Wprod(2:5))/Wprod-
tot
dgopm = [0.32 0.32 0.37 0.37]*Wprod(2:5)'/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh, 0, 365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                      % Total daily demand
c                                            % Cost per kWh for each unit
ctot                                         % Total daily production cost
caverage = ctot/Wprodtot + d + t             % Average cost per kWh
```

Scenario4d.m

```
% Scenario4d:
% Wind power + diesel gensets. High load with CFLs

figure(1)
CFLloads
scenario_parameters
wind_parameters
pf = 0.7;

figure(2)
ldc = LC2LDC(HighLoad,segment);

% Wind power 600 kW, 97% availability
ldc = ELDC(ldc, pwind, Pwind, Pr);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 450 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 450*pf], 450*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Diesel genset, 170 kVA, 80% availability
ldc = ELDC(ldc, [0.8 0.2], [0 170*pf], 170*pf);

% Calculations:
LDCplot(ldc, T)
Wprod = energy_production(ldc, T);
Wprodtot = sum(Wprod);
Wdemand = energy_demand(ldc, T);
c = zeros(1,3);
wind_price = 662000 + 64000;
c(1) = energy_cost(wind_price,interest, 20, 0, 0.002, 365*Wprod(1));
c(2) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(2));
c(3) = energy_cost(63950*1.23,interest, 7, 0, 0.32, 365*Wprod(3));
c(4) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(4));
c(5) = energy_cost(0,interest, 7, 0, 0.37, 365*Wprod(5));
ctot = c*Wprod';

% Cost for wind power (investmend and operation & maintenance):
winv = energy_cost(wind_price,interest, 20, 0, 0, 365*Wprod(1))*Wprod(1)/Wprodtot
wopm = 0.002*Wprod(1)/Wprodtot

% Cost for diesel gensets (investment and operation & maintenance):
diesel_price = (63950 + 63950)*1.23;
dginv = energy_cost(diesel_price, interest, 7, 0, 0, 365*sum(Wprod(2:3)))*sum(Wprod(2:5))/Wprod-
tot
dgopm = [0.32 0.32 0.37 0.37]*Wprod(2:5)'/Wprodtot

% Cost for distribution (investment and operation & maintenance):
dinv = energy_cost(DistrCostHigh,interest, 25, 0, 0, 365*Wprodtot)
dopm = energy_cost(0,interest,25, 0.05*DistrCostHigh, 0, 365*Wprodtot)
d = dinv + dopm;

% Cost for transformers at power house:
t = energy_cost(12000,interest,25,0,0,365*Wprodtot);

% Display results:
Wdemand                                           % Total daily demand
c                                                 % Cost per kWh for each unit
ctot                                              % Total daily production cost
caverage = ctot/Wprodtot + d + t                  % Average cost per kWh
```

Scenario5.m

```
% Scenario 5:
% Grid extension

scenario_parameters

KasuluPowerMarket
WLow = 365*energy_consumption(LowLoad);
WHigh = 365*energy_consumption(HighLoad);

CFLloads
WLowCFL = 365*energy_consumption(LowLoad);
WHighCFL = 365*energy_consumption(HighLoad);


% Costs for the distribution system (investment and operation & maintenance):
dLowinv = energy_cost(DistrCostLow, interest, 25, 0, 0, WLow)
dHighinv = energy_cost(DistrCostHigh, interest, 25, 0, 0, WHigh)
dLowCFLinv = energy_cost(DistrCostLow, interest, 25, 0, 0, WLowCFL)
dHighCFLinv = energy_cost(DistrCostHigh, interest, 25, 0, 0, WHighCFL)
dLowopm = energy_cost(0, interest, 25, 0.05*DistrCostLow, 0, WLow)
dHighopm = energy_cost(0, interest, 25, 0.05*DistrCostHigh, 0, WHigh)
dLowCFLopm = energy_cost(0, interest, 25, 0.05*DistrCostLow, 0, WLowCFL)
dHighCFLopm = energy_cost(0, interest, 25, 0.05*DistrCostHigh, 0, WHighCFL)
dLow = dLowinv + dLowopm;
dHigh = dHighinv + dHighopm;
dLowCFL = dLowCFLinv + dLowCFLopm;
dHighCFL = dHighCFLinv + dHighCFLopm;

