ZAMBIA: ENERGY IN THE RURAL ECONOMY

A pilot study of possibilities of improving the energy infrastructure of farming households in Magoye area

Jan van den Akker

M.Sc research
J.H.A. van den Akker
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Supervision:
Zambia: dr.ir. A.M.C. Lemmens
Netherlands: prof.dr. C.J.L. Bertholet
drs. H.Gaillard
PREFACE

This report represents the final stage of my study in the M.Sc. course Technical Development Science. The course falls under the responsibility of the Faculty of Philosophy and Social Sciences of the Eindhoven University of Technology (in The Netherlands). The report is the result of a ten-month research, carried out in the Technology Development and Advisory Unit (TDAU) of the University of Zambia, Lusaka, Zambia.

A M.Sc. research is not a one man's piece of work. Many people have contributed with information, ideas and efforts towards completion. To these people I wish to express my thanks.

First I would like to thank TDAU for making this research possible and providing the necessary facilities, and the TDAU (staff) members for their co-operation. With appreciation for the others I mention my supervisor in Zambia, Lex Lemmens, for his advice and criticism; Steve Ng'ona, who introduced me in Magoye area; and Jonah Banda, who took me to Luimba area.

Further I thank Sylvester Hibajene (Department of Energy) for providing information on the energy sector; Jack and Irene Kasanda (Magoye Block) for assisting me during my fieldwork, for the fruitful discussions; all the respondents of the interviews in Magoye area; Fred Bwembya (BP Zambia Ltd) for the information on solar energy; Elias Chulu (A.W.Tarry Ltd) for the information on waterpumping.

I thank my supervisor at the University, Chris Bertholet, for persistantly going through my text.

I thank for their financial assistance the "Werkgroep Studiereizen Ontwikkelingslanden", the Eindhoven University of Technology and, last but certainly not least, my parents.

A research in a foreign country can only be successful, if the private side of your stay in that country is so too. A special place is dedicated to Ivy Makoye, for lending my jacket in Magoye; Peter Kumwenda, Brenda Mwanza and Irene Chibiya, for accepting me as a friend; Ton Colijn, who provided accommodation and guided me through Lusaka during my first days; Cees Lafeber, for the technical assistance; the people of Zambia, to whom I would like to say: "Zikomo. Tsalani bwino!"
SUMMARY

Scope of the research

The Technology Development and Advisory Unit (TDAU) of the University of Zambia initially requested for a study on possibilities to improve energy supply in rural areas. The final problem definition was formulated as:
"How and by what means can farming households in Zambian rural areas reach higher production levels and a higher standard of living through improvements in the energy infrastructure?"

Low-cost new and renewable energy technologies (NRETs) are gaining more and more attention in the world since the seventies. As Zambia is a landlocked oil-importing country it is a prime candidate for introduction of such technologies.

Main consumer group of fuel in Zambia is formed by households. Most important fuel in Zambia is wood, consumed in the form of firewood (rural households) and charcoal (urban households). Coal and hydropower are indigenously available resources. Other important fuels are petroleum products, which are produced from imported crude oil.

Charcoal, the main fuel for urban households, is traditionally produced from wood; an energy-inefficient process. Due to charcoal production, located woodfuel shortages occur in the densely populated line-of-rail provinces (Southern, Lusaka, Central, Copperbelt). These shortages will become more widespread in the decades to come.

Diesel and gasoline engines form a well-established technology to provide stationary and motive power. However, with the present economic crisis in Zambia prolonging, and an acute foreign exchange deficiency, conservation of petroleum products consumption will be the trend for the coming decades. The large-scale hydropower infrastructure is not able to deal with the interests of the vulnerable rural poor.

Therefore, new and renewable energy technologies (NRETs) are means to improve the energy infrastructure, especially in the Zambian rural areas. NRETs comprise:

a) new technologies that convert existing primary energy sources (as wood) into useful forms of energy, but in a more efficient than existing technologies. Examples are improved wood stoves, improved charcoal production methods, wood gasifiers.

b) technologies that convert new/renewable energy sources. Renewable resources in Zambia are (besides wood and other biomass) solar, wind, hydro, and geothermal energy.

But what about costs? Is it so, that new and renewable energy sources are cost competitive already vis-a-vis conventional energy sources, such as grid electricity or diesel power. Can NRETs be afforded by rural households?

