Characterization of power system loads in rural Uganda

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Abstract

Despite the fact that the majority of Uganda's population lives in the rural areas only 1% of them have access to electricity. To be able to extend the grid to new areas, models of the consumption of electricity are needed. The aim of this thesis is to provide such models based on data collected in Uganda. The modeling effort is based on a field study carried out in Uganda where survey based interviews and measurements were made. The measurements cover four different transformers that provide the customers of Najjeera village with power. The time span of the measurements varies between 24h and 7 days. The interviews with 67 of the 93 customers, have been used to determine the distribution of the load between the customers. These show that electrification of rural areas is not, at this time, a solution to the increasing deforestation that is partly caused by the usage of firewood. Electricity does not substitute firewood since it is mainly used for lighting and entertainment. From the collected data energy consumption on a daily basis has been derived. A closer look has been made on the different parts of the day: night (0-06), morning (06-09), daytime (09-19) and evening (19-24). During the evening hours the major consumption of electricity occurs, while during the daytime hours the usage of electricity stays at very low levels. The sets of data have been grouped depending on the financial situation of the customers since economical factors are dominating in determining the amount of electricity consumed. Domestic and non domestic loads have been identified. The domestic load has been divided into four different groups: "low", "middle", "middle-high", and "high". The daily mean power value has been calculated for each group. The results of the categorization have also been used to estimate the load arising from a poultry farm and a boarding school in the field study area. When dimensioning power systems, peak loads are important and in this case they occur in the morning and evening hours. For three different groups of these peaks a Generalized Pareto Distribution has been fitted. The estimated parameters of the distribution have also been tested on other groups of customers with similar economical background, with varying results.

Key-words
Rural electrification, Uganda, load characterization, energy usage, fuel-wood, regression, categorization, peak values, POT, Generalized Pareto Distribution

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Contents

Chapter 1

Introduction

1.1 Aims and Objectives

Africa is often called the Dark Continent, even if the green vegetation should suggest the name the Green Continent. But at night most of Africa turns dark, unlike most of the western world, and the name becomes more suitable. The lack of electricity, especially in the rural areas, is the main cause of darkness.

In Uganda over 85% of the population live in rural areas but less than 1% of them have access to electricity, instead traditional energy sources such as fuel-wood are used to cover domestic needs. In 1998 the World Bank together with the Nordic aid organizations started Africa Rural & Renewable Energy Initiative (AFRREI) in order to try to find solutions to this problem in Sub-Sahara countries. The aim of the program is to increase the percentage of electrification from 1% to 10% in the rural areas in 10 years and at the same time extend small-scale renewable energy production to about 70 MW. One of the first programs, Energy for Rural Transformation, is centered in Uganda. The University of Makerere in Kampala plays an important role in designing, disseminating and monitoring the different programs.

To be able to construct a well functioning electrical grid it is important to have load prediction models that can describe consumption patterns. These are needed for network planning and operation, power production planning, load management and pricing. With correct models unnecessary investments can be avoided and the needs of customers can better be fulfilled.

The aim of this work is to suggest models that can give an appropriate and realistic picture of the situation. To reach the goal the models should be based on field studies and measurements carried out in Uganda. These should then improve the chances to develop a well functioning electrical grid that can supply the rural areas with reliable energy at low cost. This is essential for a sustainable development that can create jobs and other income generating activities.

1.2 Structure of the report

In many cases the nature of loads is dependent on external factors such as meteorological variables but in the case of rural settings in Uganda, the socio-economical background is of larger importance. The next chapter gives a closer description of background phenomena that can influence the consumption of electricity. Both a picture of the general situation of Uganda and of the power sector are given. The chapter ends with a description of the efforts being made at the moment to extend the grid to the rural areas.

To be able to compute models that are reliable, locally collected data is needed. For this purpose the first part of the project consisted of field studies carried out in Uganda. This was done during a four-month stay by the author. The collected data includes not only a quantitative part but also a qualitative since pure measurements were combined with interviews. Measurements were carried out at an aggregated level, each measurement covering between 5 and 15 customers. The interviews give an idea of how this load is distributed between the individual consumers. Another purpose of the interviews was to try to give a picture of the social factors that influence the consumption. A more detailed description of the field studies is presented in chapter 3.

The second phase of the project has been to analyze the collected data. The results of this analyses are given in chapter 4. The first part is dedicated to the results given only by the survey. The second part presents the results based on the collected data. Issues that have been looked into are energy needs, both on a daily basis and for the different parts of the day, a categorization based on the financial situation of the customers that gives a daily mean value of the power, and finally a closer look at the morning and evening peaks that have been fitted to extreme value distributions.

The conclusions of the work are presented in chapter 5 and suggestions of future studies are given in the last chapter.

Different tables and graphs that illustrate the results are found in the appendices. A list of the abbreviations used in the report is also presented as an appendix.

Chapter 2

Background

2.1 About Uganda

This chapter aims at giving some background information that is needed to understand the nature of the consumption of electricity in Uganda.

Uganda is situated in eastern Africa in the great lake region. The equator passes through the country just a few kilometers south of the capital Kampala. Due to elevation (average of 1228m) the climate is, what many people would agree on, ideal. The average temperature is around $25-26°C$ all year around. The seasonal variations will depend on the rainfall. There are two rainy seasons, March to May and September to November, even if lately global climatic phenomena such as El Niño have shifted these seasons to a very irregular pattern. The proximity to the equator also makes the daylight variations non-existing, the sun rises around six in the morning and by seven in the evening it is dark.

At its independence in 1962, Churchill called Uganda "The pearl of Africa". Since then Uganda has had a tormented history with military regimes lead by dictators such as Amin and Obote. Wars have been fought and are still being fought in certain areas of the country. This unfortunate history has left Ugandas economy and social development devastated. It is only since 1986 and the raise of power of president Musenveni, that a certain recovery has taken place. In the latest ranking of the HDI (Human Development Index) in July 2002, Uganda reached the 150th position out of 173. The average income is 200 USD/year and life expectancy at birth is 43 years. The majority (85%) of Uganda's population is living in the rural areas. The average rural income is hard to determine since most peasants are subsistence farmers with no monetary income. Every now and then a chicken or certain crops are sold leading to an average income of 15 000-30 000 USh/month (1 USD $\approx$ 1800 USh-Uganda Shilling).

The basic energy consumption is connected to cooking. The staple food for most people is matooke, a kind of cooking banana. This is traditionally steamed in banana leaves over a charcoal or firewood oven. Besides matooke, beans, g-nut (peanuts) sauce and posho (maize porridge) are also common dishes.

2.2 The Ugandan Power Sector

The total consumption of energy in Uganda corresponds to 5 million tons of oil equivalent (TOE) per year, per capita that is 0,25 TOE (1999: 20 millions inhabitants). The majority of this energy (90%) comes from biomass in forms of wood, charcoal and agricultural residues. If one looks at the electricity consumption per capita the numbers are very much lower in fact only 0.02 TOE per capita. This is a direct reflection of the fact that only 6% of the population has access to electricity and the majority of these live in urban areas.

Estimated numbers for the year 2000 [4]:

	Total	Urban	Rural
Population	22M	3.4M	18.6M
# households	4.6M	0.8M	3.8M
# electrified households	0.25M	0.17M	0.08M
Electrification coverage	5.9%	21%	2.1%

Until 2002 there was one main state owned body that was responsible for the generation, transmission and distribution of electricity in Uganda, i.e. UEB (Uganda Electricity Board). Today the company has been split into four units. These are:
- UEDCL : Uganda Electricity Distribution Company Limited
- UETCL : Uganda Electricity Transmission Company Limited
- UEGCL : Uganda Electricity Generation Company Limited
- UEB Statutory : will be responsible for ongoing projects before they are handed over to the other companies.

These four are all still state owned but at least transmission and distribution are up for bidding for private enterprises. For the regulation of licenses, tariffs, quality of service, standards and technical codes the Electricity Regulatory Authority has been created.

Hydro power is the main source of electricity. The plant at Owen Falls and the newly built Kira Power station stand for 98% of the generation. The old station built 1954, during the British rule, has a capacity of 180 MW and Kira power station supplies 120 MW. At Kira two more units of 40 MW are planned but funding is still lacking. The remaining 2% arise from small-scale diesel generators or mini-hydros.

Electricity is generated at 11 kV, while High Voltage transmission is done through a 132kV network, but also 66 kV and 33 kV lines are used for transmission. The distribution is carried out by 11 kV lines in the rural areas and 33 kV in the urban areas. These voltages are then transformed to 240 V single phase and 415 V 3-phase. In rural areas single phase transformers can also be found. Distribution by single phase is most adequate for simple household consumption. Problems arise when lines are expanded and large areas are supplied by only one phase. Another disadvantage is that small-scale industrial loads within the agricultural sector, such as water pumps and maize mills, can not always operate on single phase. The electrification of these areas then loses one of its possibilities to increase economical development.

In 1993 the yearly consumption for the whole of Uganda amounted to approximately 500 GWh [1], which could be compared to Sweden that, despite having half the population of Uganda, has a yearly consumption of 150 TWh. It should also be noted that since 1993 the Kira power station has been installed, increasing the generating capacity with 120 MW. The consumption is divided between different customer groupings with the ratios: 55% residential, 25% commercial and general and 20% industrial [4].

Uganda also exports electricity to Kenya, Tanzania and Rwanda. This amounted to a total of 260 GWh in 1993 [1].

2.3 Rural Electrification

According to the Electricity act from 1999 the government through the Ministry of Energy and Mineral Development is responsible for rural electrification.

This is financed through the government and by aid donors such as Sida. The World Bank program Energy for Rural Transformation (ERT) has granted a loan of USD 49.5M, that has been approved by the Ugandan parliament (06/05/02) and a grant from GEF (Global Environmental Facility) of USD 12.12M targeted for renewable energy sources such as mini-hydro plants. The planned extension of the grid is advertised out to private contractors. The contractor will thereafter also manage the constructed line. Electricity supplied to the area will be bought from the transmission company. The right to use any distribution line that is not part of the area constructed by the contractor will also be settled financially.

A feasibility study is done of the area that analyses the number of possible consumers, gives an economical analysis of the area and takes into consideration social factors such as health facilities, schools, etc. It also looks into which form of electrification is most appropriate for the area. The three main options are: grid extension, mini-grids through mini-hydro plants, and Photo Voltaic systems.

To ensure that even economically disadvantaged areas will be electrified a Rural Electrification Fund is being created. The Fund is managed by a central Board. An Agency, which takes care of the day-to-day management, is responsible for the implementation of the decisions taken by the Board. It is also the Agency's duty to report back to the Board. These facilities are still in the making and the Fund will partly be financed by the above mentioned loan from ERT.

Priority areas are:

1. The West Nile area. Today electricity is mainly provided through diesel generators that are run a few hours in the evening. This area is far from the main grid and there is a common discontent of not being connected. The main plan is to construct a mini-hydro at Nyagak with the capacity of 5,5MW and distribute this through 33kV lines.

2. The Sembabule area in the south western part of the country.

3. Katuna in the south. Sida is the main funding agency in this area.

4. The Karamoja area is of interest for political reasons. This is an unstable area due to repeated cattle raids carried out by local tribes. The extension of the grid to this area can be used as a way to convince them to lay down arms. It could also create alternative income sources.

The location of the areas can be found in the map in appendix A.

To be able to implement the electrification of these areas in an efficient way, more appropriate load models are needed, since the existing ones do not always give a realistic picture of the consumption of electricity. For this reason it is important that more studies on load profiles and load prediction models for rural areas are carried out.[7]

Chapter 3

Field Studies

The first step in creating the needed models is the collection of data from areas that are similar to the targeted ones. This was the first phase of the study and was carried out in Uganda between May and August 2002. The field studies consisted of two parts: measurements of power at an aggregated level and interviews with individual consumers. Since help was needed for installing the instrument and communicating with the local people a technician from the distribution company was hired to assist the work.

3.1 Description of the area

The study was focused to one area. Through collaboration with the Uganda Electricity Distribution Company Limited, UEDCL, an appropriate village was found. The name of the village is Najjeera situated a few kilometers northeast of the capital Kampala. This village had recently been rehabilitated, i.e. poles and feeders had been changed and two new transformers had been installed to give a better load distribution and enable a growth of the total load. This means that compared to many other areas both the technical losses and the non-technical losses can be seen as minor. The proximity of the area to Kampala results in a higher standard of living than other rural areas. This is directly reflected in the load that will be higher. Approximately 250 households reside in Najjeera, of these 93 are connected to the grid. In the village there is also a church, 3 schools (1 connected to the grid), one bigger poultry farm and two smaller ones. The different clients are supplied by four 100 kVA transformers.

3.2 Interviews

The interviews with the households were based on the survey that can be found in appendix F: Survey form for Households. The questions were either asked directly by the author or through the technician that in this case served as a translator. The answers were registered by the author. A total of 67 customers (66 households + 1 school) answered the survey, while the total number of customers is 93. The questions are meant to give a picture of what lies behind the consumption of electricity in each household. The questionnaire also tried to cover issues such as background information, the quality of the electrical distribution, and the consumption of other energy sources. The accuracy of the answers varies depending on who answered the questions and how well informed the person was about the situation of the household. Workers, maids and children were sometimes the persons who answered.

Figure 3.1: The overhead distribution to the individual households made it easy to find the customers to interview

3.3 Measurements

The measurements were made at four different transformers. The collected data consists of active and reactive power, registered with a sampling interval of 5 minutes. Two instruments were used simultaneously due to prior inconvenience with the measuring equipment. The two instruments were a LEM memobox 603 and the net analyzer FFT HTR 9220. Values collected from LEM memobox 603 are mean values over a 5 minutes interval while FFT HTR 9920 measured instantaneous values, every 5 minutes. The LEM memobox 603 also registered voltage and current values. Figure 3.2 shows how the instruments were installed. A three phase to three phase installation was used for both instruments. The duration of the measurements is between 24 hours and 7 days. One of the limiting factors was the security of the measuring equipment. The instruments were locked into a wooden box and installed by the pole mounted transformers. Due to the proximity to the high voltage lines electromagnetic field disturbed the equipment used from the beginning. The two instruments that were used at a later stage of the project served as a check that the registered values could be considered reliable. For a list of the amount of measurements carried out see appendix B. The measurements of active power from the two instruments coincide quite well, while the reactive power differs and shows an inexplainable behavior. Due to the nature of the load from a power system point of view it was most interesting to just use the active power measurements. For most of the analyses the values from LEM memobox 603 were used since these had a higher sensitivity for low values. Measurements have also been carried out at a coffee factory situated in a different area, as an example of an industrial load that can be found in a rural setting.

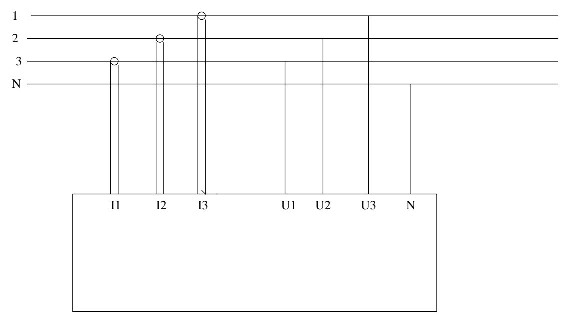


Figure 3.2: Installation of instrument

Figure 3.3: Technician installing instrument by the transformer

Chapter 4

Results

4.1 Survey

4.1.1 Different types of customers

Generally customers are divided into three different groups: residential, commercial and industrial. In Najjeera all consumers can be classified as residential, with the exception of a broiler farm. The commercial activity in the rural areas consists mainly of small shops and bars. These are not charged with any commercial tariff since they are normally home-based. The consumption is also very similar to a domestic load and consists mainly of lighting and a fridge to be able to serve cold drinks. Another form of commercial activity that can be found is hair-salons that use hair dryers and shaving machines. The commercial activity is situated in the trading centers next to the main road and this is also where the load is the largest (transformer 4).