% Costs for transmission line:
KasuluShare = 4.6e6;
tLowinv = energy_cost(KasuluShare, interest, 25, 0, 0, WLow)
tHighinv = energy_cost(KasuluShare, interest, 25, 0, 0, WHigh)
tLowCFLinv = energy_cost(KasuluShare, interest, 25, 0, 0, WLowCFL)
tHighCFLinv = energy_cost(KasuluShare, interest, 25, 0, 0, WHighCFL)
tLowopm = energy_cost(0, interest, 25, 0.05*KasuluShare, 0, WLow)
tHighopm = energy_cost(0, interest, 25, 0.05*KasuluShare, 0, WHigh)
tLowCFLopm = energy_cost(0, interest, 25, 0.05*KasuluShare, 0, WLowCFL)
tHighCFLopm = energy_cost(0, interest, 25, 0.05*KasuluShare, 0, WHighCFL)
tLow = tLowinv + tLowopm;
tHigh = tHighinv + tHighopm;
tLowCFL = tLowCFLinv + tLowCFLopm;
tHighCFL = tHighCFLinv + tHighCFLopm;

% Display results:
cLow = [dLow+tLow+0.1 dLow+tLow+0.2]
cLowCFL = [dLowCFL+tLowCFL+0.1 dLowCFL+tLowCFL+0.2]
cHigh = [dHigh+tHigh+0.1 dHigh+tHigh+0.2]
cHighCFL = [dHighCFL+tHighCFL+0.1 dHighCFL+tHighCFL+0.2]
```

Appendix E

MATLAB FUNCTIONS FOR LOAD CURVE ANALYSIS

For analyse of the scenarios in chapter 3 and to describe the results of the interviews in appendix C, we have written the following Matlab functions:

For handling load curves:

`add_demand`	Adds a load between specified hours to a load curve.
`energy_consumption`	Calculates the energy consumption in kWh for a load curve.
`LCplot`	Plots a load curve.
`LCplot2`	Plots two load curves in the same figure.
`newLC`	Creates a new load curve.

For handling load duration curves:

`ELDC`	Performs a convolution of one power plant into a load duration curve.
`energy_cost`	Calculates the energy price per kWh for a power plant.
`energy_demand`	Calculates the energy demand in kWh for a load duration curve.
`energy_production`	Returns a row vector with the energy production for each power plant installed in an equivalent load duration curve.
`LC2LDC`	Converts a load curve into a normalized load duration curve.
`LDCplot`	Plots a load duration curve.
`LOLP`	Calculates the Loss Of Load Probability.
`UE`	Calculates the Unserved Energy.

The theory behind these functions is explained in appendix A. Below is the Matlab code for each function listed.

add_demand.m

```
% add_demand adds demand to a load curve between specified hours
% Arguments:
%  P - The power (in kW) that should be added to the load curve
%  start_time, stop_time - The demand P is added between these times
%  lc - load curve
%       Should be created with newLC or add_demand
%
% Example:
%  Create a load curve with a demand of 100 kW between 8.30 and 14.45:
%
%  lc = newLC(0);
```

```
%  lc = add_demand(100, 8.5, 14.75, lc);
function updatedLC = add_demand(P, start_time, stop_time, lc)
start = round(start_time*4)+1;
stop = round(stop_time*4);
updatedLC = lc;
for i = start:stop
  updatedLC(i) = lc(i) + P;
end
```

energy_consumption.m

```
% energy_consumption calculates the energy consumption in kWh for a given
% load curve.
% Argument:
%  lc - A load curve created with newLC or add_demand
function W = energy_consumption(lc)
W = sum(lc(1:96))/4;
```

LCplot.m