Methodology

Methodologically this M.Sc. research can be divided into two parts:
A) A study of literature available in Zambia (a description of
potentials and constraints in the development of rural Zambia, constraints in the energy sector, application possibilities of NRETs in rural Zambia).

B) A case study of Magoye area in Southern Province. Key-informants in the area (w.u. small-scale farmers) were interviewed to get an impression of the complex life of Magoye area and the 'constraints' that hamper further development.

c) Development of a format for evaluation of NRETs and conventional energy conversion technologies.

Two issues are central:
- the necessity to consider 'aims' of the target groups of the case study: traditional and emergent farming households.
- the consideration of all available energy technologies that have a potential for application in Magoye area, and can contribute to tackle the constraints identified in the fieldwork.

Zambia: a national level description of the energy sector

A major bottleneck is the growing deforestation, which will cause a woodfuel crisis in Zambia's line-of-rail provinces (Southern, Lusaka, Central, Copperbelt) in the coming decades. Other bottleneck is the lack of foreign exchange reserves. This sets a limit on consumption of petroleum products, as all crude oil has to be imported. Furthermore, the deteriorating financial-economic situation has led to severe breakdowns in the raw material / manufacturing / distribution chain of Zambian equipment supply industry. Clearly, there is limit in the extent to which mechanization by means of employing diesel or gasoline engines, can contribute to rural development. The economic crisis, deepening since the early eighties, makes large-scale investments by the Government in energy infrastructure an unattainable option in the foreseeable future.

In view of these constrains new and renewable energy technologies (NRETs) are an alternative for conventional energy sources and conversion technologies. An inventory of NRETs was made for this study, which is presented seperately in AKK 89. A description of each technology is given and the potential applicability in rural Zambia is scanned.

Magoye area

A first step in evaluation of alternative technologies is analysis of financial costs and benefits of introduction. Yet, financial impacts are a condition of introduction of technologies, but are not the reason for introduction. These reasons relate to the aims and needs of people involved in introduction. A case study of a rural area facilitates confrontation of alternative technologies with the reality of Zambian rural life. Magoye area, located in the line-of-rail area of Southern Province, was chosen as the geographical location of this case study. Reasons for this choice were:
- Magoye area is one of the pilot areas chosen by TDAU,
- it is an area in a transitional development stage, enabling to study the role of energy in the transition process from traditional to modern farming systems.
A profound knowledge of the complex aspects of rural life is necessary for a proper evaluation of the applicability of energy technologies.

Fieldwork was carried out to get a global insight in Magoye rural life. To fulfill their needs, rural population carry out various energy-consuming tasks (e.g. cooking, water supply, livestock husbandry, crop production). In Magoye area the performance of tasks is hampered by a.o. fuelwood shortage, drying out of water resources during the dry season, cattle diseases and resulting shortage of ox power. In this report we will focus on improvements in the energy infrastructure that can overcome identified constraints. Various energy technologies can be harnessed as such an improvement. An analysis of financial costs and benefits of introduction of alternative energy(-related) technologies is developed. The NRETs are compared mutually and with existing energy conversion technologies.

The cost analysis leads to a choice of most promising technologies. An evaluation of the impacts of introduction of these technologies in Magoye area is presented in chapter 7. This evaluation culminates in an attempt to formulate an energy scenario for introduction of energy technologies in Magoye area. In this scenario short, medium, and long term options are presented.

Generalization on basis of a case study of one area to the national level is a tricky exercise. Therefore, we will limit ourselves to indicate the similarities of the developed scenario for Magoye area with Zambian national energy policy.
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Medium term (woodfuels, human and animal power, new and renewable energies, infrastructure)