The broiler farm by transformer 1 is the only industrial load present in Najjeera. This farm consists of 9 breeding houses for a total of 3200 chickens. Each house has a 3 phase automatic feeding systems that is used 16h/day. Besides this, 26 light bulbs are used in every house. There are three more small-scale broiler farms that, compared to a normal residential load, use extra lighting for heating purposes when the chickens are small. Among the customers of transformer 4, there is also a combined day and boarding school with 600 pupils. The pattern of consumption is the same as for domestic loads when it comes to lighting even if, of course, the number of light bulbs is a lot higher. At the school there are also loads such as a photocopying machine, printer and computer.

4.1.2 Consumption groups

Depending on the number of appliances possessed, three different consumption groups have been created to classify the customers. The criterion of division was based on the fact that it was hard to get any accurate information about the income and that number of appliances better reflected the consumption of electricity. The groups are the following:
Group I: Lighting, radio, TV
Group II: Lighting, radio, TV, 1 or 2 appliances (fan, fridge, flat iron)
Group III: Lighting, radio, TV, 3 or more appliances (fan, fridge, cooker, video, flat iron)

Transformer & phase	Group I	Group II	Group III
1B	4	2	1
1Y	1	2	2
1R	2	1	2
1 Total	7	5	5
2B	1	4	0
2Y	4	3	0
2R	2	2	0
2 Total	7	9	0
3B	1	4	2
3R	1	0	0
3 Total	2	4	2
4B	3	2	5
4Y	2	4	0
4R	2	3	4
4 Total	7	9	9
Total	23	21	22

Table 4.1: Groups for each transformer and phase. For Transformer 4, yellow phase there is also a school, not included in the grouping.

Table 4.1 shows the division between the different groups at each transformer and phase (B=Blue, Y=Yellow, R=Red):

The spread amongst the groups is very even, which complies with the assumption that the field study area probably has a higher income than the average rural area. According to "Optimisation Study" [2] carried out by EDF for UEB in 1997 the level of low income would be around 80% and high 2%. It is to be noted that their tool for separating the groups is based only on income values.

4.1.3 Appliances

If one only looks at the different appliances, the division between the transformers is described in the table in appendix G. All of the households had at least one or two light bulbs for internal lighting. Besides this 51% of the households also use outdoor lighting for security reasons. The determining factor of the usage of light bulbs is the setting of the sun, since Uganda is right by the equator, the time for dusk is very constant throughout the year. Light bulbs are turned on around 19 hours and turned off some time between 22 and 24. Security lights are used all night until 6 or 7 in the morning. TVs and radios are very common amongst the households (72% in both cases; for TVs: 31% of the households have a black and white TV and 40% colored one). Radios are used during varying hours of the day but evening hours are most common. News is a popular listening program. During the evening hours not only the lights and radios are frequently used, but also TVs are then switched on. Popular TV shows or events such as the World Cup in football can have an increasing effect on the consumption.

Fans exist in certain households (30%) but are rarely used since the temperature hardly ever exceeds bearable limits. Moving out to the shade is a much more common way of cooling off. The flat iron belongs to one of the more common appliances (63%). The electrical flat iron replaces the charcoal heated iron. Fridges are used in the small shops or bars by the trading centers or in households with a slightly higher income (totally 50% of the interviewed customers). Some fridges are used 24h a day, others when needed. One shop owner for example would keep the fridge on until the drinks were cooled and then turn it off. Cookers are not very common, they were only found in 18% of the households, and even the existing ones are not always in use (25% of the households with cookers). Many times the cost for using electricity for cooking is too high.

4.1.4 Other energy sources

Other energy sources than electricity are actually most commonly used in rural Uganda. This applies even to areas that are electrified. Energy is mostly needed for cooking, entertainment and lighting. Electricity normally substitutes other sources for the last two usage categories but is normally not used as an alternative for cooking. As a matter of fact all the interviewed households used other energy sources for cooking, even those with a cooker. The cookers and coils were most of the time used to boil tea water or heat up food.

For cooking there are three main energy sources: charcoal, firewood and paraffin. Charcoal is the most common one. Out of the 66 households 54 used it and 20 of these combined it with firewood. Totally 27 households used firewood as fuel. Unfortunately this means that electrification does not at the present time give any solution to the problem of deforestation. Biomass in the form of either firewood or charcoal is still being commonly used, both out of economical and cultural reasons. The traditional cooking styles are normally not easily transferable to a cooker. The alternative to biomass that is used at the moment is paraffin. It was used by 19 households, but even this time often used in combination with either firewood or/and charcoal. Two of the households use gas cookers.

The average monthly expenditure per household for charcoal lies between 8000 and 16000 USh. Firewood is many times collected on the own plot of land and does therefore not constitute an extra cost for the household. The households that do pay for it have varying cost between 3000 and 15000 USh a month. The average expenditure for the total consumption of cooking fuel of 53 of the households is 16 500 USh/month. It should be noted that many households use a combination of the different kinds of fuel. The average expenditure for electricity is somewhat higher (22 000USh based on 46 answers) but these figures are very uncertain and many times based on estimations.

Paraffin is still used for lighting purposes in case of blackouts or other problems with electricity (26 households). Batteries for torches (8) and candles (3) are also used at these occasions. For entertainment purposes dry-cell batteries are used to power radios. This was found in 27 households. Charcoal is sometimes still used for ironing (3 households).

4.1.5 Other questions

To be able to get some background information about the electricity consumption general question were asked. This was also done to get some insight into issues such as suppressed demand and future consumption.

Figure 4.1: Woman in Najjeera village selling charcoal

Weekly patterns
In industrialized countries there is a large difference in load between weekdays and weekends. This is mainly due to the large role that industrial and commercial loads play. Since this component is not present the variation should not be as obvious. It is still of interest to know if there are any weekly behavior patterns that can have an affect on the variation of the load. The interviewed households were asked if they believed that there was any difference in their consumption of electricity between weekdays and weekends. Of the 66 households that where interviewed, 32 answered that the consumption was equal, 29 that they used more electricity on weekends and 1 on weekdays. The increased consumption on weekends is due to TV watching, radio listening and usage of the flat iron. In power terms an extra television will give an increase of 120 W and a radio only 15 W. The flat iron has a power rating of 1000 W but is normally used during a short period of time. The increased consumption during weekends can therefore be considered as minor.

Even for other types of customers there are no major variations, at least not for those present in Najjeera village. In the case of the broiler farm there is no difference since the birds need feeding every day. For the school there is no specific information.

Blackouts
Blackouts are commonly occurring in the rural setting. These can either be caused by technical failure somewhere along the feeder line or due to a shortage of available electricity from a central level. The last one is called load shedding and occurs normally in the evening at peak hours (19-21). In the collected data the power failure on the evening of day 7 at transformer 4 can be attributed to this, see appendix C. The field study area had recently been rehabilitated so technical blackouts where not frequent anymore. The consequences that the old blackouts had where minor and affected mainly lighting for dinner eating and not being able to watch the favorite TV-program. The only ones that were truly affected by blackouts were the three chicken farms since during the breeding season, light bulbs are used for heating the chicks. The larger broiler farm was most troubled since automatic feeding machines were used. A diesel generator was used

Figure 4.2: Woman cooking in the traditional style

when power failures occurred. Small shops or bars did not complain much over power shortages. A bar owner's comment on the issue was: "As long as the beers are cold it is OK."

Satisfaction

Almost everyone answered that they were satisfied with the distribution of electricity. However, since the interviews were carried out in the presence of UEB personnel and vehicle, there is a strong chance that the answers do not give a complete picture of the situation. It should also be taken into consideration that the area had recently been rehabilitated and that the service therefore had improved and could be considered to be at a higher level than in many other areas. The complaints heard were about the billing system, which was considered unclear and the rates were too high.

New appliances

28 answered that they had no plans of purchasing new appliances. Of those that had the most popular one was a fridge (11 households). 8 wanted to buy a plate cooker or coils. For the other appliances the results were:

TV	6
Fan	5
Radio	4
Flat iron	2
Washing machine	1
Computer	1
Juice machine	1

These answers reflect a combination of people's wishes in case their economical situation would improve and realistic plans for future acquisitions.

Price sensitivity

Economical factors are many times dominating in determining the load of a household. A hypothetical question was asked on how an increase of the price per unit (kWh) would affect the households consumption. 12 answered that their consumption rate would stay the same. As one of the interviewed said, “can’t go to sleep much earlier”. But the majority, 43, did say that they would try to reduce their consumption. This would mostly be done by using fewer bulbs or decrease the amount of time they were lit (17 answers). Many times it was the security lights used at night that would be shut down. Three of the interviewed said they would buy energy-saving bulbs. Other energy saving measures were to iron less (2), watch less TV (3), use the fridge only certain hours (3), stop using the kettle (2), stop using the cooker (2).

4.2 Analysis of measured data

4.2.1 Description of data

The collected data is separated by transformer and phase. The presented data are from LEM memobox 603, due to its higher sensitivity, with an exception on the third transformer where only measurements from FFT are available. For the first transformer

Transformer & phase	Mean kW	Standard deviation kW	Max kW	Min kW
1 B	7.1285	5.3235	20.2	0.4
1 Y	4.893	2.381	11.5	1,3
1 R	4.5959	2.2537	10.0	1,2
2 B	1.3855	1.0432	5.3	0.4
2 Y	2.1586	1.7347	7.5	0.2
2 R	1.0201	1.0472	4.0	0
3 B	2.5731	2.4024	10.7	0
4 B	9.4067	4.8572	27.5	2.8
4 Y	1.9729	1.0078	7.2	0.5
4 R	4.1143	2.5895	12.9	0.7

Table 4.2: Description of data

measurements were carried out from 12:35 on the 25th of June until 11:00 the 26th. At the second and third transformer the instrument registered values during approximately 72 h and the fourth transformer the data series covers 1 week. For a more exact description see appendix C. An overview of the collected data is presented in table 4.2.

For the analyses the data has been divided into sections of 24 hours, beginning at 00:00. Figure 4.3 shows the 24 hours sequence of the blue phase on the second transformer. This is a typical profile for the daily load in the rural areas and one can easily observe that the variation during the hours of the day is very large. This is also the cause of the high standard deviation that can be found in the collected data, see table 4.2. To be able to deal with this behavior the day has been divided into four different time spans within which a similar behavioral pattern can be found. These four groups are: night between 00 and 06, morning from 06 to 09, day from 09 to 19 and evening 19 to 24. The criterion of division is based on the survey and on observation of the plotted data.

As a comparison a 24h profile of an industrial load is presented in figure 4.4. This is a coffee factory that is not situated in in Najjeera village.

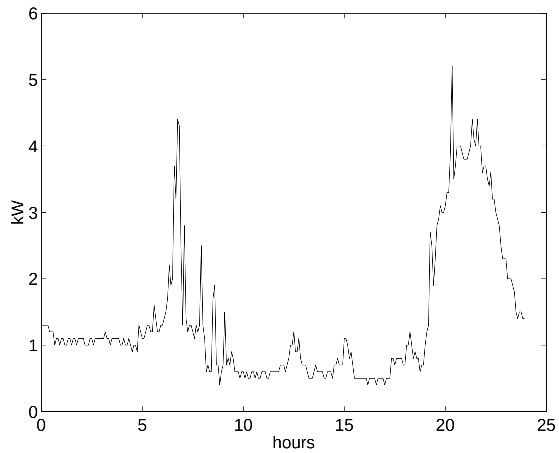


Figure 4.3: 24h profile of a group of the 5 customers on the blue phase of transformer 2

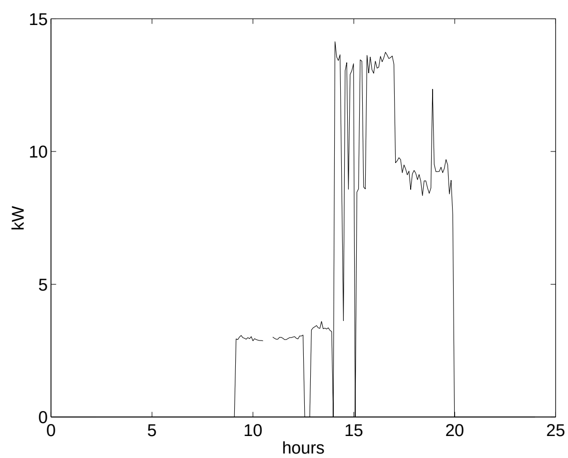


Figure 4.4: 24h profile of the consumption of electricity of a coffee factory

4.2.2 Energy values

Sub-Saharan countries normally have a shortage of electrical energy. It can therefore be interesting to look into not only the power ratings but also the energy values. Important issues are the location of the time span in which most energy is consumed and the relation between the different times of the day. Through numerical integration of the data, energy consumption values were calculated. The calculation has been done per day and per each individual time span per day. This has been done for all transformers except the first one. The results can be seen in appendix D and the mean power can be seen in appendix E. We can compare the values for the fourth transformer with values given by UEB that have been used for billing. Their total is 7 700 kWh/month while from the measured weekly value it is approximately 10 000 kWh. These figures can be seen as approximately the same since in the data from UEB 6 customers are missing. An average of 200 kWh/month and customer gives the expected difference.

Transformer & phase	Date	Night (00-06), kWh	Morning (06-09), kWh	Daytime (09-19), kWh	Evening (19-24), kWh	24h kWh
2R	11/7	6.3	3.0	2.2	13.7	25.2
2Y	10/7	5.4	4.8	23.2	22.6	56.0
4R	25/7	24.1	19.9	26.9	28.8	99.6

It is interesting to note that the evening period, though shorter in time, often leads to higher energy consumption than during daytime. The five evening hours constitute in average almost 40% of the total daily energy consumption. The percentage varies between 28% and 54%.

The lowest values can be found by the transformers with a higher concentration of group III costumers, apparently higher status appliances are used during more varied times of the day while TV, radio and lighting, that are dominant in the groups with lower consumption, are mainly used in the evening, leaving the day time consumption low. It is also during the evening that the peak power values are registered. The daytime period is normally the one with the lowest registered values. Even the night has many times a higher mean power rating than the day. The energy values are more equal while comparing day and night but this is due to the different length of the period (6h for the night and 11h for the day). The power values registered at night can mainly be explained by the usage of security lights that remain lit all night. The morning peak that can be observed in the daily variations can be found in the mean power values but many times not in the energy values since the integrated time span is only 3h and therefore much lower than the other periods.

4.2.3 Categorization of domestic load

In section 4.1.2 the customers were categorized in different consumption groups depending on the number of appliances that they owned. The number of customer in each group varies from transformer and phase. This difference was used when trying to categorize each transformer and phase. At a first stage three different categories were used: “low”, “middle” and “high”. To find the parameters that would describe each category linear regression was used. In the model

$$y = \alpha + (\beta_i \beta_{i+1} ...) * \begin{pmatrix} x_i \\ x_{i+1} \\ . \\ . \end{pmatrix} + \varepsilon$$

y is the mean power per day and customer, x_i a indicator variable (or dummy variable) that can assume the value of 1 or 0 and ε the residuals, i.e. the difference between the actual value y and the calculated values $\alpha + \beta * \mathbf{X}$ [8]. The indicator variables correspond to:

x_1	x_2	
0	0	low: dominated by group I
1	0	middle: dominated by group II
0	1	high: dominated by group III

With this model α will give an approximation of the mean daily power per customer in a "low" area, β_1 what should be added to α to get the mean daily consumption per customer in an area classified as "middle" and β_2 what should be added to α for a "high" area.