```
% LCplot plots a load curve.
% The argument should be a vector created with newLC or add_demand.
% The return value of LCplot is the peak demand during the day.
function max = LCplot(x)
clf, hold on
max = x(1);
x(97) = x(1);
for i = 1:96
  if x(i) > max
    max = x(i);
  end
  currtime = (i-1)/4;
  nexttime = i/4;
  plot([currtime, nexttime], [x(i),x(i)]);
  plot([nexttime, nexttime], [x(i),x(i+1)]);
end
axis([0 24 0 max])
xlabel('hour')
ylabel('power demand [kW]')
title(sprintf('Daily energy consumption: %.2f kWh  Peak load: %.2f kW', energy_consumption(x),
max));
```

LCplot2.m

```
% LCplot2 plots two load curves in the same figure
function max = LCplot(lowEstimation, highEstimation)
clf, hold on
subplot(2,1,1), hold on
maxLow = lowEstimation(1);
lowEstimation(97) = lowEstimation(1);
for i = 1:96
  if lowEstimation(i) > maxLow
    maxLow = lowEstimation(i);
  end
  currtime = (i-1)/4;
  nexttime = i/4;
  plot([currtime, nexttime], [lowEstimation(i),lowEstimation(i)]);
  plot([nexttime, nexttime], [lowEstimation(i),lowEstimation(i+1)]);
end
axis([0 24 0 maxLow])
xlabel('hour')
ylabel('power demand [kW]')
title(sprintf('Low estimation (%.2f kWh, peak %.2f kW)', energy_consumption(lowEstimation), max-
Low))
```

```
subplot(2,1,2), hold on
maxHigh = highEstimation(1);
highEstimation(97) = highEstimation(1);
for i = 1:96
  if highEstimation(i) > maxHigh
    maxHigh = highEstimation(i);
  end
  currtime = (i-1)/4;
  nexttime = i/4;
  plot([currtime, nexttime], [highEstimation(i),highEstimation(i)]);
  plot([nexttime, nexttime], [highEstimation(i),highEstimation(i+1)]);
end
axis([0 24 0 maxHigh])
xlabel('hour')
ylabel('power demand [kW]')
title(sprintf('High estimation (%.2f kWh, peak %.2f kW)', energy_consumption(highEstimation),
maxHigh))
max = [maxLow maxHigh];
newLC.m
% newLC creates a new load curve for 24 hours.
% The demand is set to d kW
function lc = newLC(d)
lc = d*ones(97,1);
```

ELDC.m

```
% ELDC calculates the equivalent load duration curve to a normalized load
% duration curve supplied with one power plant.
% Arguments:
%  ldc - load duration curve
%         Should be a load duration curve obtained with LC2LDC or ELDC
%  p - probability for failure
%       Should be a row vector. The sum of the elements in p should be 1.
%  P - corresponding failing power (in kW)
%       Should be av vector of the same size as p.
%  Pmax - Maximum produced power in the power plant
%
% Example:
%  Perform a convolution for a power plant of 100 kW and availibility of 90%
% into the load duration curve ldc:
%
%  newldc = ELDC(ldc,[0.9 0.1],[0 100], 100);
%
%  Perform a convolution for a power plant which have an availibility of 90%
%  and produces 20 - 80 kW (approximatly of equal probability) into a load
%  duration curve ldc:
%
%  newldc = ELDC(ldc,[0.2 0.2 0.2 0.2 0.2],[0 20 40 60 80], 80);
%
function newldc = ELDC(ldc,p,P,Pmax)
if round(sum(p)*1000) ~= 1000
  error ('Incorrect probability vector, sum should equal 1 with at least 3 decimals');
end
size(p);N=ans(2);
newldc = zeros(size(ldc));
noofsegments = ldc(2,1);
Psegment = ldc(2,2);
P = round(P/Psegment);
stop = 0;
x = 1;
while (stop == 0)
  newldc(1,x) = 0;
  for i = 1:N
    xP = x - P(i);
    if xP > 0 & xP < noofsegments
      newldc(1,x) = newldc(1,x) + p(i)*ldc(1,xP);
    elseif xP <= 0
      newldc(1,x) = newldc(1,x) + p(i);
    end
```