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<tr>
<td>ADP</td>
<td>animal draught power</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>EUT</td>
<td>Eindhoven University of Technology</td>
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<tr>
<td>FD</td>
<td>Forest Department</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>ha</td>
<td>hectare</td>
</tr>
<tr>
<td>MAWD</td>
<td>Ministry of Agriculture and Water Development</td>
</tr>
<tr>
<td>MLNR</td>
<td>Ministry of Land and Natural Resources</td>
</tr>
<tr>
<td>NAMBoard</td>
<td>National Agricultural and Marketing Board</td>
</tr>
<tr>
<td>NCSR</td>
<td>National Council of Scientific Research</td>
</tr>
<tr>
<td>NRET</td>
<td>new and renewable energy technology</td>
</tr>
<tr>
<td>SIDO</td>
<td>Small-scale Industries Development Organisation</td>
</tr>
<tr>
<td>SPCMU</td>
<td>Southern Province Co-operative and Marketing Union</td>
</tr>
<tr>
<td>toe</td>
<td>tonne oil equivalent (1 toe = 41.686 Gigajoule)</td>
</tr>
<tr>
<td>TDAU</td>
<td>Technology Development and Advisory Unit</td>
</tr>
<tr>
<td>UNZA</td>
<td>University of Zambia</td>
</tr>
<tr>
<td>ZESCO</td>
<td>Zambia Electricity Supply Corporation</td>
</tr>
<tr>
<td>ZCCM</td>
<td>Zambia Consolidated Copper Mines</td>
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An exchange shadow rate of US$ 1.00 = K 12.00 (mid 1987) is used throughout the report, unless stated otherwise.
A GUIDELINE TO THE READER

A M.Sc. thesis of about 100 pages (and about 80 pages appendices) requires a justification of its size. This lies in the broad nature of the study as requested by TDAU (Technology Development and Advisory Unit) of the University of Zambia:

1) - a macro-level analysis of problems in the Zambian energy sector, especially related to rural areas,
   - a description of (small-scale) new and renewable energy technologies (NREts) that can contribute to tackle these problems, and are of interest for TDAU, as an institution involved in appropriate technology,

2) - a micro-level description and analysis of energy(-related) problems in one of Zambian rural areas.
   - a comparative evaluation of existing energy technologies and NREts as means to handle the identified problems.

The beginning reader might have a feeling of getting lost in the host of details presented in this report. When compiling this report I decided not to omit these. This would have reduced the practical usefulness for TDAU, as a database that can be used when preparing, implementing and evaluating energy(-related) projects.

Chapter 1 discusses overall methodology and the place of this research in the activities developed by TDAU.

Part I gives the results of the study of a energy sector on the national level. Chapter 2 gives a short introduction to the main features of the Zambian energy sector and a review of major constraints is given. Chapter 3 focusses on the sector of 'farming households'.

The largest part of the report, part II (chapter 4,5 and 6) discusses the micro-level: a case-study of one of Zambia's rural areas: Magoye area in Mazabuka District, Southern province. Chapter 4 elaborates the general results of fieldwork carried out in Magoye area. An area description and an analysis of constraints in rural development of the area is given.

Chapter 5 deals with farming households as target group of this study: energy demand, present and alternative supply sources. Impacts (capacity, reliability, affordability) of energy sources and technologies are identified. Options for tackling constraints in energy in farming households and in Magoye area in general are worked out in chapter 6. This culminates in an attempt to formulate an energy scenario for the coming two decades for Magoye area.

In Part III (chapter 7) results of the Magoye case study are confronted with the national energy policy on household energy and renewable energy.

This reports intends to serve different types of readers. General
readers will be more interested in the practical results of this study than going through all the details. That is why detailed information is subsumed in appendices.

To get a bird's eye view of present constraints in the energy sector, and possibilities for improvement the energy infrastructure in rural areas, those readers should read chapters 2 and 3. Some preliminary conclusions regarding applicability of energy technologies in Zambian rural areas are presented in the paragraphs 2.4 and 3.3. These are supplemented in chapter 7.

Readers not too much interested in details in could restrict themselves to reading the conclusions and recommendations of the case-study of Magoye area (chapter 6) only. Of course, this would deprive them of the possibility to get acquainted with that demanding task of the researcher: collection, analysis and interpretation of data.

The second type of readers are those who intend to use this report for further research. Those interested in description of Magoye area and rural areas in general are referred to paragraph 3.1, chapter 4 and the paragraphs 5.1-5.3. Those who are interested in research methodology, and in the format developed here to compare and evaluate energy-related technologies, should read chapter 1, paragraphs 5.4-5.6 and appendix E. Readers involved in policy making, should go through paragraphs 2.4, 3.3 chapters 6 and 7. These readers are also referred to a the 'Supplement to the M.Sc.Thesis', AKK 89, parts A, B and C.