Table 4.1, that shows the number of customers in the three consumption groups at each transformer and phase, was used to decide which category was best suited to each transformer/phase. Unfortunately it was not possible to interview all the customers so the number of uncertain customers will also play a decisive role. To try to compensate this lack of information the actual value of the mean consumption per customer was also used as a guideline for the categorization.

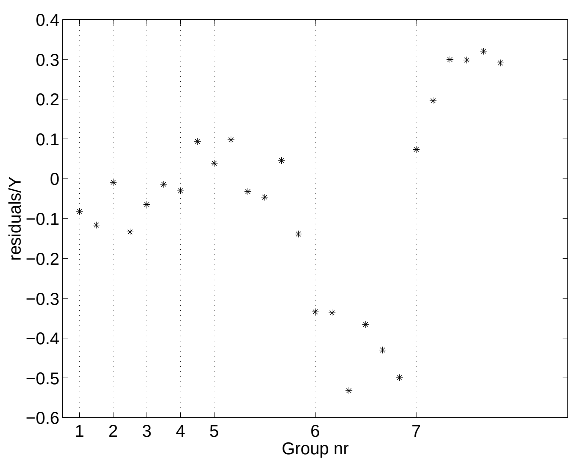


Figure 4.5: Residuals from the first model with 3 categories. Each value relates to one day of measurements

Table 4.3 explains the connection between the different transformers and phases and the residuals plotted in figure 4.5. The plotted residuals are each from the mean power of the different days of measurements for each group. The different amount of values plotted depends on the amount of available data. For the four first groups only

No	Transformer & phase	Category	24h sequences used
1	2 B	middle	2
2	2 Y	middle	2
3	2 R	low	2
4	3 B	low	2
5	4 B	high	6
6	4 Y	middle	6
7	4 R	middle	6

Table 4.3: Connection between group number, transformer & phase, and category

two full days can be used. The parameters given by the regression are: $\alpha = 0.1794$, $\beta_1 = 0.1198$, $\beta_2 = 0.4397$. Meaning that an area that can be classified as "low", will have a mean daily power of 180 W per customer, in an area that can be described as "middle" instead, the mean is 300 W per customer and in a "high" area, 600 W per customer.

The last two groups, 6 and 7, i.e yellow and red phase on transformer 4, give raise to very large residuals. These are both classified as "middle". A closer analyses of the load per customer and the connection to the category was made. One approach was to plot the load per customer versus the corresponding category. The results can be seen in figure 4.6. The middle category has a large spread compared to the other two

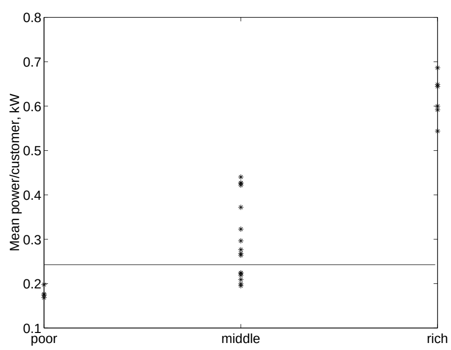


Figure 4.6: Mean power per customer versus category

and the lowest values are almost coinciding with the ones in category "low" (the ones below the line in figure 4.6). These low values are the ones from the yellow phase of transformer 4, group 6. An attempt to handle this problem was made by recatogorizing this transformer and phase group to "low". The new residuals can be seen in figure 4.7, it should be observed that the scaling is different from figure 4.5.

The parameters for this model are $\alpha = 0.1989$, $\beta_1 = 0.1527$, $\beta_2 = 0.4202$. The problem with group 6 has been solved since these residuals are much lower while the first two groups are affected by the difference in categorization since group 7 with a high consumption will play a more dominant role in the "middle" group.

The main problem seems to lie in the "middle" group that has quite large spread and that is hard to determine exactly where to place the groups that are close to the

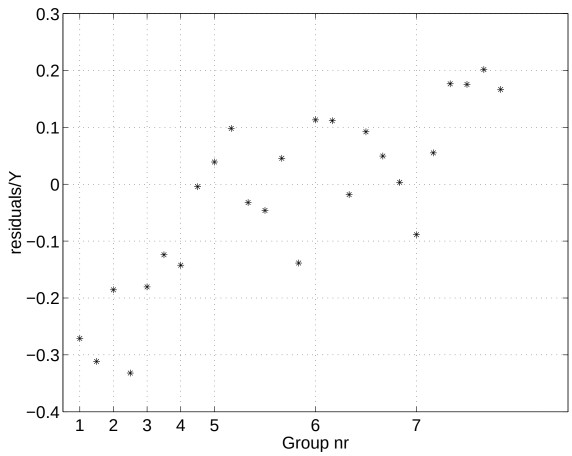


Figure 4.7: Residuals from the second model with 3 categories

other categories. An attempt to deal with this was to increase the number of categories. Two different scalings were tested. At a first stage the category “middle-high” was included. Group 7 was assigned this category and the rest kept their category. The second attempt was to include even a “middle-low” category that would describe group 6. The results of are shown in figure 4.8. If one observes group by group the first two

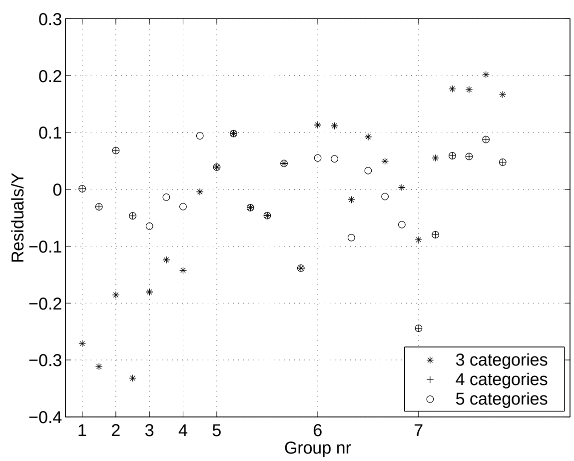


Figure 4.8: Three different models with different number of categories

groups maintain the category “middle” through all the three models. The model with four categories coincides with the one with five, but in the case of only three categories the residuals are much larger. This is due to the strong influence of group 7 that has a higher consumption per customer than the other groups in category “middle”. The two “low” groups 3 and 4 show an improvement when the 5 scale model is used, except for one value. Group 5 shows the same results for all three models which is not that strange since it is the only one in the category “high” in all the models. It is more interesting to follow the changes for group 6 since this is one of the cases which was difficult to categorize. The five scale categorization shows an overall better performance since in this model there has been created a category specifically for this group. For group 4 the two models where the category “middle high” was introduced to describe this group, the residual are much lower than in the three-scale model.

The main problem is to determine which category a group of customers actually belongs to. Since the categorization of the individual households was based on the number of appliances, the total number of appliances in each group was used to see if the categorization is valid upon these premises as well. Taking into consideration that the number of customers per group differed, an average number of appliance per customer at each transformer and phase was used. The tables used for the observation can be found in appendix G. Once again the problem lies in the groups that are on the border between the categories such as group 6 and 7.

The parameters for the model with four categories are $\alpha = 0.1989$, $\beta_{100} = 0.0774$, $\beta_{010} = 0.2029$, $\beta_{001} = 0.4202$. The interpretation of these values is that in a “low” area a customer will have a mean power rating of approximately 200 W, in a “middle” area 280 W per customer, in a “middle-high” area 400 W per customer and a “high” area 620 W per customer. For the model with five categories the values are: $\alpha = 0.1794$, $\beta_{1000} = 0.0325$, $\beta_{0100} = 0.0969$, $\beta_{0010} = 0.2224$, $\beta_{0001} = 0.4397$. In this model a customer in a ”low”area will have a power rating of 180 W, in a “middle-low” 210 W, in a middle area 280 W, i.e. the same as in the four category model. The values 400 W for the “middle-high” area and 620 W for a “high” area are also the same as in the four category model.

Comparing the two models shows that the introduction of a “middle-low” category only affects the lower categories and this effect is not very large. Still the residuals for this model will be slightly lower for most values in group 2, 3, and 6, i.e. the groups that have been classified as either “low” or “middle-low”. Since the models are calculated with a not too large number of values the results should be seen as guidelines and a 4 category model can give a good approximation. A 5 category model becomes too specifically adjusted to the groups in this study and therefore harder to generalize to other areas. Another factor that should be taken into consideration is the fact that the field study area has a slightly higher level of income then an average rural setting, it is therefore not sure that there will always exist a distinction between “middle-high“ and “high”.

With these results an estimate of the total mean daily power rating of an area can be made. After the financial level of an area has been evaluated a corresponding daily average consumption of energy per customer can be found (200 W if the area is “low”, 280 W if “middle”, 400 W if “middle-high” , and 620 W if “high”). To get the total daily average the value should be multiplied with the total amount of customers.

Regression with number of customers in each consumption group

Instead of categorizing a diverse group of households into a specific group an attempt was made to make a regression model where the explanatory variables were the number of customers in each group. The new model is $y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon$ and x_1 is the number of customers in group I, x_2 the number of customers in group II, x_3 the number of customers in group III and x_4 the number of uncertain customers, i.e. households that were not interviewed. In this model y is the total consumption at the transformer and phase. This model did however not turn out to be a successful description of the load: mainly due to the large impact of the number of non-interviewed customers.

Linear regression gives the following parameters: $\beta_1 = 0.9896$, $\beta_2 = -0.3518$, $\beta_3 = 0.9006$ and $\beta_1 = 0.4016$. As can be seen these parameters are not very realistic since β_2 is negative meaning that one would have a lower load when the number of customers at group II increases, especially compared to group I, which is not very plausible.

Night load

Another approach to understand the nature of the load is to describe the different parts of the day through the defined categories. Does the pattern remain the same or are there variations? As an example the mean power during the night hours (00-06) was used as response variable. The three different scales and categorization of the groups from the previous models are used. For the three category model the parameters are: $\alpha = 0.2080$, $\beta_{10} = 0.0808$, $\beta_{01} = 0.2110$. The first observation is that the magnitude for the night mean power is quite equal to the daily mean for the category "low" (≈ 200 W) while a bit lower for the category "high" 420 W at night and around 600 W for the whole day. Increasing the number of categories does not improve the results since certain parameters turn to negative. For the 4 category model the parameters are: $\alpha = 0.2080$, $\beta_{100} = -0.417$, $\beta_{010} = 0.1624$,$\beta_{001} = 0.211$ and for the 5 category model: $\alpha = 0.2126$, $\beta_{1000} = -0.0076$, $\beta_{0100} = -0.0463$, $\beta_{0010} = 0.1579$, $\beta_{0001} = 0.2064$. Figure 4.9 shows the residuals of these three models. Even if the three category model gave parameters that are non-negative, the residuals for group 2 are very large, almost the double of the actual value. They remain quite large even for the other models. This is caused by the fact that despite being categorized as "middle" this group has a lower nightly mean power rating then the "low"groups. The conclusion that can be drawn

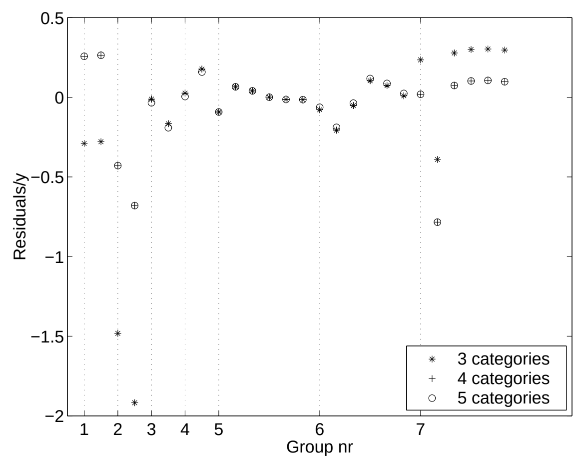


Figure 4.9: Residuals of regression with night load as response variable and 3 different models

is that a small increase of the economical situation does not always have to result in an increase of the night power consumption. A simple interpretation of this is that the number of security lights is not affected. While in a high area appliances such as fridges that are left on all night will also be present. To test if this conclusion was realistic a new regression model was made with only two categories. If one looks only at the number of fridges (see table 4.4) it would be logical to try to place group 1 and 4 in the category two. This has been done but resulted in very large negative residuals,

Group	fridges/customer	category
1	0.4	0
2	0.25	0
3	0	0
4	0.38	0
5	0.47	1
6	0.33	0
7	0.5	1

Table 4.4: Number of fridges per customer and given category; 0:low fridge user; 1: high fridge user

implying that the economical situation (group 1 is categorized as "middle" and 4 as "low") also has an influence. Since those with a weaker financial situation will many times just have the fridge on certain hours and not the whole day. The results from the new model can be seen in figure 4.10 and the calculated parameters are: $\alpha = 0.1961$ and $\beta = 0.1986$. Meaning that an area with few fridges or with fridges used mainly during the day will have an average night consumption of 200 W and one with fridges of 400 W (same results as in earlier models).

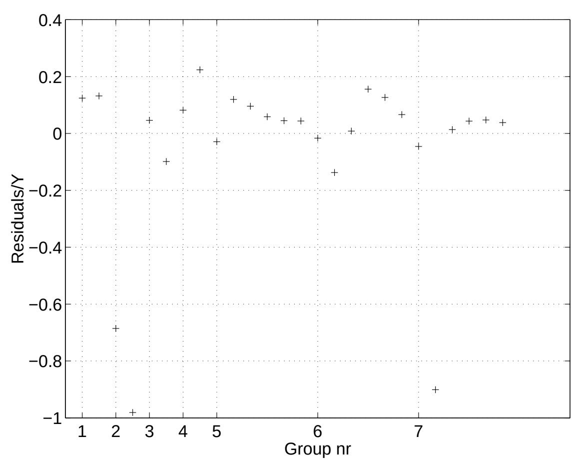


Figure 4.10: Residuals of regression with night load as response variable, 2 categories

To improve the model even more a new regression can be made by omitting the the groups or days that differ from the general behavior, because in the end it is the "normal" behavior that is interesting. The residuals in the new model are smaller, almost all being in the range of 0.1. The new parameters are $\alpha = 0.211$ and $\beta = 0.201$.

Looking only at the night load the division of customer grouping is much simpler than taking into consideration the load of the whole day. Two main groups are found, those with a high usage of fridges and those with a low usage. The first group has an average night power rating of 410 W per customer and the second 210 W per customer.