```
  end
  if newldc(1,x) == 0
    stop = 1;
  end
  x = x + 1;
end
size(newldc);newldc(2,1) = ans(1,2);
newldc(2,2) = Psegment;
newldc(2,3) = ldc(2,3) + Pmax;
noofPowerPlants = ldc(2,4);
for i = 5:5+noofPowerPlants;
  newldc(2,i) = ldc(2,i);
end
newldc(2,6+noofPowerPlants) = UE(ldc,1) - UE(newldc,1);
newldc(2,4) = noofPowerPlants + 1;
```

energy_cost.m

```
% energy_cost calculates the energy cost for a certain power plant
% Arguments:
%  investment - Investment to build the power plant (in economic units)
%  interest - Interest rate to be used in the calculus (in %)
%  n - Economic life span for the power plant (in years)
%  fixed - Fixed yearly costs for the power plant (in economic units)
%  variable - Variable costs for the power plant (in economic units/kWh)
%  W - Yearly energy production in the power plant (in kWh)
function cost = energy_cost(investment,interest,n,fixed,variable,W)
i = interest/100;
a = investment*i/(1-(1+i)^(-n));
cost = (a + fixed + variable*W)/W;
```

energy_demand.m

```
% energy_demand returns the demanded energy for a certain load duration curve
% and review period, i.e. T*(area below duration curve)
% Arguments:
%  ldc - a load duration curve created with LC2LDC or ELDC
%  T - review period in hours. If omitted 24 hours is assumed.
function W = energy_demand(ldc,T)
if nargin == 1
  T = 24;
end
W = ldc(2,5)*T;
```

energy_production.m

```
% energy_production returns a row vector with the energy production (in kWh)
% for each of the power plants supplying an equivalent load duration curve
% Arguments:
%  ldc - a load duration curve created with LC2LDC or ELDC
%  T - review period in hours. If omitted 24 hours is assumed.
function W = energy_production(ldc,T)
if nargin == 1
  T = 24;
end
noofPowerPlants = ldc(2,4);
if noofPowerPlants < 1
  W = 0;
else
  W = T*ldc(2,6:5+noofPowerPlants);
end
```

LC2LDC.m

```
% Converts a load curve to an normalized load duration curve
% Arguments: lc - a load curve created with newLC
%            Psegment - segment length in kW
```

```
%           from - a row vector of start times
%           to - a row vector of stop times
% The last to arguments could be omitted. In that case the load duration
% curve is created from the whole load curve.
%
% Example:
%  Create a load duration curve using the load curve lc, excluding the load
% between 6 am and 6 pm:
%  ldc = LC2LDC(lc, 1, [0 18], [6 24])
%

function ldc = LC2LDC(lc,Psegment, from, to);
if nargin == 2
  from = [0]; to = [24];
  worklc = lc(1:96);
else
  k = 1;
  for i = 1:length(from)
    start = round(from(i)*4)+1;
    stop = round(to(i)*4);
    for j = start:stop
      worklc(k) = lc(j);
      k = k + 1;
    end
  end
end
Pmax = max(worklc);
Pmin = min(worklc);
l = length(worklc);
noofsegments = ceil(Pmax/Psegment+2);
if noofsegments < 5
  noofsegments = 5
end
ldc = zeros(2,noofsegments);
ldc(2,1) = noofsegments;
ldc(2,2) = Psegment;
for i = 1:noofsegments
  P = i*Psegment;
  if P <= Pmin
    ldc(1,i) = 1;
  else
    for j = 1:l
      if worklc(j) >= P
        ldc(1,i) = ldc(1,i) + 1/l;
      end
    end
  end
end
ldc(2,5) = UE(ldc,1);
```

LDCplot.m