TDAU is involved in research and development of appropriate technology. 'Appropriate energy technologies' are therefore of interest of TDAU as a field to concentrate activities on. For this purpose such technologies, so-called new and renewable energy technologies (NRETs) are identified and described in AKK 89, part D.
1.1 Introduction

In Zambia about 58% of the people live in rural areas. The majority is formed by farming households (about 92%). Their purchasing power is small. Farming households in Zambia primarily fulfill their energy needs by their own muscle power, animal power, sunlight and firewood.

The importance of woodfuels (firewood, charcoal) cannot be overlooked as these form 66% of national fuel demand. Demand for firewood is largest in rural areas, and dominated by use for domestic purposes (cooking). Charcoal is predominantly used by urban households (for cooking). Inconsiderate exploitation for charcoal production has led to depletion of wood resources in the peri-urban areas.

Agriculture, the main income-generating activity in rural areas is characterized by a relatively low use of fuel.

Rural and urban areas do not enjoy separate economies with their own set of processes. Rural areas receive e.g. paraffine through the urban-based distribution system. Charcoal is produced in rural areas and the bulk is sold in urban areas. Urban charcoal consumption will, proportional to urban growth, increasingly cause pressure on the (fire)wood resources in the rural surroundings. In tackling the problem of rural woodfuel scarcity, one has to include options for urban household energy supply as well.

Increasing rural development means also increasing per capita energy consumption. Improvement of living conditions for a growing population means a higher energy consumption. Increased agricultural production is necessary to feed the growing population, and to diversify export, which is now heavily lobsided towards copper. Such increased agricultural production can only be achieved by increased energy intensity in its production. Development of rural areas in general will lead to an intensified rural-urban trade and a correspondingly increasing energy consumption in transport. Also, establishment of rural industries means an increased energy demand.

An energy policy is therefore an important part of any rural development plan, as rural activities, energy technologies and policy interventions cannot be separated from each other. The success of any rural development programme depends on a thorough understanding of the rural community, of the concepts of "development" and "improving the quality of life" and of the acceptability of plans and technologies to the rural population.

Efforts to expand the Zambian economy are heavily dependent on commercial fuels, but threatened in the wake of ever-increasing international oil prices and heavy capital investment needed in large-scale development of indigenous energy resources: coal and
hydropower. For liquid fuel requirements Zambia depends entirely on imported oil, and this is a considerable drain on her foreign exchange earnings.

In agricultural production and transport human muscle power is used extensively. This power source alone however cannot sustain an adequate development effect in the rural sector to enhance its productivity and profitability. Only cheap and abundant energy can bring about a substantial improvement in production and the standard and quality of life of people in general.

The relevance of this report is to contribute to discussions on rural development and the role of energy therein and to induce awareness towards various small-scale energy technologies in Zambia. So far, Zambian energy policies have resulted in implementation of large-scale projects (electricity grid, oil refinery, Maamba coal mine), as has been the case in many developing countries. This macro-approach seems rather disappointing, from the viewpoint of the vulnerable rural and urban poor, as it has simply failed to deal with their interests. Since the seventies the concept of small-scale, renewable and low-cost energy (animal power, solar, wind, hydro, biomass energy) is gaining more attention in developing countries. The effectiveness of the concept, however has to be proved in the years to come. Of course, macro and micro-approaches should not exclude each other, but be mutually supportive.

1.2 The objectives of the research

1.2.1 Counterparts

The research, of which this report is the final stage, was carried out during March-December 1988 within the Assessment and Extension Unit of the Technology Development and Advisory Unit (TDAU) at the University of Zambia (UNZA). TDAU is attached to the School of Engineering of UNZA.

The aims of TDAU are described as (TDA 87, p.2):
- to serve as a development centre for new agricultural and household equipment and processes;
- to serve as an information centre for various local industries;
- to act as a clearing house for designs and prototypes of other organisations;
- to stimulate self-sufficiency of rural areas by helping and advising on design and local manufacturing (e.g. in rural workshops) of equipment.

Prototypes should not only function well, technically, but also be economically viable and socially acceptable. Tasks of the A&E unit are to perform need assessment surveys, and feasibility studies.