4.2.4 Non-domestic loads

Transformer 1 and the broiler farm

The categorization made in the previous section can be used to determine the size of other loads such as the broiler farm on the first transformer, since this load will be present in the residuals. The farm uses three phase feeding machines and lighting for the chickens. The first step was to categorize the three different phases. This was not an obvious task. The blue phase seems to have a dominant of group I (see table 4.1), on the other hand the household in group III is a very rich customer with an unusually high load. The other two phases seem both to have a "middle-high" profile if one looks at the distribution of customers and the number of appliances. The mean consumption per customer will in this case not give us any guideline since this includes the broiler farm. After assigning the category "middle-high" to all three phase, the next step was to multiply the typical consumption for the chosen category with number of customers and deduct this from the mean power. The results are:

from the blue phase	3.5 kW
from the yellow phase	2.5 kW
from the red phase	2.6 kW

To see if this result is plausible monthly energy ratings from UEDCL were used. During two different months the monthly consumption of the farm was of 1500 kWh. This gives and average of 2 kW a day. This shows that the results are reasonable. Two things should be kept in mind, first of all that the monthly rating from UEDCL sometimes shows a large increase probably depending on the amount of birds or small chicks. There is no information about the status at the time of the measurements. Second the calculation made for the three phases is very insensitive for variations in the mean consumption used to calculate the households consumption. The value used was 400 W, if instead 500 W would have been used a result around 2 kW would have been found anyway. The higher value from the blue phase arises probably from the presence of a group III consumer with a high load.

Another approach is to look just at the daytime values, i.e. the mean power between 9 o'clock in the morning at 19 hours in the evening. At first a new regression had to be made with the mean day time values as response variables. The most interesting regression is the one with 4 categories. The residuals can be seen in figure 4.11. The calculated parameters are: $\alpha = 0.1192$, $\beta_{100} = 0.0799$, $\beta_{010} = 0.1123$, $\beta_{001} = 0.3640$. The residuals for group 3 are very large since the daily consumption for this phase is almost non existing. An attempt was made to calculate the parameters by omitting the third group. The residuals show a much better behavior but the calculated parameters do not affect the category " middle-high". The parameter α is different but the sum of α and β_{010} will remain the same. Meaning that the mean day time consumption for a "middle-high" area is 0,23 kW. This value should then be multiplied with the number of customers at each phase and deducted from the measured mean day time power. The results from this calculation do not give a clear picture of the mean daily power values of the broiler farm. These are:

from the blue phase	0.73 kW
from the yellow phase	1.96 kW
from the red phase	1.32 kW

The result from the blue phase this time instead of illustrating the dominance of the "high" customer will show the lack of consumption during day time from the customers in group I connected to this phase. If we would have classified this phase as "low" instead the result would have been 1.53 kW, which is in the range of the other two

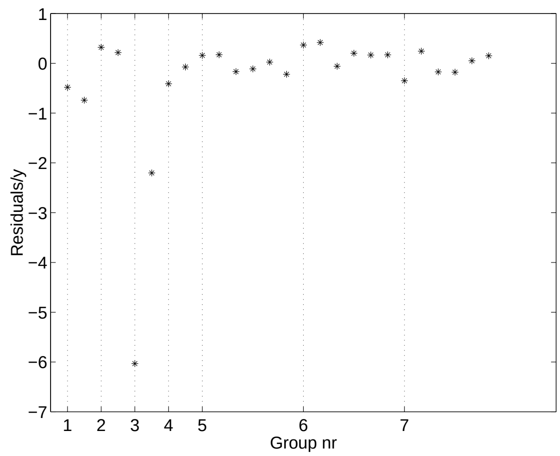


Figure 4.11: Residuals of regression with day time load as response variable

phases.

The 24h mean power rating of the broiler farm is approximately 2-2.5 kW while during the day time hours the value decreases to 1.5 kW. As a comparison one can look at the other industrial load at which measurements were taken, i.e. the coffee factory. The mean power for 24h is much higher then for the broiler farm and lies at 3.2 kW, and since the activity is concentrated to the day time the mean between 09 and 19 is even higher, reaching the level of 6.9 kW.

Day and boarding school

In Najjeera village there is also a day and boarding school that is connected to the grid on the yellow phase of transformer 4. The school has around 600 pupils that attend classes. The author has no information of how many of these children are just daytime pupils. Electricity is used to lit up 24 rooms in the evening and for 13 security lights. Other loads that are present during day time are a photocopying machine, a computer and a printer. At the school there are also 5 staff houses. The specific load for the school during the day has been estimated by subtracting the estimated domestic load from the total load registered at the yellow phase of transformer 4. The result of this can be seen in figure 4.12. The graph illustrates the estimated load for 6 different days. There seems to be a regularity between certain dips of the load. No suitable explanation has been found. It is interesting to observe that despite the fact that the school is quite large the daytime load is only around 1 kW, with some momentary higher peaks. This is probably due to the fact that electricity is not used much for the classes but mainly for administrative purposes. The computer, photocopy machine and printer are situated in the main office. The school load will be larger until the afternoon hours and after 18:00 the domestic load becomes dominant.

4.2.5 Maximum values

This part of the analysis strives at finding probabilistic distributions that can describe the evening and the morning peaks. Maximum values are of special interest in the di-

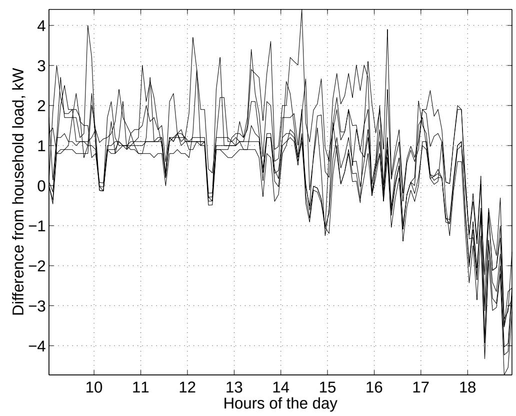


Figure 4.12: Estimated school load, calculated by subtracting estimated domestic load from total load

mensioning process when planning power systems. Models and distributions that can describe their behavior and predict their values are therefore desirable.

Theory

Peak Over Threshold analysis (POT) was used to study the exceedance over high value levels. This analysis is based on the observed fact that the extreme tail of a distribution is independent of the shape of the central distribution. A simple distribution is therefore fitted to the observations that exceed a certain threshold. Hopefully this distribution will also be able to describe the more extreme values. The choice of the exceedance level becomes a crucial part of the analysis. If a too low level is chosen the standardized form will not be found and a high bias will occur. On the other hand, if the level is too high, there will be too few values that can be used for the estimation and the variance of the estimated parameters will be high.

The distribution used to fit the values that exceed a threshold u is the Generalized Pareto Distribution, with the following distribution function:

$$F(x;k,\sigma) = \begin{cases} 1-(1-kx/\sigma)^{1/k}, & \text{if} \quad k \neq 0, \\ 1-exp\{-x/\sigma\}, & \text{if} \quad k = 0, \end{cases} \tag{4.1}$$

for $0 < x < \infty$ if $k \leq 0$ and for $0 < x < \sigma/k$ if $k > 0$.

The parameters that describe the distribution and that are estimated are k and σ. The shape of the distribution will depend on k and the scale on σ. The different methods to estimate these parameters are Maximum Likelihood (ML), Method of Moments (MOM), Method of Probability-Weighted Moments (PWM) and Pickand's estimator (PKD). The different methods have different performance depending on sample size and the values of the parameters to estimate, especially the value of k plays an important role on the performance of the estimators. Maximum Likelihood is recommendable when the sample size is large and $k > 0.2$, but the algorithm may have problems to converge if k exceeds 0.5. Low bias is often achieved with PWM, this method is especially recommended if k might be smaller then 0. If k is close to 0 or $k > 0$ then moment methods are to be preferred. Pickand's method is recommended as a first estimator for k, that can then be improved by using a method more suitable for the estimated parameters. For further information on the different methods see [10] and [12].

If the exceedance over a level u can be described by the Generalized Pareto Distribution and if $k > -1$ then the mean exceedance over this level u is a linear function of u according to:

$$E(X-u|X>u) = \frac{\sigma - ku}{1+k}. \tag{4.2}$$

This property is used to find a suitable threshold u.

Results

Data from transformer 4 was used to analyze the morning and evening peaks since a 6 day data series could be used. For each phase a suitable threshold u was found by observing the mean exceedance over the threshold and identifying the u after which the curve has a linear behavior. Thereafter an estimation of the parameters k and σ was made. The different methods described in the previous theory section were chosen depending on the properties of the peak sample. A more thorough search for a suitable threshold was made by comparing the covariance of the estimators and comparing the extreme values with the quantiles of a Generalized Pareto Distribution. In the quantile to quantile plot (QQ-plot) a straight line should be seen if the estimated distribution complies well with the peak values.

Evening peaks

Blue phase. From figure 4.13 one can see that linear behavior can be found after $u \approx 16$ kW. An irregular form appears at levels that are higher than $u = 24$ kW, this is caused by the small sample size, in fact only 7 values can be found exceeding this larger threshold.

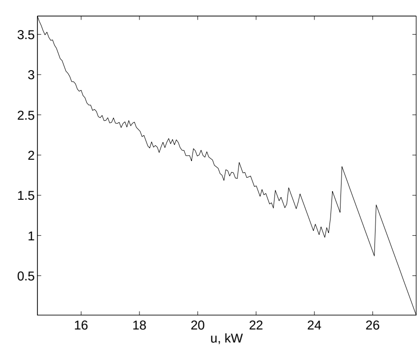


Figure 4.13: Mean exceedance over level u as a function of u, blue phase

The threshold that gives the best estimation is $u = 16.5$ kW. Since the sample size is large (192 values) Maximum Likelihood gives a good estimation of the parameters:

k	std (k)	σ	std(σ)
0.2133	0.0568	3.1120	0.2817

The plotting of the quantiles, see figure 4.14, also shows that this is a good estimation.

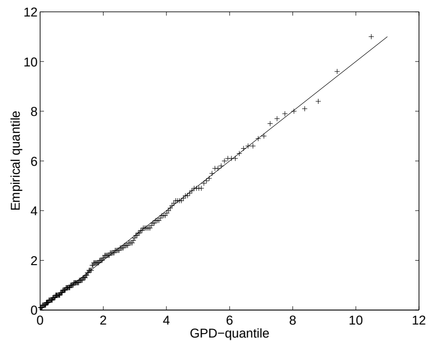


Figure 4.14: QQ-plot, parameters estimated with ML-method, blue phase. In the graph x=power-u

Yellow phase. The peak values from the yellow phase show a discrete behavior with clusters of 10-13 measured values. This can easily be seen in the mean exceedance plot shown in figure 4.15 since they are the cause of the jagged character of the curve. Despite the discretisation a certain linearity can be observed after $u \approx 3$ kW, so an attempt to fit the given values to a GPD was made anyway. The threshold level that gave the best results was $u = 3.3$ kW. With the MOM-method the following estimations were made:

k	std (k)	σ	std(σ)
0.2665	0.0954	0.9205	0.1157

Even if groups of values occur the peaks can still be described quite well by a Generalized Pareto Distribution. The plot of the empirical distribution function versus the estimated CDF (Cumulative Distribution Function) and the QQ-plot are found in figure 4.16. The stepwise appearance of the empirical distribution function is a consequence of the discrete grouping of the values. In both graphs of figure 4.16 x equals $Power - u$.

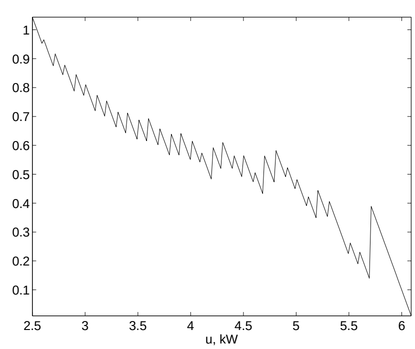


Figure 4.15: Mean exceedance over level u as a function of u, yellow phase

To try to find an explanation to the discrete behavior of the data every evening was treated separately to see if a repetitive pattern could be found. The estimated parameters did not show any apparent resemblance, but it is hard to draw any real conclusions

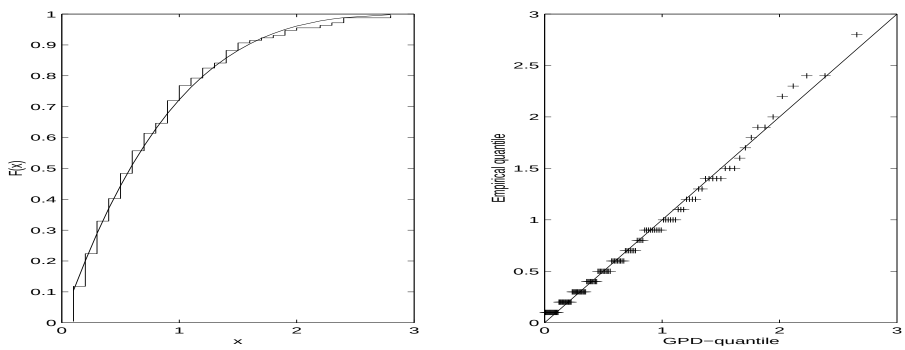


Figure 4.16: CDF and QQ-plot for yellow phase. In both graphs x=power-u

Evening	k	std(k)	σ	std(σ)
2	1.0220	0.5766	1.4828	0.6118
3	0.1687	0.2321	0.6428	0.2092
4	0.3747	0.2564	1.2373	0.3826
5	0.0999	0.2668	0.6853	0.2624
6	0.1378	0.2427	0.6115	0.2109
7	0.2371	0.2979	1.0103	0.4050

Table 4.5: Estimation of parameters for GPD per evening, yellow phase

since the standard deviation is large. This means also that the test does not support the hypothesis that each evening has a different behavior. The estimated values are found in table 4.5. It should also be noted that the sample sizes were very small and that the variance of the parameter estimates therefore was large. The same threshold was used for every evening, so the assumption that the parameters could be the same but the threshold varying has not been looked into.

Red phase. The best estimation for the red phase is received by using the MOM-method. The given estimates are :

k	std (k)	σ	std(σ)
0.6750	0.1334	3.6243	0.4493

Despite the large sample size of 146 values over the threshold of 7.75 kW, the ML-method can not be used for the estimation of k and σ since $k > 0.5$ and the algorithm does not converge. Observing the daily maximum values it is noticeable that the first evening (a Saturday) has much lower values than the following days, 8.4 kW instead of values around 12 kW. There was nothing found in the results from the survey that could explain this dip.

A comparison with the yellow phase shows the importance of the economical background. Despite a similar number of customers, 10 on the red phase and 9 on the yellow, the peak values on the last one are lower. The peaks encountered on the yellow phase are around 5-6 kW versus 12 kW on the red phase. The explanation of the higher load can be found in the fact that on the red phase there are 4 customers that belong to group III while on the yellow phase there are none at all.

Morning peaks

Blue phase. The morning peaks are not as easily described by a GPD. One of the causes is the lower sample sizes. The mean exceedance curve for the blue phase in figure 4.17 shows as linear behavior until u reaches 18 kW. Above this threshold there are only 18 values. If one looks at the plotted peaks from 7 days in figure 4.18 it is easy

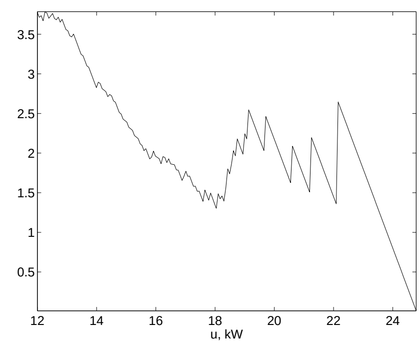


Figure 4.17: Mean exceedance over level u as a function of u, blue phase

to see some kind of trend, but this could also be interpreted as two different groupings. The first one includes the four first peaks. This group presumably dominates in the mean exceedance curve until u reaches 18 kW. The three later peaks are the second grouping that will dominate the curve after $u = 18$ kW. This distinction in behavior

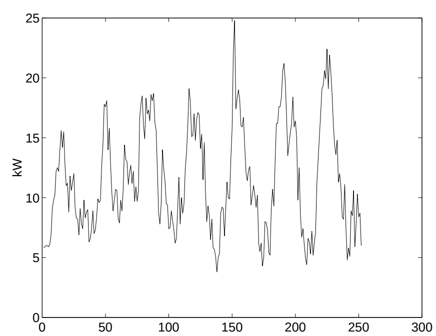


Figure 4.18: Morning peaks on blue phase

between the values under 18 kW and those over can also be observed in the graph with the empirical distribution together with the estimated CDF and in the QQ-plot, see figure 4.19. The deviation from the expected behavior occurs around $x = 2.5$. Since $x = Power - u$ and $u = 15.5$ kW the irregular pattern appears at the expected value of 18 kW. A possible way of describing the behavior is to use two different distributions one for the values before 18 kW and one for the higher ones.