```
% LDCplot plots a normalized load duration curve
% The arguments should be a matrix created with LC2LDC or ELDC and the length
% of the time period (in hours). If no time period is given, 24 hours is
% assumed.
function LDCplot(ldc, T)
if nargin == 1
  T = 24;
end
clf, hold on
noofsegments = ldc(2,1);
Psegment = ldc(2,2);
for i = 1:(noofsegments - 1)
  Plow = (i-1)*Psegment;
  Phigh = Plow + Psegment;
  plot([Plow, Phigh], [ldc(1,i),ldc(1,i)]);
  plot([Phigh, Phigh], [ldc(1,i),ldc(1,i+1)]);
end
```

```
xaxismax = Psegment*noofsegments;
axis([0 xaxismax 0 1.2]);
xlabel('x [kW]');
ylabel('F(x)');
leftedge = 0.3*xaxismax;
Pmax = ldc(2,3);
S = sprintf('Installed power: %.1f kW', Pmax);
text(leftedge,1.15,S);
lolp = LOLP(ldc);
S = sprintf('LOLP: %.2f %%', lolp*100);
text(leftedge,1.1,S);
S = sprintf('UE: %.2f kWh', UE(ldc,T));
text(leftedge,1.05,S);
plot([0 Pmax Pmax],[lolp lolp 0.0],':')
```

LOLP.m

```
% LOLP calculates the Loss Of Load Probability for a normalized load duration
% curve. The argument should be created with LC2LDC or ELDC.
function lolp = LOLP(ldc)
Pmax = ldc(2,3);
Psegment = ldc(2,2);
lolp = ldc(1,Pmax/Psegment+1);
```

UE.m