Need assessment surveys, design, fieldtesting and dissemination are
by no means isolated activities, but are part of cyclic process with continuing feedbacks. The final selection of implements by TDAU to be developed is based on the outcome of the feasibility studies, TDAU capacity and the results of the needs assessment surveys.

My research forms part of the need assessment survey program of TDAU, with as 'need' being investigated 'energy'.

1.2.2 Problem definition and research objectives

Problem definition

In my research proposal the general problem thesis was formulated as:
"What are the needs and aims of selected target groups in Zambian rural areas, with regard to problems in energy supply? Which options and technical means can be chosen as solutions to tackle the identified problems? What are the effects of the chosen means and how do these effects relate with the identified needs and aims?"

As target group 'farming households' was chosen. In a more operational form the problem description has become:
"How and by which means can farming households reach higher production levels and a higher standard of living through improvements in the energy infrastructure?"

Motivation for Magoye area as a case study

Farming households function within the socio-economic and environmental system of the region they are part of. Characteristics of these systems differ per region. As not to make the unit of study, farming household, a hypothetical one, it was decided to focus on one particular rural area: Magoye area. The area was chosen, because:
- it is one of the areas TDAU focusses its extension and assessment activities on,
- it is an area in a transitional development stage between a traditional and a modern farming system. This facilitates studying the role of energy in such a transitional process, and making comparisons between traditional, transitional and modern farming systems.

Fieldwork was carried out in Magoye area, to generate the necessary data of the area (see further paragraph 1.3.3).

Objectives

From the problem description the following objectives in this study are derived:
1) to describe and evaluate constraints to development of the Zambian energy infrastructure.
2) to describe and evaluate constraints that hamper development in
Magoye area as a database for this study.

3) to identify constraints in energy infrastructure that inhibit farming households in Magoye area to carry out their domestic and productive tasks.

4) to evaluate the role of energy in a farming system in the transition process from a traditional to a modern system.

5) to make a comparative evaluation of (energy)-related technologies as possibilities for improving the energy infrastructure in the pilot area.

6) to develop a format for economic comparison of energy(-related) technologies.

1.3 Methodology and data collection

1.3.1 The basic philosophy: aims-tools-impacts cycle

The basic philosophy of this research can be described as 'aims-tools-impacts' cycle. An elementary description will follow below (see figure 1.1). An extensive treatment of the philosophy can be found in LEM 87. The basis idea is that 'aims', as formulated by the target groups (and other parties concerned) with respect to their needs, form the basis for the identification of problems in an area and their rankordering. 'Aims' can be assessed by performing 'need assessment surveys'.

Starting from the 'aims' a list of 'tools', i.e. options and technical means, that fit can be compiled. By means of 'impact analysis' (techniques of evaluation and forecasting effects of technological action) the 'impacts' of introduction of chosen alternative options and means can be assessed. The number of impacts resulting from introduction
of a technology can be unlimited in principle, but in practice they are ordered in various areas: environmental, socio-economical, technological, political-institutional and legal.

The 'impact analysis' will result in rank ordering of the 'tools' according to criteria of environmental, socio-economical and technical feasibility. Finally a feedback to the 'aims' of the target groups takes place. Usually there will be a discrepancy between 'impacts' of feasible tools and 'aims'. If so, two choices have to be considered:

1) alternative options: complementary measures to match aims and impacts more to satisfaction, or new tools,
2) adjusting the aims by the parties concerned, and the cycle will start again.

When finally aims and impacts match, the cycle ends with implementation: introduction of the technology. If it becomes clear that aims and impacts cannot be made to match the cycle ends by choosing the 'no-go'-option: no implementation.

Aims

The range of aims and tools that can be chosen in a Technology Assessment study is infinite in principle. The assessor of such a study introduces restrictions therefore, leading to omission of aims that are not relevant in the context of the study, and cannot reasonably linked with tools.

In this study as "aim" is taken: 'demand for energy, which is needed to perform various energy-consuming tasks'.

In economical terms a farming household is a unit, both involved in consumption as production. Farming households need energy:

1) in consumptive tasks, such as food preparation, personal transport, heating, water supply,
2) in productive tasks, such as crop growing and processing, livestock keeping, transport of farm in- and outputs.