In the estimation process the ML- method and MOM-method have a similar performance. The results here presented are from the ML-estimation and the chosen threshold is $u = 15.5$ kW. The estimated values are:

k	std (k)	σ	std(σ)
0.1482	0.1229	2.4395	0.4596

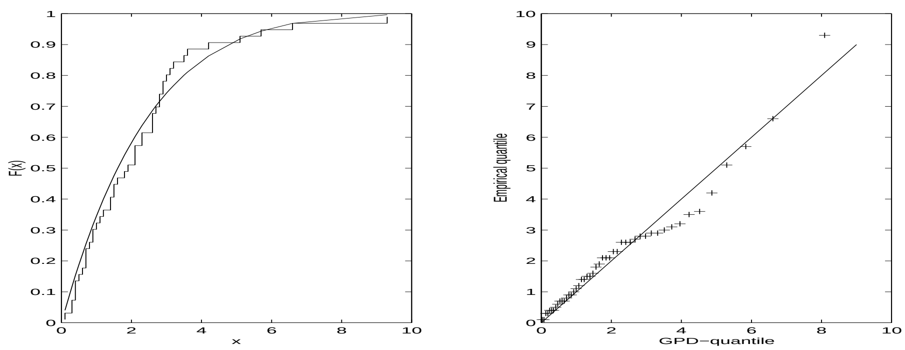


Figure 4.19: CDF and QQ-plot for morning peaks of blue phase. In both graphs x=power-u

Yellow phase. The irregularities in the mean exceedance curve for this phase are even higher than for the blue phase, see figure 4.20. A linear behavior is only found during a small interval. The irregularities are probably caused by the small sample size after 4 kW, in fact only 8 sample values exceed this threshold. An attempt to adapt a

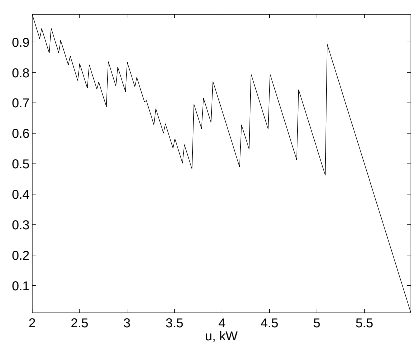


Figure 4.20: Mean exceedance over threshold u as a function of u, yellow phase

GDP to all the values exceeding 2.5 kW was anyway made. The method which gave the best result was the MOM, since the sample size was small and the estimated k larger then 0. The estimated values are:

k	std (k)	σ	std(σ)
0.2124	0.1308	1.0063	0.1799

Figure 4.21 shows the graphical results of the estimation. Some irregularities occur and the fitted estimation is not always ideal.

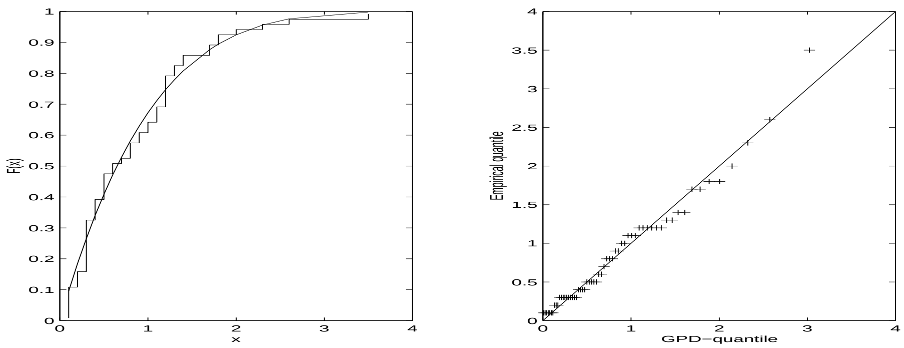


Figure 4.21: CDF and QQ-plot for morning peaks of the yellow phase.In both graphs x=power-u.

Red phase. This phase shows a much more regular behavior (figure 4.22), than the previous ones. Except from a large jump at the end of the curve. There are only 5 values that are larger than 10 kW, i.e. the value of u where the jump occurs. The most appropriate threshold is $u = 5.75$ kW. Due to the larger sample size of 92 values

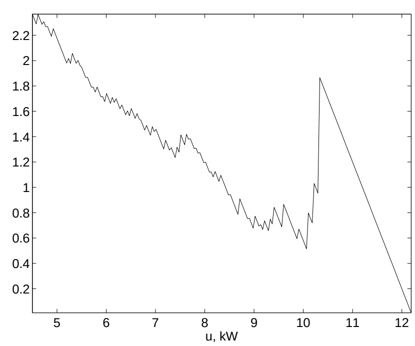


Figure 4.22: Mean exceedance over level u for red phase

that exceed this threshold, the ML-method had the best performance. The results of the estimation are:

k	std (k)	σ	std(σ)
0.3121	0.0717	2.3143	0.2830

These parameters have been estimated including the the 5 values that are larger than 10 kW. A better estimation could be made by omitting them.

General. An attempt was made to see if there was any time correlation between the maximum values for the three phases, but no such pattern was found for the evening hours. For the blue phase the peaks were mainly between 20:00 and 21:00, for the yellow phase almost all were after 21:00 and for the red phase most maxima occurred between 19:30 and 20:00. The interviews give no closer explanation then the fact that the expected peak should lie between 19:00 and 22:00. In the morning most of the peaks occur between 6:00 and 7:00. This is probably the time of day when most people start their day.

One of the question that can be asked is if there is any similar behavior between the phases. An attempt to answer the question has been done by comparing the parameter k of the three groups to see if the shape of the fitted distribution for the different phases is similar. When it comes to the evening peaks the blue and yellow phase both have an estimated k around 0.2 while the red phase distinguishes itself from the other two by having an estimated k of 0.67. The estimated ks for the morning peaks are much closer in range with the following values 0.15 for blue, 0.21 for yellow and 0.31 for red. The standard deviation lies around 0.1 implying even more the fact that the shape parameters are similar.

The three phases all have been categorized to different groups and this can be used to see if the parameters can describe other groups in the same category. The parameters from the yellow phase, that was categorized as "low", were used to try to described the blue phase of the transformer 3, also categorized as "low". At a first look the parameters do not seem to be very well suited for the task. But a comparison with the estimated parameters for the third transformer and a closer look shows that the shape parameter k is within the confidence interval. The main problem lies in the scale parameter σ. This can be explained by the fact that despite the fact of being in the same category the two groups have a different mean and threshold since the number of customers is different.

	k	σ
4 Y	0.2665 ± 0.187	0.9205 ± 0.2268
3 B	0.2	1.5

The same phenomena arises when the two "middle" groups are compared, i.e. red phase on transformer 4 and yellow phase transformer 2. In this case it should also be kept in mind that the red phase on transformer 4 has a slightly higher consumption per customer since it has at a more detailed level been categorized as "middle-high".

	k	σ
4 R	0.6750 ± 0.2615	3.6243 ± 0.8806
2 Y	0.49	0.1476

There is no other "high" group more than the blue phase of transformer 4 so the parameters of this one can not be checked on any other group.

These calculations makes us believe that an estimated shape parameter k of the GPD for a certain group of customers can be generalized to another group of customers with a similar economical situation. The number of customers that is included in the groups is of minor importance. The scale parameter σ on the other hand can not be generalized as easily.

Chapter 5

Conclusions

The financial situation of an area and of the individual household is the most determining factor behind the electrical load. For the individual household the economical situation will both determine the capacity to buy appliances and the amount of electricity that can be used. If the rural income lies between 30000 USh and 100000 USh per month then it is maybe not so surprising that a fridge costing around 300000 USh or a cooker with the price of 1000000 USh, is a large investment for a normal household. This is reflected in the fact that the main usage of electricity is for lighting and entertainment in the forms of radio and TV. The traditional energy usage is instead connected to cooking and is often not affected by the introduction of electricity. Many times cooking on electrical cookers is too expensive and many households can not afford the investment. Instead biomass in the form of either charcoal or firewood is still used. Traditions also play a role and the opinion that the food taste differently cooked on an electrical stove. So despite the fact that rural electrification is often promoted as a tool against deforestation this can still not be included in one of its advantages. To reduce the usage of firewood and charcoal it is much better to introduce more efficient stoves that are promoted by certain Non Governmental Organizations. These are often cheap and easy to construct since they are made out of locally found mud and make it possible to maintain the traditional cooking style. Information and education of people is always an important tool. When dealing with energy issues it is crucial to create an awareness about the consequences of the usage of biomass and at the same time to be able to present viable alternatives. In the case of the usage of electricity people need to be educated in the connection between the usage of electricity and the costs. This can help to avoid unpleasant surprises that can arise when the electricity bill is presented.

The results of the study are all based on a single area and the question that is naturally asked is how valid and general these conclusions are. Considering the field study area one can say that it has a typical rural structure with a trading center by the main road where the economical activity is concentrated to and also, where the largest consumption of electricity occurs (transformer 4). This is quite a general feature of rural settings. In fact most electrical feeders are drawn along main roads and rarely penetrate deeper into the landscape. The economical situation in Najjeera village can be seen as slightly higher than in other areas. Especially in areas that are further away from the economical center around Kampala, such as the West Nile area and the Karamoja area. Both are priority areas for rural electrification (see section 2.3). The validity of the analysis is very much connected to the amount of data collected. The limited sample sizes have not always made it possible to validate the calculated models or to be sure that certain observed behaviors have any explanation in reality or are just caused by noise or haphazard. This limits the conclusions that can be made from the collected data. Nevertheless a general picture of the nature of the load can be made, taking into consideration that any reliable or accurate information about details is hard to give. The focus of the analysis has been to find a general behavior so unusual cases have not been looked closer into. It should anyway be noted that when the residuals have been very large they have also been negative meaning that the values from our models are larger than the actual values. From a dimensioning point of view this is much better than the opposite. Another observation of the residuals is that explanations of them can be found in the collected data. But unusual behavior can not always be found in the results from the survey. The other problem with the results from the survey is that the calculated daily energy consumption from these, in almost all cases, gives a lower value than when the collected data is used instead. The daily energy consumption from the measured data sometimes is even double the one from the surveys even after compensations for losses and non interviewed customers has been taken into consideration. This could be a sign that load models just based on interviews can show lower consumption levels than the actual values.

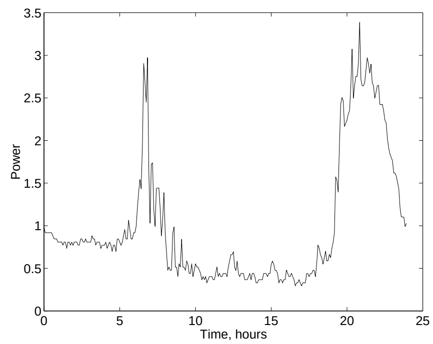


Figure 5.1: Mean daily profile of transformer 2, blue phase. The mark '1' on the y-axis represents the daily mean value

One of the guidelines that can be derived from the gathered information is how the economical situation influences the average consumption per customer. If the area can be considered as “low” this is around 200 W, “middle” 280 W, “middle-high” 400 W and “high” 620 W. The average will then be distributed between the different hours of the day. Figure 5.1 shows a typical daily profile, the mark '1' on the y-axis represents the mean power. Looking at the daily profile one can see that the power consumption will be very low during the day and raise to peaks during the evening hours and the morning. The main energy consumption occurs in the hours between 19:00 and 22:00 (approximately 40% of the daily energy consumption). A smaller peak occurs even at the morning hours, but due to its limitation in time it will influence the total energy consumption less. It is hard to connect any clear characteristic with the different groups even if in the “low” areas the difference between the evening peaks and the daily values tends to be larger than in the “high” areas.

When planning the expansion of the grid it is important to have a picture of the maximum load that can occur, since this gives an appropriate picture of the peak load that is needed. A first observation is that this load is normally up to 3.5 times the daily mean and occurs in the evening hours around 20 hours. The morning peak will be closer to 3 times the daily mean. Both peaks can be described by extreme value distributions. The evening peaks show a much better fit than the morning peaks that have less extreme values. The three different phases give rise to different parameters. When the parameters from the evening peaks have been tested on other transformers with similar economical conditions it is possible to see that the shape parameter k can give a fair and general description of these, while the scale parameter σ is much harder to generalize since it will also be dependent on the number of customers connected.

The results of this report are useful in the case a new area needs to be electrified. With the help of the calculated values, an estimate of the financial situation of the area and the number of customers a picture of the needed electrical energy can be made, taking into consideration both the mean and peak values.

Chapter 6

Future work

This is a very pristine area of research so there are still many things that can be looked into. Here comes a small list:

- This study has mainly looked into the domestic loads. It could also be interesting to identify and measure other loads that have a more industrial characteristic, mainly connected to the food processing industry. Examples of these kind of loads are: welding machines, maize mills, sugar cane processing, water pumps. These may not be very common but have a crucial role in developing the rural areas and connecting electrification with increased financial possibilities.
- More social loads such as schools and hospitals can also be of interest.
- The impact of the introduction of electricity to a rural setting. Does it create new financial possibilities? Does it enhance the agricultural businesses? Does it affect the level of education? One source of information could be the micro-finance agencies.
- The generation of electricity is today very centralized in Uganda. Is it possible to create small scale decentralized generation, that takes advantage of local resources. Mini-hydro and Photovoltaic are two solutions. Is it possible to use a combination of different sources? Can agricultural residues be used?

When it comes to the analysis of the collected data there are aspects that due to limitations of the collected that have not been looked into. These are:

- No prediction models have been computed. The main reason is the limited sample size.
- A more detailed discrimination into the different consumption groups could be made based on the different appliances or group of appliances.

References

[1] Bhagavan, M.R., ed. *Reforming the Power Sector in Africa*. AFREPREN & Zed Books Ltd, 1999.

[2] EDF. *Optimisation Study, Load forecast, final report*, 1998.

[3] ESMAP. *UGANDA: Rural Electrification Strategy Study*, 1999.

[4] Government of Uganda. *Power Sector: Restructuring and Privatisation. New Strategic Plan*, 1999.

[5] Kyokutamba, J. ed. *Power Sector Reform in Uganda- Proceedings of a National Policy Seminar*, occasional paper no. 8, AFREPREN, 2000.

[6] Ministry of Energy and Mineral Development. *Rural Electrification Strategy and Plan Covering the Period 2001 to 2010*, Kampala, Uganda, 2001.

[7] Murengezi, M., Assistant Commissioner, Ministry of Energy and Mineral Development. Personal communication, 2002.

[8] Blom,G. & Holmquist,B. *Statistikteori med tillämpningar*. Studentlitteratur, 1970

[9] Coles,C. *An Introduction to Statistical Modelling of Extreme Values*. Springer, 2001

[10] Hosking,J.R.M.& Wallis,J.R. *Parameter and Quantile Estimation for the Generalized Pareto Distribution*. Technometrics, 1987, vol.29, No. 3, pp 251 - 261.