```
% UE calculates the Unserved Energy for a normalized load duration curve.
% Arguments:
%  ldc - a load duration curve created with LC2LDC or ELDC
%  T - review period in hours. If omitted 24 hours is assumed.
function ue = UE(ldc,T)
if nargin == 1
  T = 24;
end
noofsegments = ldc(2,1);
Psegment = ldc(2,2);
Pmax = ldc(2,3)/Psegment;
Pstart = ceil(Pmax) + 1;
ue = T*sum(ldc(1,Pstart:noofsegments))*Psegment;
if Pmax ~= round(Pmax)
  Pmax - floor(Pmax);
  ue = ue + (Pmax - floor(Pmax))*T*Psegment*ldc(1,ceil(Pmax));
end
```

Appendix F

COINCIDENT FACTORS

In our load curve estimations we have made use of coincident factors to compensate for the fact that not all electric equipment will be used at the same time. We define coincident factors like this:

$$c.f. = \frac{P_{average}}{P_{max}} \quad \text{(F.1)}$$

where

$P_{average}$ = average load during a certain time period

P_{max} = total installed load

Problems with coincident factors

Our definition of coincident factors has the advantage of simplifying the load estimation, but might in some cases be misleading.

Consider figure F.1. We have some electric equipment, that we know consumes 20 kW during two hours any time between 8 a.m. and 4 p.m., but exactly which two hours it will be used is unknown. Since two hours is 25% of the possible time period we would assume a coincident factor of 0.25. This means that the resulting load curve will contain a load of 5 kW during 8 a.m. to 4 p.m. instead of the real load which for instance could occur between 11 a.m. and 1 p.m. (like in the figure).

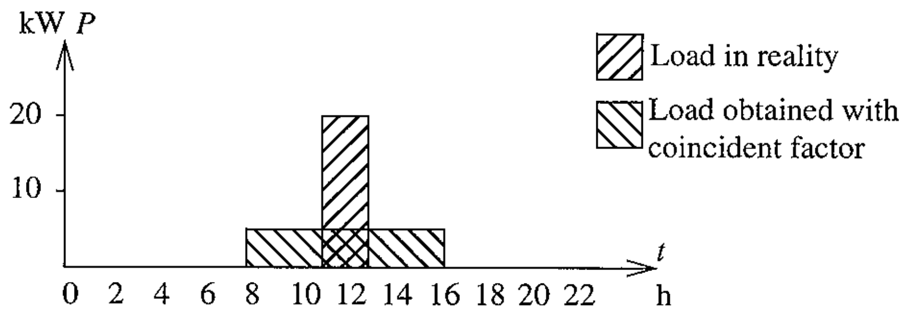


Figure F.1: Illustration of the problem with coincident factors

The resulting load curve have been "smoothed" compared to the real one. This means that there is a possibility that we are missing a peak in the demand. However, if there are several loads that have been "smoothed" like this and if they are independent of each other and equally distributed during the time period, the average consumption of all loads will be closer to the sum of the "smoothed" loads, meaning that the error caused by the coincident factors will be smaller as the quantity of equipment increases.

In most cases the conditions above are fulfilled, but there is one exception: Some lighting is only used cloudy days, and since only a few days every year are cloudy have we chosen a coincident factor of a few per cent for these lights. But the condition that the loads should be independent of each other is not fulfilled, because all these lights will be used the same days. The solution to this problem is to make separate load curves for cloudy and clear days, but since these lights represent a very minor load, we have chosen to neglect this error as it is very small compared to the error made in all other assumptions.

Appendix G

RESERVOIR AT RIVER CHOGO