The overall aim 'energy demand' is to be broken down in subaims per task. The equipment and processes of each task require each a specific form and amount of energy.

Tools

Energy is not a homogenous commodity. Table 1.1 gives a review of forms of energy. Energy forms differ in their handling properties and the ease with which they can be stored or transported. Available energy sources are not necessarily already in the end-use form. Transforming primary energy sources into the usable form as required in a specific task, is an important aspect of energy supply. Some energy conversions are inexpensive, efficient, others expensive, difficult, inefficient.

As "tools" 'energy-related technologies' are considered. In a more operational definition, tools comprise:

- primary energy resources, biomass (human and animal power, woodfuels, crops) and crop).
- energy conversion technologies, that transform a (primary or secondary) form of energy into a usable form.
Chapter 1

TABLE 1.1 Primary energy sources, derivative energy forms, and nomenclature, as often mentioned in literature.

Legends:
1) renewable source of energy, 2) conventional source, 3) modern source, 4) traditional source, 5) non-conventional source.
6) Indirect solar energy sources are: biomass (conversion by photolysis), fossil fuels (which in fact is stored biomass), hydropower, wind energy and wave energy.
* secondary source of energy can be used as fuel in heat, shaft power or electricity generation applications.

<table>
<thead>
<tr>
<th>PRIMARY ENERGY SOURCES</th>
<th>CONVERSION</th>
<th>SECONDARY SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOMASS 1) 4) *)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- silvicultural crops</td>
<td>- direct combustion</td>
<td>heat</td>
</tr>
<tr>
<td>- aquacultural crops</td>
<td>- carbonization</td>
<td>charcoal 1) 4)</td>
</tr>
<tr>
<td>- agricultural crops</td>
<td>- liquefaction</td>
<td>oil 1)</td>
</tr>
<tr>
<td>- wastes (domestic, crop, animal)</td>
<td>- gasification</td>
<td>gas 1)</td>
</tr>
<tr>
<td>- residue (agricult... forestry)</td>
<td>- distillation</td>
<td>alcohol 1) 5)</td>
</tr>
<tr>
<td>- food/fodder</td>
<td>- anaerobic digestion</td>
<td>biogas 1) 5)</td>
</tr>
<tr>
<td></td>
<td>- alcoholic fermentation</td>
<td>alcohol 1) 5)</td>
</tr>
<tr>
<td></td>
<td>- hydrocracking</td>
<td>hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>- metabolism living beings</td>
<td>muscle power 1) 4)</td>
</tr>
</tbody>
</table>

FOSIL FUELS (stored biomass, hydrocarbons) 2) 3) *)
- liquid fuel (oil) | - refinery | petroleum products |
- gaseous fuel (natural gas) | - refinery | gas products |
- solid fuel (pet: coal) | - washing, briquetting | coal products |

SOLAR ENERGY (sunlight) 1) 5)
- photolysis | biochemical energy, in plants (biomass) |
- hydrophotolysis | hydrogen, hydrocarbons |
- photovoltaics | electricity |
- solar collectors | heat (thermodynamic engines) | shaft power |

WIND ENERGY 1) 5)
- turbine and transmission | shaft power |
- turbine and generator | electricity |

HYDROPOWER 1) 2) 5)
- turbine and transmission | shaft power |
- turbine and generator | electricity |

GEOTHERMAL ENERGY 1) 5)
- thermal power plant | electricity |
- heat transmission | heat |

WAVE AND TIDAL ENERGY 1) 5)
- generator | electricity |

NUCLEAR ENERGY 3)
- nuclear fission | heat, electricity |
- nuclear fusion | heat, electricity |

---

The table categorizes primary energy sources into biomass, fossil fuels, solar energy, wind energy, hydropower, geothermal energy, wave energy, and nuclear energy. Each category is further divided into conversion methods, and the secondary sources of energy they provide. The legends provide a breakdown of source types, with renewable, conventional, modern, traditional, and non-conventional sources. Indirect solar energy sources include biomass (converted through photolysis), fossil fuels (considered stored biomass), hydropower, wind energy, and wave energy. Secondary sources of energy can be utilized for heat, shaft power, or electricity generation applications.
Impacts

'Identification' of impacts means detection and qualifying the effects of tools. In 'impact analysis' impacts are quantified to make comparisons possible. In 'impact evaluation' impacts are given a relative importance and are evaluated in light of the aims.