[11] Lindgren,G. & Rychlik,I. *Tillförlitlighet och säkerhet - Statistiska metoder och tekniker*.Mathematical Statistics, Centre for Mathematical Sciences, Lund Institute of Technology, Lund University, 1997.

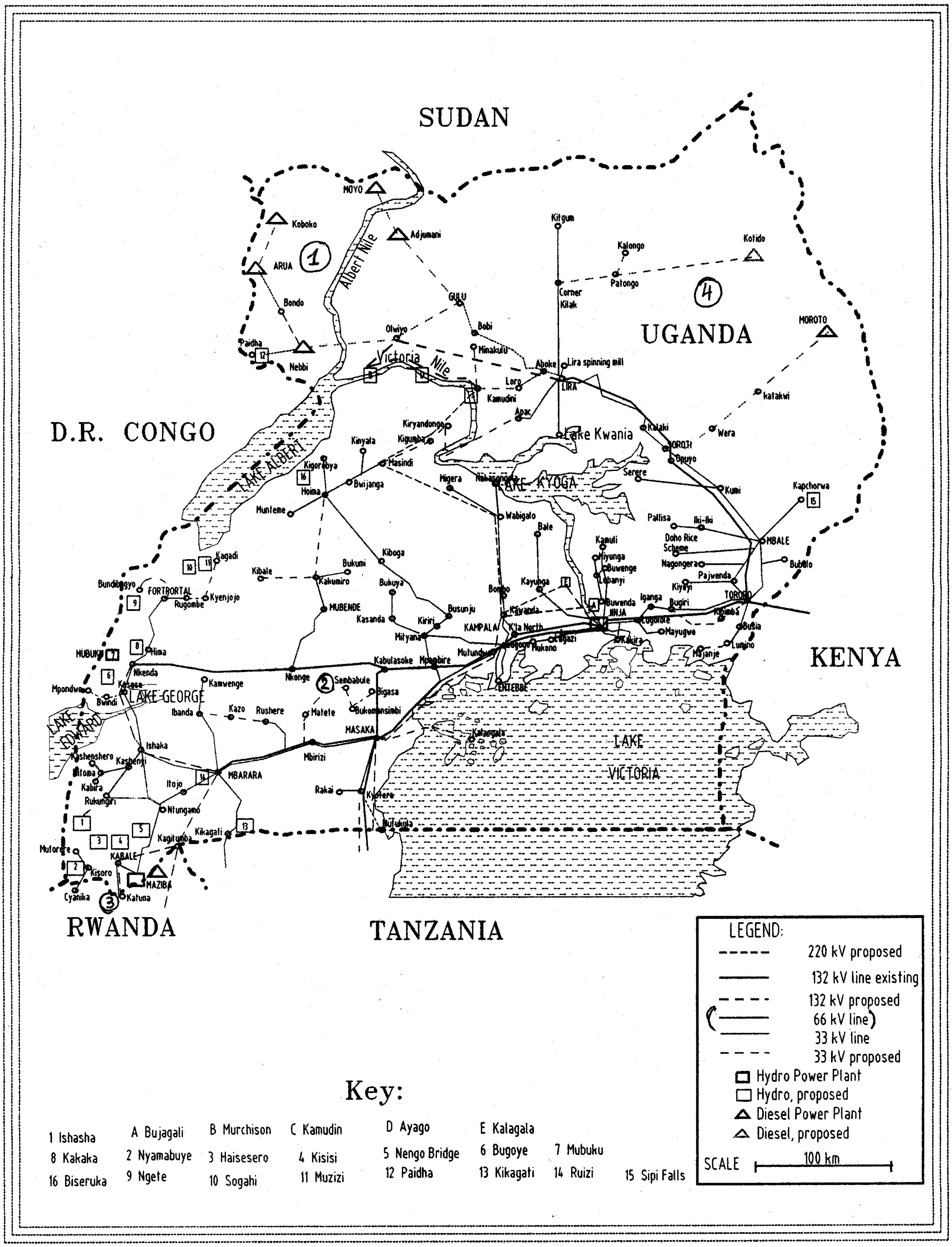
[12] The WAFO Group. *WAFO-A Matlab Toolbox for Analysis of Random Waves and Loads*. Mathematical Statistics, Centre for Mathematical Sciences, Lund Institute of Technology, Lund University, 2000.

Appendix A

Map of Uganda with electrical network

The numbers in the map show the priority areas for rural electrification, see section 2.3 Rural Electrification.
Najjeera village is in the proximity of Kampala (middle of the map, close to Lake Victoria).

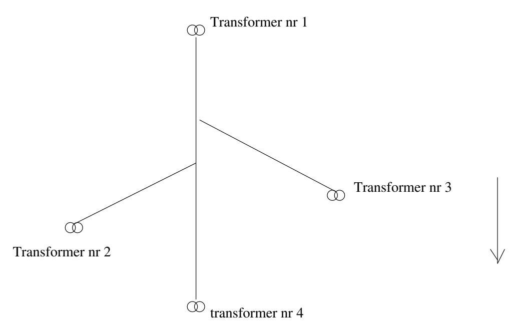
PRESENT AND FUTURE UEB NETWORK



Appendix B

Collected data

Najeera village



The arrow shows the direction towards Kampala.

Transformer 1

Measurements between 12:35, 250602 and 11:00, 260602

Phase	# of customers	# of interviews
Blue	9	6
Yellow	6	4
Red	5	5
Total	20	14

Broiler farm connected to all three phases.

Transformer 2

Measurements between 11:35, 090702 and 10:05,120702

Phase	# of customers	# of interviews
Blue	5	5
Yellow	8	7
Red	6	4
Total	19	16

Transformer 3

Measurements between 11:12, 150702 and 10:37, 180702

Phase	# of customers	# of interviews
Blue	13	7
Yellow	-	-
Red	1	1
Total	14	8

Transformer 4

Measurements between 11:05, 190702 and 10:30, 260702

Phase	# of customers	# of interviews
Blue	15	11
Yellow	9	7
Red	10	9
Total	36	27

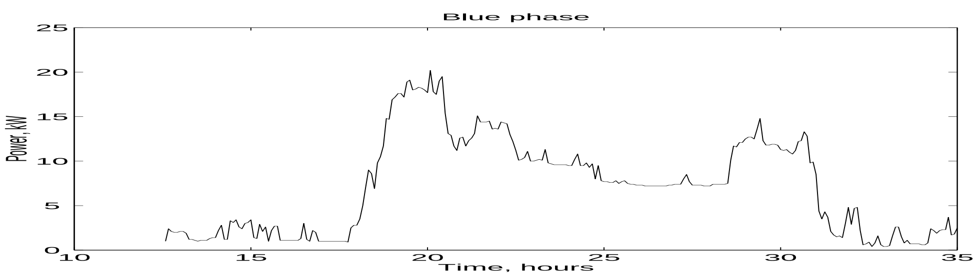
Coffee factory

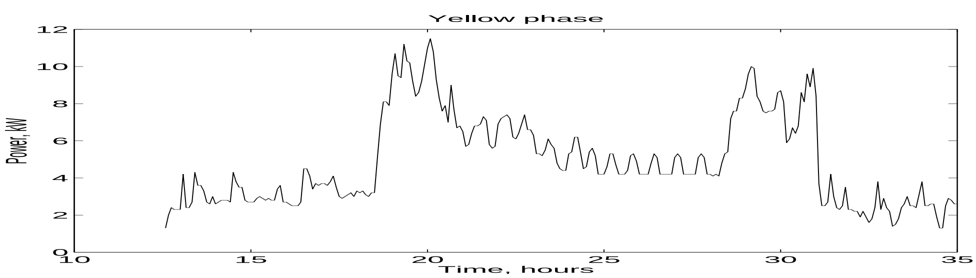
The factory is not situated in Najjeera village.
Measurements between 10:59, 070802 and 10:30, 090802