We have not made a deeper study of the possibilities to build a reservoir in connection with a hydro power plant at River Chogo, but we have made an estimation of the possible size, provided that the ground is solid enough.

Reservoir size

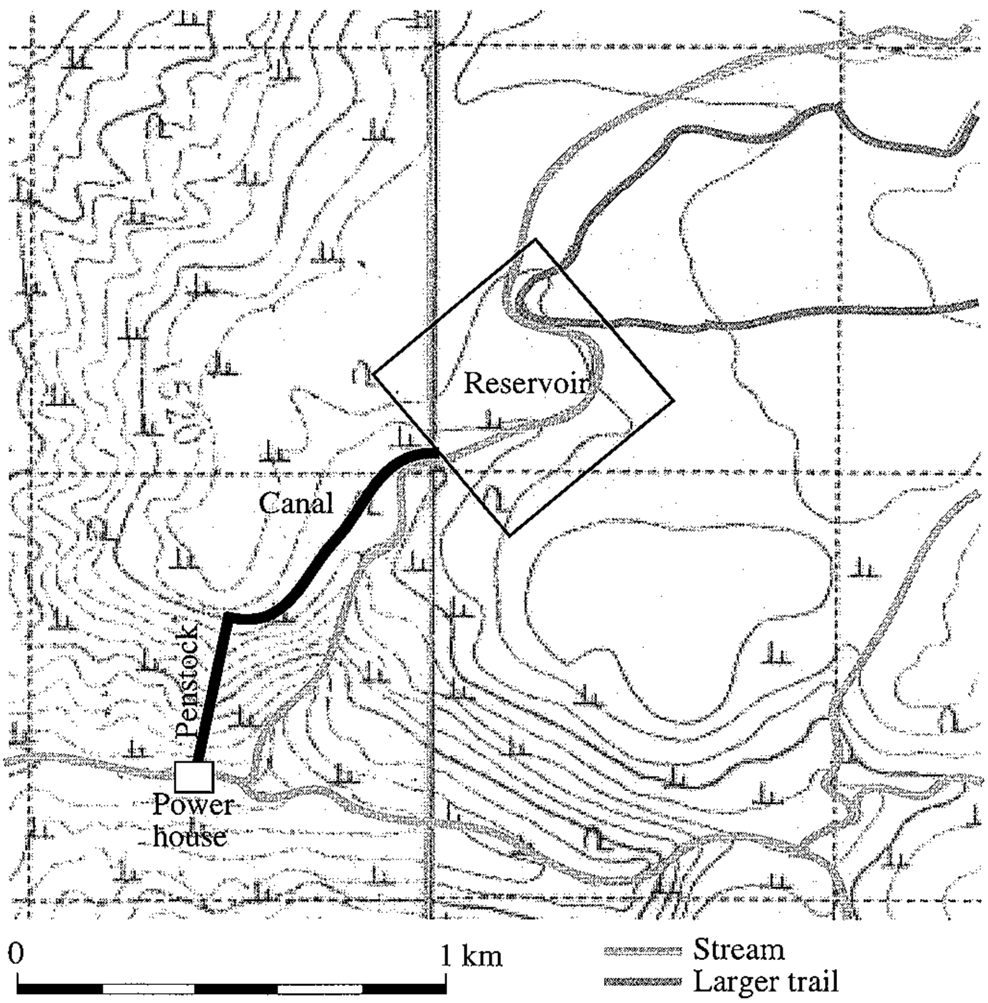


Figure G.1: Map over the Chogo Area

The reservoir indicated on the map in figure G.1 has been approximated to a volume with the upper horizontal surface as a square with the side 400 m and a vertical cross section parallel to the dam as an equally sided triangle. The triangular cross section has a height of 40 m in level with the dam and decreases linearly to zero at the side opposite to the dam. According to equation G.1 the volume of this reservoir is 1.6 million m^3:

$$V = \int_0^{400} \frac{400}{2} \cdot \frac{x}{10} dx = 10x^2 \Big|_0^{400} = 1.6 \cdot 10^6 \text{ m}^3 \quad \text{(G.1)}$$

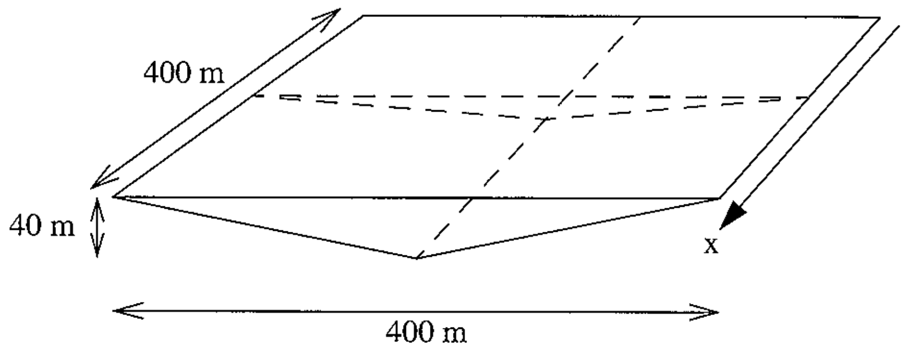


Figure G.2: Shape of the reservoir

The maximum storage of electric energy E in this reservoir is taken as the energy efficiency η of the hydro power plant multiplied with the potential energy of the water filled reservoir at the height difference of 180 m. E is equal to 588 000 kWh according to equation G.2:

$$E = \eta mgh = \eta V\rho gh = 2.12 \cdot 10^{12} \text{ J} = 5.88 \cdot 10^5 \text{ kWh} \quad \text{(G.2)}$$

$\eta = 0.75$

$V = 1.6 \cdot 10^6 \text{ m}^3$

$\rho = 1000 \text{ kg/m}^3$

$g = 9.81 \text{ m/s}^2$

$h = 180 \text{ m}$

Appendix H

COMPACT FLUORESCENT LAMPS

With modern energy-saving technologies it might be possible to lower the costs of the electricity system. The major load in a rural system in a developing country is lighting. Most lights are used a few hours in the evenings, which causes a peak in the load curve during the evening hours. If this peak is considerable higher than the load during the rest of the day, it might be profitable for the production company to encourage the use of CFLs, because if the peak is lowered the production company might not need to invest in an extra power plant. Also, reducing the load means that the losses will decrease as shown in equation B.5.

More information on CFLs can be found in for instance [3] and [21].

When are CFLs profitable for the consumer?

CFLs consumes about 25% of the electric energy for the same light output as normal incandescent lamps. The lighting cost per hour can be calculated through

$$C = \frac{I}{T} + \frac{P \cdot c}{1000} \qquad \text{(H.1)}$$

I = Cost of one lamp [$]

T = Expected life time [h]

P = Power [W]

c = Energy price [$/kWh]

Table H.1: Prices for incandescent lamps and CFLs*

Lamp type	I	T†	P
Incandescent	0.47	1000	60
CFL	22	8000	11

* From [21], p. 53.