In this report we will study as effects of energy tools: the possibilities of (present and alternative) tools to meet (present and future) energy aims in a sufficient, reliable and affordable way. Environmental, political, institutional, technological, social, legal, and economical factors influence the possibility of energy tools to meet energy demand. In this report financial factors will receive special attention.

Policy recommendations

Evaluation of impacts of presently employed and alternative tools leads to three policy options:
1) introduction of alternative tools or complementary measures,
2) 'no-go' option: continuation of the use of present tools,
3) change of aims: future (desired or projected) energy demand cannot be met, nor by presently used, nor by alternative tools.

1.3.2 Scope of this study; limitations

Aims, tools and impacts can be studied on the national level (Zambia as a whole), regional level (e.g. Magoye area) or village level or household level. Also, analysis can comprise all sectors of a society or focus on one sector (e.g. industry, households).

Core of this report is analysis of energy demand and supply in tasks performed by farming households in Magoye area, as in accordance with the problem description.

This study starts with a funnel approach, however. First a short analysis of national level is given (part I). Aims, tools, impacts are studied on the national level: Zambia as a whole, and the sector of 'farming households' in particular. Present and future energy demand, and the possibilities of energy tools (present and alternative) to meet demand, are discussed in the chapters 2 and 3. Similarly, before discussing Magoye farming households (part II), we shortly elaborate on Magoye area as a whole in chapter 4. Purpose of this funnel approach is to identify those factors in energy supply and demand on the national level and in Magoye area, and constraints in development in general, that condition the functioning of farming households.

Conclusions and recommendations, as given in chapter 6, apply in first instance to Magoye farming households. As far as possible an attempt will be made to generalize results to Magoye area as a whole and, in part III, to the national level. The reader should notice however that it is not my intention:
- to design a complete and comprehensive energy policy. Of course, for implementation of such a policy this report can serve as an aid.
- to carry out in-depth research in a concrete energy improvement, but rather to point out at the potentials of application.

This study is essentially an exploratory one, fitting within:

a) the time limits of the study period in general and the time limits of the fieldwork in Magoye area,
b) the initial requirements of TDAU (that asked for a pilot study on energy supply alternatives in rural areas, see problem description),
c) the method of data collection (see the next section 1.3.3).

1.3.3 Methods of data collection; reliability of data

Main methods of data collection used in this research were:
- study of international and Zambia-specific literature (books, reports, pamphlets), available in Zambian institutions:
  - UNZA
  - Ministries (MAWD, DoE)
  - research institutes as TDAU, Institute of African studies, National Council for Scientific Research).
- information of key-informants (private communications, draft and/or unpublished reports). Especially information of key-informants in Magoye area was of prime importance.

Data collection of national level analysis and general topics

Within any country there may be the following main types of data sources that provide information on energy demand and related variables:
- national energy balance,
- national energy survey,
- local meso/micro surveys.

Most countries have 'energy balances' which record domestic production, trade, conversion and losses, delivered energy consumption and prices of the main types of fuels. Such balances are developed on a regular basis (annual, five-yearly). Final consumption is broken down in greater or lesser details by major sectors. In Zambia most recent figures are from 1986 (to be published), and these data form the basis for chapter 2 and 3.

Such balances have some serious drawbacks:
- balances record usually from the supply side, i.e. based on commercial fuels traded and recorded by the commercial sectors. From the supply side it is difficult however to separate say households from other sectors, and usually are treated as a homogenous group. For example, our unit of study, farming households, is not distinguished as a seperate sector in the Zambian energy balances.
- consumption of traditional sources of energy is very approximate. Non-fuels (sunlight, muscle power) are not included, because these are non-traded and/or hardly quantifiable). Traditional fuels, as woodfuels, are usually traded at unofficial markets, and therefore only roughly estimated in energy statistics.

National energy surveys are usually conducted specifically to measure consumption in a sector or of a fuel or a combination thereof. In Zambia WOO 86 is an example of such a survey, measuring woodfuel demand in households in Zambia.
Local surveys, usually cover a small area on the village level (5-500 households). Usually these surveys allow careful quantitative estimates. Main purpose is to understand the social and micro-economic complexities of energy supply and demand. Valuable information can also be gained from micro-studies that do not focus on energy (alone), such as anthropological, sociological, agricultural and economical studies.