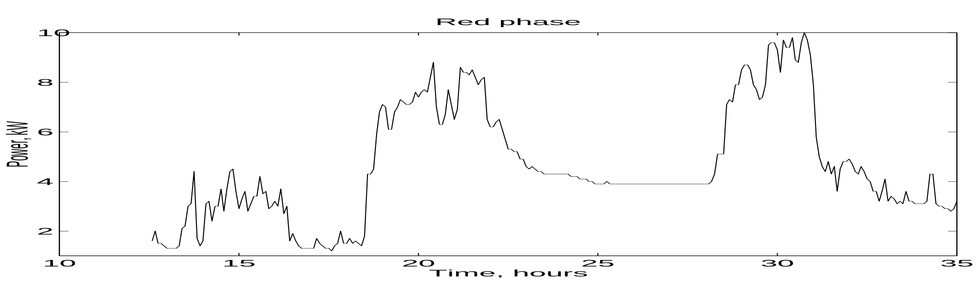
Appendix C

Graphs

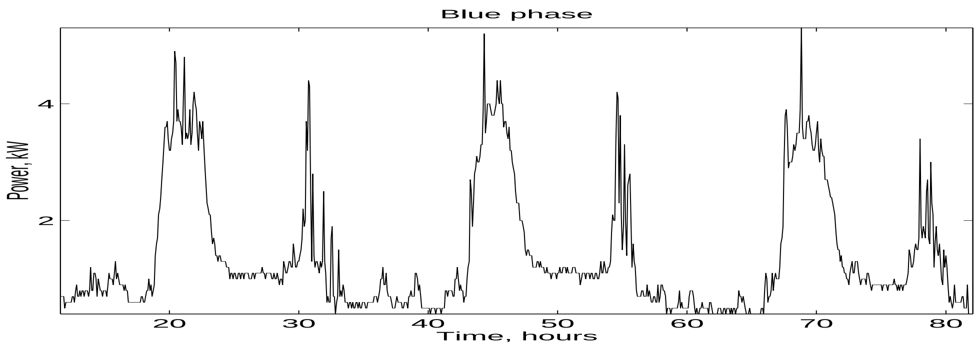
Transformer 1

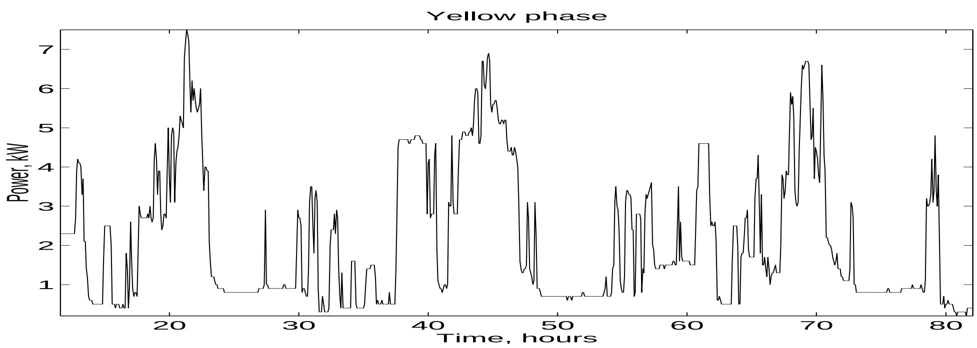


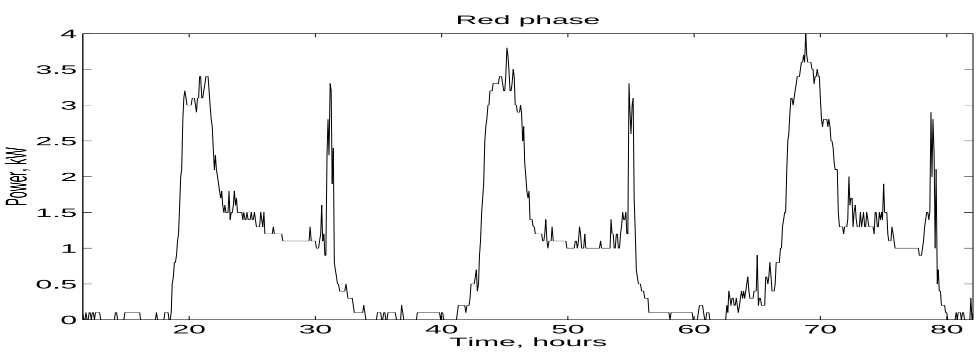




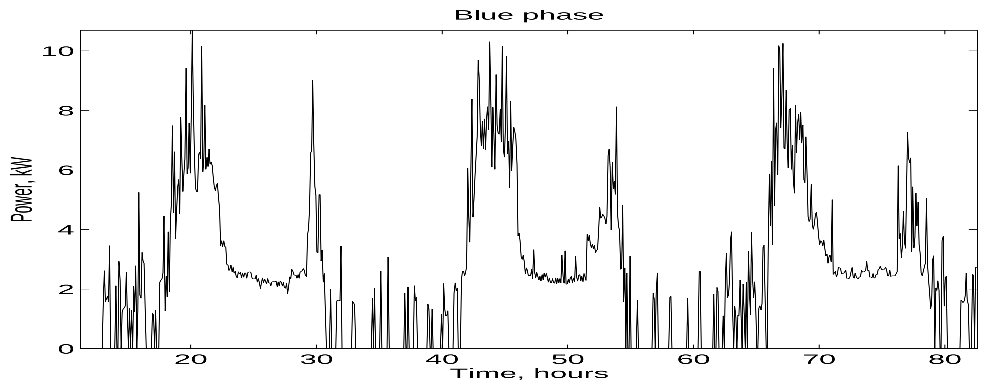
Transformer 2



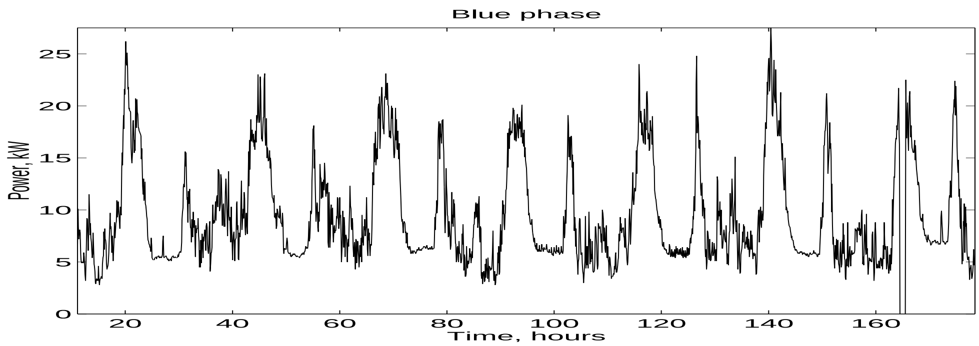


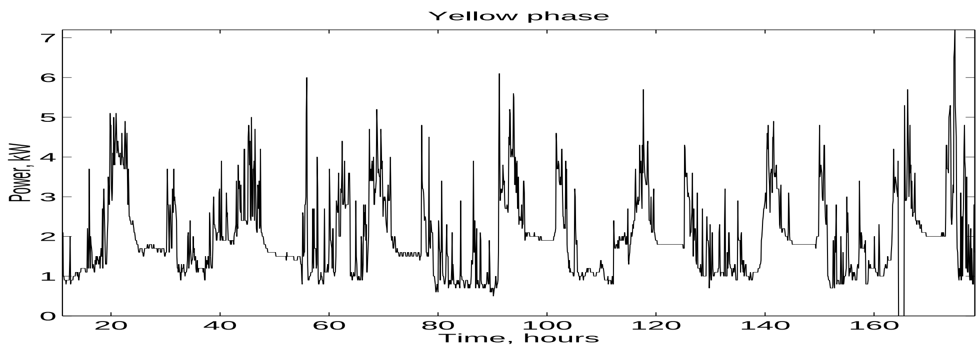


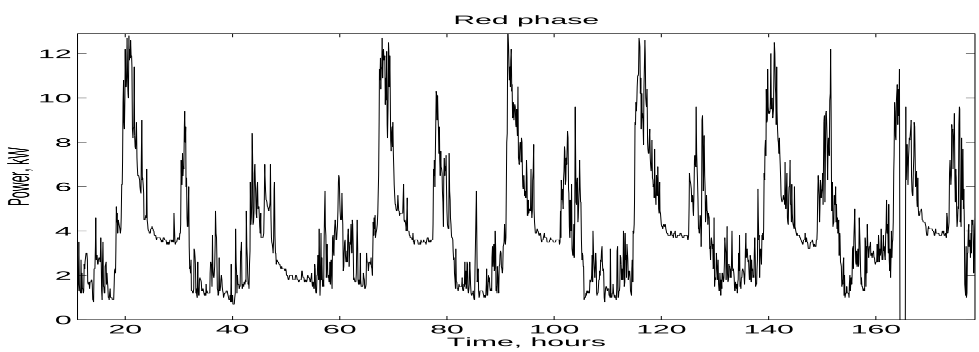
Transformer 3



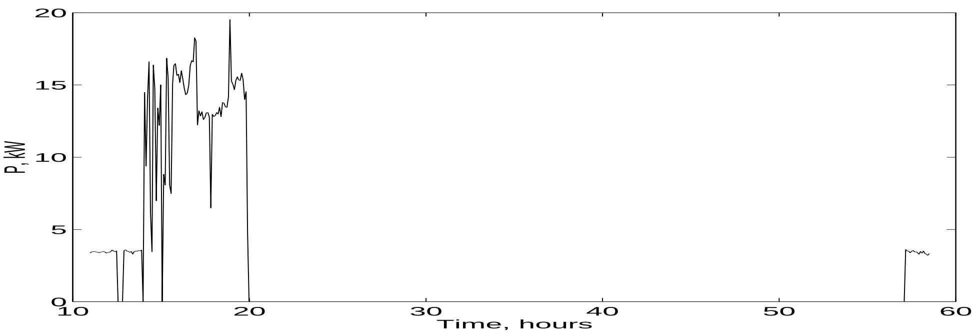
Transformer 4







Coffee factory



Appendix D

Energy table, kWh

Transformer & phase	Date	Night (00-06)	Morning (06-09)	Daytime (09-19)	Evening (19-24)	24h
2B	10/7	6.6083	4.8208	6.6667	14.7500	32.8458
2B	11/7	6.6667	5.2375	5.6458	14.2500	31.8000
2Y	10/7	5.4250	4.7750	23.1875	22.5875	55.9750
2Y	11/7	4.6708	6.2958	20.1000	19.0792	50.1458
2R	10/7	7.2917	3.1250	0.9875	12.5708	23.9750
2R	11/7	6.3292	2.9875	2.1875	13.6750	25.1792
3B	16/7	16.344	3.483	10.541	27.384	57.752
3B	17/7	19.419	2.610	14.046	24.390	60.465
4B	20/7	33.900	28.560	85.39	80.97	228.82
4B	21/7	39.71	32.60	86.34	84.84	243.50
4B	22/7	38.51	36.50	61.38	76.25	212.65
4B	23/7	37.11	32.62	64.54	75.99	210.27
4B	24/7	36.46	34.54	73.68	86.07	230.75
4B	25/7	36.45	35.68	58.97	62.05	193.16
4Y	20/7	10.254	6.179	16.8	14.55	47.783
4Y	21/7	9.171	5.088	18.275	15.296	47.829
4Y	22/7	10.525	4.646	10.067	16.5	41.738
4Y	23/7	12.308	6.788	13.354	14.2	46.65
4Y	24/7	11.917	5.375	12.792	14.508	44.592
4Y	25/7	11.108	6.2	12.788	12.183	42.279
4R	20/7	22.21	13.45	16.97	23.74	76.37
4R	21/7	12.26	5.77	30.43	39.83	88.28
4R	22/7	23.46	18.95	19.46	38.82	100.69
4R	23/7	24.17	16.27	19.26	40.70	100.40
4R	24/7	24.48	17.20	24.10	38.44	104.21
4R	25/7	24.08	19.86	26.95	28.75	99.64

Appendix E

Mean Power table, kW

Transformer & phase	Date	Night (00-06)	Morning (06-09)	Daytime (09-19)	Evening (19-24)	24h
2B	10/7	1.1194	1.6333	0.6725	2.9700	1.383
2B	11/7	1.1292	1.7750	0.5717	2.8700	1.3403
2Y	10/7	0.9306	1.6694	2.3500	4.5683	2.3722
2Y	11/7	0.7917	2.1528	2.0292	3.8367	2.1118
2R	10/7	1.2333	1.0611	0.1017	2.5317	1.0108
2R	11/7	1.0708	1.0111	0.2233	2.7567	1.0615
3B	16/7	2.7763	1.2273	1.0981	5.5586	2.2631
3B	17/7	3.2842	0.927	1.4433	4.9706	2.5738
4B	20/7	5.754	9.725	8.619	16.402	9.663
4B	21/7	6.726	11.125	8.754	17.165	10.296
4B	22/7	6.547	12.464	6.215	15.418	0.8997
4B	23/7	6.29	11.078	6.524	15.368	8.877
4B	24/7	6.199	11.711	7.435	17.365	9.729
4B	25/7	6.192	12.119	5.939	12.567	8.156
4Y	20/7	1.7361	2.1	1.6942	2.955	2.0181
4Y	21/7	1.5514	1.7306	1.8433	3.0833	2.0146
4Y	22/7	1.7792	1.5833	1.0142	3.3233	1.7576
4Y	23/7	2.0903	2.3278	1.3458	2.8667	1.9715
4Y	24/7	2.0208	1.8472	1.2883	2.9283	1.8830
4Y	25/7	1.8903	2.1556	1.2942	2.4683	1.7955
4R	20/7	3.775	4.5778	1.715	4.7933	3.2292
4R	21/7	2.0764	1.975	3.0658	8.0533	3.7212
4R	22/7	4.0014	6.5111	1.9758	7.835	4.2698
4R	23/7	4.1264	5.6028	1.9658	8.2217	4.2639
4R	24/7	4.1431	5.8611	2.4392	7.7683	4.4031
4R	25/7	4.1042	6.7556	2.7283	5.8167	4.219

Appendix F

Survey form for Households

1. Form no:
2. Date:
3. Phase:
4. Number of persons in the household:

Age	# of persons
0-6	
7-13	
14-19	
20+	

5. Size of household (# rooms):
6. Total household income:
7. Electricity costs:
8. When did you get connected to the grid:
9. Electrical appliances:

Type	#	Usage time (h, min)	When during the day are they used?
Light bulbs			
Radio			
TV B/W			
TV Color			
Iron			
Fan			
Fridge			
Other			

10. Do you believe there is any difference between weekdays and weekend in your electricity consumption?
11. How often do you get blackouts?
12. How do they affect your everyday planning?

13. Are you satisfied with the electricity distribution?
14. Do you have any plans of buying new equipment?
15. How would you change your consumption if the price per kWh should increase?
16. Do you use any other energy sources (firewood, paraffin, batteries)?
17. If yes, for what purpose?
    - Cooking
    - Entertainment(radio, TV)
    - Light
    - Other
18. What's the monthly cost for these other sources?

Appendix G

Appliances per transformer

Transformer 1

Appliance	Blue	Phase	Yellow	Phase	Red	Phase
	#	Total usage time	#	Total usage time	#	Total usage time
Bulbs in total	54		16		40	
Internal (used)	28	48h	11	45h	22	54h
Security	6	66h	5	60h	18	301h
Radio	5(+1)	20h	4	21h	3	19h
TV B/W	2	5h	2	9h	2	10h
TV Color	1	4h	2	6h		
Iron	2	2,5h	3	3h/w	3	2h/w
Fan	3	rarely	1	rarely	1	rarely
Fridge	3	72h	2	28h	4	31h
Cooker	2				1	15 min
Kettle						
Water heater	1		1			
Video	3		3			
Computer	1				1	3-4h

Transformer 2

Appliance	Blue	Phase	Yellow	Phase	Red	Phase
	#	Total usage time	#	Total usage time	#	Total usage time
Bulbs in total	37		56		18	
Internal (used)	34	50h	34	81h	16	41h
Security	3	26,5h	8+1fl	92h+8h	1	11h
Radio	7	23h	3	16h	4	14h
TV B/W	2	3h	3	3,5h	2	2h
TV Color	1	3h	2	4h	2	5h
Iron	5	4,5h/w	5(3 used)	30min	1	1h/w
Fan	1	not used	2	8h		
Fridge	2	18h	2	30h		
Cooker			1	Not used		
Kettle						
Water heater						
Video						
Computer						

Transformer 3

Appliance	Blue	Phase Yellow	Phase Red	Phase		
	#	Total usage time	#	Total usage time	#	Total usage time
Bulbs in total	48				6	
Internal (used)	34	107h			4	24h
Security	3	33h				
Radio	7	42h				
TV B/W	2	6h			1	4h
TV Color	5	11h				
Iron	5	12h/w				
Fan	3	rarely				
Fridge	5	82h				
Cooker	1	not used				
Kettle	1	30 min				
Water heater	1	1h				
Video	1					
Computer						

Transformer 4

Appliance	Blue Phase		Yellow Phase		Red Phase	
	#	Total usage time	#	Total usage time	#	Total usage time
Bulbs in total	95		32		59	
Internal (used)	50	295h	19	74h	34	90h
Security	15	165h	10	149h	11	125h
Radio	20	70h	5(4 used)	16h	5	7h
TV B/W	2	4h			2	6h
TV Color	6	17h	4(3 used)	9h	4	18h
Iron	7(6 used)	15h/w	4	15h	6	7h
Fan	5	rarely	1	rarely	3	rarely
Fridge	8(7 used)	133h	3	72h	7(5 used)	90h
Cooker	4(3 used)	3h			3	2h
Kettle	2		1		2	
Water heater						
Video	2					
Computer					1	
Dryer, shaving machine	2					

Appendix H

List of abbreviations

B	Blue phase
R	Red phase
Y	Yellow phase
AFREPREN	African Energy Policy Research Network
EDF	Electricitè de France
ERT	Energy for Rural Transformation
ESMAP	World Bank Energy Sector Management Assistance Programme
GEF	Global Environmental Facility
HDI	Human Development Index
kWh	kilowatt hour
MEMD	Ministry of Energy and Mineral Developments
MW	Megawatt
NGO	Non Governmental Organization
rms	root mean square
PV	Photovoltaic
Sida	Swedish International Development Cooperation Authority
TOE	Tons of oil equivalent
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UEGCL	Uganda Electricity Generation Company Limited
USD	United States Dollar
USh	Uganda Shilling, 1800USh $\approx$ 1 USD
CDF	Cumulative Distribution Function
GPD	Generalized Pareto Distribution
ML	Maximum Likelihood
MOM	Method of Moments
PKD	Pickand's estimator
POT	Peak Over Threshold
PWM	Probability-Weighted Moments
QQ	Quantile to Quantile
std	standard deviation

Appendix I

From the survey

Explanations to the table

4-phase: B is Blue phase, Y is Yellow phase, and R is Red phase

8-household size: r=rooms and h=houses

24-weekends vs weekdays: I have written when most electricity is used. If an appliances is written then this is the cause of the increased load

30-price sensitivity: yes means that they could decrease their usage of electricity. The appliance is the one that they would at first decrease the usage of.

1	**Transformer 1**				
2	Form no	2	5	6	7
3	Date	230502	230502	270502	270502
4	Phase	B	B	B	B
5	Total # of persons:	7	9	shop	5
6	# of children		1		4
7					
8	Household size	5r	6r	3 shops	2 h, 8 r
9	Income (USh)		dependant		
10	Electricity costs (USh)		5000	no meter	
11	Connection to grid	march 02	70s	just connected	90s
12	Appliances:#:usage times				
13	Bulbs	20			
14	Internal		3:19-21	3:19-22	13:19-22
15	Security			1	1:19-06
16	Radio	2:all day	1:not working		1;19-20(21)
17	TV B/W				1:19-21
18	TV Colour	1:19-23			
19	Iron	1:30 min			1:2h, sat
20	Fan	1.rarely	1:rarely		
21	Fridge	2:24h			24h
22	Other:	2 cookers			lighttube:12h
23					
24	Weekend vs weekdays	sun	equal	equal	
25	Blackouts	2/w	less now		2/w
26	Consequenses	diesel gen			
27	Satisfaction	yes	yes		
28	New appliances			fridge	
29					
30	Price sensitivity				
31	Other energy-costs (USh)				
32	Cooking:				
33	Charcoal	yes		yes	yes
34	Firewood		20 000		
35	Parafin				
36	Enterainment			batteries	batteries
37	Light		parafin:3000	kerosene	kerosene
38	Other apliances				
39					
40					
41	Comments	very well-off talked with worker		before power 5l/w of kerosene	

1							
2	1	2*	3		1	2*	3
3	250602	250602	250602		270502	270502	270502
4	B	B	B		Y	Y-toff	Y toff
5	3	1	2		2	8	13
6	2		1			2	3
7							
8	4 r	5r	2r		3 r	5 r	2h: 4r
9	150 000		~300 000			~100 000	
10	5000		5000		20 000	max 30 000	
11	96		2000			~86	~77
12							
13							
14	2:19-22	6:19-01	1:19-22		3:19-22:30	6:19-22:30	10:19-23
15		4:19-06			lighttube: 12h		
16	19-22		1:07-09; 13		1: 4h	1:5h	1:often
17			1:19-22		19-24		
18						1:19-22	19-22
19					1h on sun	blew up	weekend
20			1:rarely				1:rarely
21					1: 24h		1:4h
22					video	video	video
23							
24	equal		almost equal		equal	w-ends:video	equal
25	1/m		4/m		mon-sat	1/w 1 h	max 2/w
26	no		no		yes	yes-TV prog	no
27	pb billing		service fee too high		yes	yes	yes
28	no		fridge, iron		not sure	no	not certain
29			coil, cooker				
30	no		no		bulbs	lights off at 22	no
31	6000						
32						15 000	5000
33	yes		7000		15000	yes	
34	yes		5000				free
35							
36			batteries:2000		batteries		batteries
37	kerosene		kerosene:500		kerosene:5000	kerosene	kersosene
38							
39							
40							
41	small shop	no power owner in US			students	disconnected?	