† These are the life time expectations provided by the manufacturers. Since the voltage quality might be poor it would be advisable to use an actual value based on experience. Unfortunately are there no detailed results from the test of CFLs in Urambo [21] yet available, but of the CFLs installed in October 1994, 85% were still operating in April 1997. The CFLs in Urambo are used four hours every day.

From equation H.1 the energy price necessary to make CFL more profitable than incandescent lamps can be calculated by[80]

80. In this calculation are interest rate and benefits of reduced losses in the system not considered.

$$\frac{I_{CFL}}{T_{CFL}} + \frac{P_{CFL} \cdot c}{1000} < \frac{I_{IL}}{T_{IL}} + \frac{P_{IL} \cdot c}{1000}$$

$$\Rightarrow$$

$$c > \frac{1000\left(\frac{I_{CFL}}{T_{CFL}} - \frac{I_{IL}}{T_{IL}}\right)}{P_{IL} - P_{CFL}} \tag{H.2}$$

Data from table H.1 gives that CFLs are more profitable already at an energy price of 5 Cents per KWh.

Problems with CFLs

The largest problem with introducing CFLs is the high purchase price. Even though CFLs are more economical in the long run, many families simply cannot afford buying them.[81] This problem could for instance be solved if CFLs could be purchased by instalments through the distribution company or an electric consumers cooperative.

Another disadvantage with CFLs are their poor power factor. Conventional electromagnetic CFL have a power factor of 0.4 to 0.6, but this can be compensated with capacitors. Electronic CFLs have a typical power factor of 0.5, but this can not be compensated with capacitors, since it is caused by harmonic distortion. Equipment sensitive to harmonic distortion should though be sparse in rural systems in developing countries, so this is probably not a major problem.

81. This was found during a house-to-house survey in Urambo, Tanzania, performed by Mr. Bosco Selemani.

Appendix I

DATA FOR VESTAS V44-600

In our case study of Kasulu have we used a Danish wind power plant called Vestas V44-600 for the calculations in the wind power scenarios.

Power function for Vestas V44-600

The generated electric power (in kW) as function of the wind speed for this wind power plant can be found in table I.1.

Table I.1: Power function for Vestas V44-600

Wind speed [m/s]	Air density [kg/m^3]							
	1.06	1.09	1.12	1.15	1.18	1.21	1.24	1.27
4.5	0	0	0	0	0	0	0	0
5	24.7	25.8	26.8	27.8	28.9	29.9	31.0	32.0
6	65.2	67.4	69.6	71.8	74.0	76.2	78.4	80.6
7	115	119	123	126	130	134	137	141
8	176	181	187	192	198	203	209	214
9	246	253	261	268	275	283	290	298
10	320	329	338	348	357	366	375	384
11	393	404	415	425	436	445	454	463
12	461	471	482	492	503	511	518	525
13	517	525	534	542	551	556	560	565
14	557	563	568	573	579	581	584	586
15	581	584	587	589	592	593	594	595
16	593	594	595	596	598	598	598	599
17	598	598	598	599	599	599	600	600
18	599	599	600	600	600	600	600	600
19 - 20	600	600	600	600	600	600	600	600
Source: Information sheet from the manufacturer								