1							
2	4	5		1	4	6	1
3	270502	270502		230502	230502	230502	240502
4	Y	Y toff		R	R	R	R
5	5	5		8	14	4	small shop
6	4	2		4	10		
7							
8	small	4 r		4r	11r	6r	2r
9	max 40 000			30000/day	10 000		
10	flat rate	no meter		60 000	10-15 000		min 10 000
11	just connected			2000	1975	90ties	march 02
12							
13	2: 12h						
14		2:19-23		3:19-23	11:19-21	3:19-24	2:19-21
15		2:12h		6:24h;3:10h	5:19-06	2:12h	1:19-07
16		1:19-23		1:6-22	1:1h		
17		1:19-23		1:14-23		1:2/w	
18							
19		sundays			1	1:1/w	
20				1:occ, w-ends			
21						1:daytime	1:3h
22		waterheater		lap-top:3-4h		cooker:7-15'	
23							
24				w-ends:Tv	equal	w-ends:TV	equal
25				1/w		1/w 18-20	1/w
26				chicken breeding	dinner	TV	no
27				yes	yes	yes	yes
28	radio			repare fridge	TV, coils	washing machine	computer
29				cooker			fan
30				yes, sec lights	bulbs	iron, bulbs	sec lights
31				45 000			
32	20 000						5000
33	yes	yes		yes		8000	
34	yes				yes	3000	
35							
36				batteries		batteries	batteries
37	candle:6000;	kerosene		kerosene	candles	candle	kerosene
38	lamp:3000						
39							
40							
41		children answered		Smal scale chicken breeding			cold drinks improve business

1	
2	2
3	240502
4	R
5	1
6	
7	
8	1 bar+shop
9	
10	20 000
11	
12	
13	
14	1:19-24; 2:19-21
15	1:19-07
16	all day
17	
18	
19	1
20	
21	2:06-14
22	
23	
24	equal
25	1/w
26	no
27	yes
28	TV
29	
30	energy saver
31	
32	3000
33	
34	
35	
36	
37	kerosene
38	
39	
40	
41	

1	**Transformer 2**					
2	Form no	4	8	10	4	6
3	Date	90702	90702	90702	120702	120702
4	Phase	B	B	B	B	B
5	Total # of persons:	13	7	7	14(9t)	2
6	# of children	7	3	3	7(4t)	
7						
8	Household size	5+1r	5r	7r	4r+5t	2r
9	Income (USh)	~120 000	250 000	250 000	60 000	50 000
10	Electricity costs (USh)	15 000	40 000	25 000	20 000	5 000
11	Connection to grid	90	97		91	2000
12	Appliances:#:usage times					
13	Bulbs	9:19-22	6:19-22	7:19-22		
14	Internal				10:19:30-22	2:19-23
15	Security				1:19:30-06	2:22-06
16	Radio	3:7-22	1:20-22	1:19-21	1:20-21	1:12-15
17	TV B/W	1:19-21	not functioning		1: 2/w	
18	TV Colour			1:19-22		
19	Iron	1:2h wends	1h wends	5min/day	30min/w	1h wends
20	Fan			1:no use		
21	Fridge		wends	1.all day		
22	Other:					
23						
24	Weekend vs weekdays	w-ends:radios	w-ends:fridge	equal	equal	equal
25	Blackouts	no	2/month	no	no	2/month
26	Consequenses		no			no
27	Satisfaction	yes	yes		yes	yes
28	New appliances	Fan	cooker		no	TV
29						
30	Price sensitivity		yes	yes	yes:bulbs	no
31	Other energy-costs (USh)					
32	Cooking:					
33	Charcoal	8000	8000	16000	rarely	7000
34	Firewood	free	8000		free	
35	Parafin	5000		10 000		3000
36	Enterainment				batteries:1000	
37	Light				parafin:1500	
38	Other apliances					
39						
40						
41	Comments					

1							
2	2*	6	7	9	1	3	5
3	90702	90702	90702	90702	120702	120702	120702
4	Y	Y	Y	Y	Y	Y	Y
5	5	5	5	6	8(5t)	3	7
6	1	3	2	3	3(2t)		4
7							
8	5r	6+3r	5r	6r	4r+11tr	6r	4r
9	30 000		300 000		300 000		300 000
10	15 000		not yet payed	7-10 000	20 000	20 000	20 000
11	96		recently	apr-02	95	98	01-jul
12							
13	4:19-07		2:19-23	8:19-22	23		
14		3:19-21,6:20-21			6:19-22	8:19-21	4:19-22
15		2:19-06			2:19-06	1:22-06(fl)	
16			almost all day	1:20-22			1:11-13;20-22
17		1:3/w 20-21		1:20-22	1:20-21		
18			morn.&even.	1			
19		1h sundays	15 min daily	1:not used	5min/day	1:not used	
20				1:at night		1:not used	
21				1: off and on		1	
22						cooker:	
23						not used	
24	equal	w-ends	equal	w-ends:2 TV	equal	equal	equal
25		2/2months		not anymore	no	no	no
26		flot iron					
27	no	yes	yes, but ?	yes	yes	yes	yes
28	no	Fridge	Fridge	no	Fridge	no	fridge,fan
29							cooker
30	yes	no		TV, fridge	no	yes	yes
31							
32							
33		8000	8000	16000		8000	10000
34	free				free	free	
35		2000					
36		batteries:1400			batteries.1000		batteries:1500
37	kersosene:5000		torch	5000			
38			gas:15000				
39							
40							
41	2m dis bc lagging feeder						

1				
2	1	3	5	2
3	90702	90702	90702	120702
4	R	R	R	R
5	8	5	4	5
6	3	3	2	3
7				
8	6r	7r	2r	5r
9	dependent	250 000		
10	10 000	10 000		
11	75	93	this year	71
12				
13	4:19-22	6:19-21		5
14			3:19-22	4:19-22
15			1:19-06	
16	1:7-9,12-14,19-22	1:7-8,11-16	1:12-15	1:rarely
17	1:rarely		1:20-22	
18		1:19-21		1:19-22
19		1:1h w-end		10min/w
20				
21				
22				
23				
24	equal	equal	equal	equal
25	no	no	20days/6m	no
26			no	
27	yes	yes	yes	yes
28	no		Fridge,fan	no
29				
30	2 bulbs	yes	yes	no
31				
32	40 000			
33	yes	16000	8000	free
34	yes	free		
35			5000	500
36				batt:500
37	kerosene			
38	charcoal iron		charcoal iron	
39				
40				
41				

1	**Transformer 3**					
2	Form no	1	2	3	4	5
3	Date	150702	150702	150702	150702	150702
4	Phase	B	B	B	B	B
5	Total # of persons:	6	4	5	7	9
6	# of children	2	2	3	5	6
7						
8	Household size	6r+g	5r	5r	5r	6r
9	Income (USh)		300 000	300 000	250 000	400 000
10	Electricity costs (USh)		20 000	20 000	10 000	20 000
11	Connection to grid		02-apr	2001	78	95
12	Appliances:#:usage times					
13	Bulbs		5	8		10
14	Internal	6:19-22	3:19-21	5:19-21	4:19-22	6:19-22
15	Security					
16	Radio	1:7-9	all day	all day	1:20-22	1.sunday
17	TV B/W	1:18-22				1:19-21
18	TV Colour		1.20-21	1:19-21	1:19-22	
19	Iron	1:3h	1h sund	1h wends		1:3h/week
20	Fan	1:not used		1.not used		1:rarely
21	Fridge	1:all time		1:all time	9h* 3/w	1:18-22
22	Other:	cooker(not func)				
23		video				
24	Weekend vs weekdays	w-days	sun:iron	w-end:iron	wends	w-ends:radio
25	Blackouts	no	no	no	not now	no
26	Consequenses					
27	Satisfaction	yes	yes	yes	yes	yes
28	New appliances	no	no	no	no	no
29						
30	Price sensitivity	yes; less hours	no	no	yes	yes
31	Other energy-costs (USh)					
32	Cooking:					
33	Charcoal	16000	8000	8000		5000
34	Firewood				free	10000
35	Parafin	2500	5000	10000		2000
36	Enterainment		batteries:250	batteries:500		
37	Light					
38	Other apliances					
39						
40						
41	Comments					

1				
2	7	8		6
3	150702	150702		150702
4	B	B		R
5	10	5		12
6	3	3		11
7				
8	8r	4r		6r
9	400 000			100 000
10		10 000		20 000
11	01-mar	99		86
12				
13				8
14	8:19-23	7:19-22		6:19-23
15	3:19-06			
16	all day	1:not used		
17				1:19-23
18	1:19-23	1.14-23*2/w		
19	1h/day morning			
20				
21	1 all time			
22	cettle morn;eve;			
23	waterheater:18-19			
24	equal	equal		wends
25	no	no		no
26				
27	now yes	yes		yes
28		fridge		radio
29				
30	iron; cettle	bulbs		bulbs
31				
32				
33	32000			8000
34		free		free
35				10000
36				batteries:1000
37				
38				charcoal iron
39				
40				
41				

1	**Transformer 4**				
2	Form no	1	4	5	6
3	Date	190702	190702	190702	190702
4	Phase	B	B	B	B
5	Total # of persons:	2+5t	6	8+12t	6
6	# of children	1	0	6	2
7					
8	Household size	4r	8r	6r+12tr	6r
9	Income (USh)		30 000	400 000	140 000
10	Electricity costs (USh)	30 000		80 000	10 000
11	Connection to grid	72	2002	78	87
12	Appliances:#:usage times				
13	Bulbs	5+5(t)	6+2fl.	11+14(t)	9
14	Internal	19-22	19-24	20:19-22	2:19-22
15	Security		2;1:13-24	5:19-06	
16	Radio	1:19-21		13;4:07-22	1:19-22
17	TV B/W			1:19-22	
18	TV Colour			1:19-22	
19	Iron			3: 2h sun	
20	Fan			1: rarely	
21	Fridge		1:24h	2;1:06-19	not func
22	Other:		dryer;	dryer;	
23			shaving machine	shaving machine	
24	Weekend vs weekdays	sun:radio	saturday	wends more	equal
25	Blackouts	no	no	no	no
26	Consequenses				
27	Satisfaction	yes	yes	yes	yes
28	New appliances	no	TV	no	no
29					
30	Price sensitivity	yes	bulbs;energysavers	yes	energysavers
31	Other energy-costs (USh)				
32	Cooking:				
33	Charcoal	4000	8000	16 000	8000
34	Firewood		free	15 000	free
35	Parafin		5000	1 000	1000
36	Enterainment	batteries:250	batteries 500		batteries
37	Light		parafin	parafin	parafin
38	Other apliances				
39					
40					
41	Comments		1 bar & 1 saloon	kiosk+saloon	

1					
2	8	3	4	10	11
3	190702	260702	260702	300702	300702
4	B	B	B	B	B
5	4	2	16	7	7
6	1	1	6	5	4
7					
8	6r	5r	6r+6bq	4r	3r
9		300 000	400 000	100 000	400 000
10	10 000	25 000	20 000		30 000
11	62	2001	75		
12					
13	9	12	17	8	
14	3:19-21	4:19-23	15:19-24	2:19-21	4:19-22
15		1:19-06		2:19-6:30	4:19-06
16		1:8h	2;1:7-9;19-21	1:7-7:30	rarely
17			1:19-20		
18		1:19:15-22:15	1:19-20	18-22	19-22
19	not used	1/w 1h	1h sun	1h*3/w	15min daily
20		1:not used		rarely	rarely
21		24h		24h	24h
22		cooker: 2h/day		kettle:10min*2	video:rarely;
23		video:rarely		cooker	cooker:rarely; kettle:1h
24	equal	sunday	wends; iron,TV,radio	TV wends	wends
25	no	no	no	not many	no
26					
27	yes	yes	overbiling	yes	yes
28	no	no	no	no	juice machine
29					
30	bulbs	cooker, fridge specific hs	no	kettle,bulbs	yes
31					
32					
33	8000	8000	8000	10 000	16 000
34	15 000		free		
35	3000	5000		gas:30 000	
36	batteries		batteries:2500		
37		batteries:500		batteries:500	batt:750
38					
39					
40					
41					

1							
2	12		2	7	1	6	7
3	300702		190702	190702	260702	300702	300702
4	B		Y	Y	Y	Y	Y
5	6		7		6	6	10
6	4		4		3	4	6
7							
8	6r		3r	school	6r	5r	6r
9	400 000		100 000	600 pupils		400 000	
10			40 000		10 000	30 000	50 000
11			96		~70	2001	2001
12							
13						5+1lysrör	
14	14:19-23		5:19-22	24	4:19-22	2:19-22	4:19-24
15	2:19-06		4:24h	13		2:19-07	3:24-06
16			1.12h			not used	1:23-24
17							
18	19-22					not used	1:20-24
19	1h daily					1:1,5h	1:3h sat
20	rarely			special:			
21	24h			computer			24h
22	cooker:not used;			photocopy		cooker:not funct	
23	kettle:rarely			printer			
24	sunday		equal		equal	Saturday	w-ends
25	no		no		no	no	no
26							
27	yes		yes		yes	yes	yes
28			TV,radio		no	fridge, new cooker	cooker
29						fan	
30	less TV, fridge		yes		bulbs	no	yes
31							
32							
33	32 000		8000		8000	8000	16000
34			free		10 000		
35	2500				5000	5000	
36			batteries:1500				
37			parafin:5000		batt:250		
38							
39							
40							
41			poulty rooms 24h lights				

1							
2	8	9		3	2	5	6
3	300702	300702		190702	260702	260702	260702
4	Y	Y		R	R	R	R
5	6	4		10	12	8	8
6	4			4	3	6	6
7							
8	3r	5r		5r	7r+quarters	8r	2r
9	400 000	800 000		400 000	200 000	400 000	300 000
10	20 000	50 000		100 000	20 000	20 000	5 000
11				2001	~80	2001	87
12							
13	1 energysaving			21		9	
14	4:19-22	3:19-22		2:19-22	3:19,30-24	4:19-22	3:19-22
15		1:19-06		6:19-06	1:19:30-06	1:19-06	
16	rarely	1.19-22		1:20-24 sun		1:not used	
17							
18	1.19-21	1:19-22		1:19-22		1:20-22	
19	1h daily	1,5h*3/w		1:not used	1:19:30-24	2/w 1h	
20	rarely			1:not used	1:not used		
21	24h	24h		1:8-14	1:not working	1:not working	
22				video		coil:2h/day	
23							
24	equal	wends		equal	wends:TV on earlier	wends	equal
25	no	no		no	no	2/w	no
26						delays work	
27	yes	yes		yes	improved	no cut off	yes
28	cooker	no		no	no		radio,TV,
29							fridge,iron
30	yes	bulbs		yes	less TV	bulbs	bulbs
31							
32							
33	8000	28 000		16 000	8000	8000	8000
34					free		
35	8000				not much	30 000	5000
36					batteries	batt:2500	
37				batt:250		parafin:5000	batt:500
38							
39							
40							
41		food for dogs					

1					
2	1	2	3	4	5
3	300702	300702	300702	300702	300702
4	R	R	R	R	R
5	6	7	4	5	5
6	4	4	1	2	2
7					
8	6r	9r	4r	5r	3r
9	150 000				500 000
10	10 000				50 000
11	98				2000
12					
13	1 flourescent	17	2 lysrör	7+1 flourescent	18
14	7:19-21	2:19-22	6:19-22	3.19-22	4:19-22
15			2:19--07	1:07-21	
16		1:19-22	1:19-22		rarely
17		1:19-22	1:19-22		
18					1:19-22
19	sun 20 min	1:daily 30min	1/w 1h sun		30min/eve
20			rarely		
21		24h	24h	3days/w	24h
22		kettle	kettle,computer	kettle:not funct	cooker:10min
23		2 platecooker:morn			
24	iron sun	wends	wends iron	equal	equal
25	no	2/w 15 min	no	no	not anymore
26		can´t iron clothes			
27	yes	yes	yes	yes	yes
28	fridge	no	doesn't know	doesn't know	no
29					
30	yes	yes	no	yes	no cooker
31					
32					
33	8000	8000	16000	32000	12000
34					
35					
36	batt:500	batteries:500	batt:1000		
37	parafin:3000	parafin:1000	parafin:1000		batt:1000;parafin:3000
38					
39					
40					
41					