Unfortunately in Zambia such micro surveys are not abundantly available. I could only trace one report (SOU 75), which specifically dealt with Magoye area. Where adequate micro level information is not available clearly some fieldwork is necessary, as was also in my case.

An account of the data collection case study Magoye area

Main objective of the fieldwork in Magoye area was fact finding:
- to identify key-constraints in energy supply and rural development in general,
- to assess main needs in development as perceived by Magoye people themselves.

Data collection has to serve research objectives. A direct approach by carrying out a survey in the target group, farming households, would have allowed quantitative estimates of energy consumption and supply. It was decided however that such data collection would go beyond the scope of the prime fieldwork objective of fact finding. For the purpose of this study interviewing key-informants would give, approximately, the same results.

Major activity during the fieldwork was interviewing of key-informants:

a) officials, extension officers (e.g. Magoye Block supervisor, District Animal Husbandry officer, and others), officials from Magoye Clinic, Barclays Bank Mazabuka, SPCMU depot Magoye, and Lusume services. These officials provided statistical information (e.g. on crop production, livestock keeping), reports (e.g. BOE 88) and general information on various topics. Most interviews had a 'free' character to enable respondents to tell their story.

b) farmers (5 male and female peasant farmers in Munjile and Chivuna Camps, 3 emergent farmers on the reserve lands, 2 settlement farmers). For additional information on repair maintenance of farm equipment it was decided to interview 3 craftsmen also). A prepared questionnaire was used as a guide (see appendix F.5). Interviewing of farmers and craftsmen gave the chance of keep on asking on interesting points, raised by the respondents, and gave the chance of personal observation of the environment, living and working conditions of the target groups. Also informal discussions in the nighttime gave important clues.

The number of key-informants interviewed was dependent on:
- the time limit of the fieldwork period,
- similarity and difference in answers given by key-informants, and correspondence with information available in statistics and reports. As long as answers were ambiguous it was tried to form a decisive opinion by interviewing an extra key-informant, and cross-checking with information available in reports and statistics.

In interviewing key-informants the following topics were covered:
- physical-geographical description of Magoye area,
- major economic activities in the area,
- agricultural infrastructure of the area,
- description of farming systems,
- crop production,
- animal husbandry,
- pricing in agriculture.
- transport,
- energy consumption and supply,
- household income and expenditure.

The choice of interviewing key-informants implicates that the depth of data collection is restricted and has only a one-moment character. Using an indirect approach as using key-informants brings in an element of subjectiveness, as the choice of a particular key-informant may be subjective. Information from key-informants could be cross-checked with data from other respondents, and literature, enabling me to come to conclusions on reliability. Another element of subjectiveness may be that this research is carried out by 1 student, representing only one science, Technical Development Science.

Reality is complex, and all aspects of rural development are mutually related. Yet, several decisions had to be made to mark the field of study (energy-related). Therefore several aspects of rural life are only touched.

Conclusively, the fieldwork can only pretend to give a first impression of the complex and interrelated aspects of Magoye rural life, and cannot be more than descriptive.

Other sources of information used in the case study of Magoye area were:
- international and Zambian literature on energy demand, energy technologies, agriculture, animal draught power and rural development in general.
- institutions and companies in Lusaka were visited to obtain information on technical and financial details of seeds, fertilizer, chemicals, agricultural, waterpumping and power equipment (ZESCO, BP Solar Ltd, AW Tarry Ltd, AFE Ltd, Water Wells Ltd, Turning and Metal Ltd, Lenco, Shell Chemicals Ltd, NAMBoard).

The reader should take notice of the fact that in making the income estimations of Magoye farming households, and the cost calculations of the various energy supply technologies (chapter 5), various assumptions had to be made. This brings in another element of subjectiveness as other assessors might have made other assumptions. This holds the more as, of many of the energy conversion technologies discussed here, only rudimentary Zambia-specific data are available. Data from international literature is used in such cases. It has to be stressed however, that e.g. prices of raw material, labour costs, maintenance and repair possibilities in other countries will deviate from Zambian circumstances.

This should not pose a big problem however, as in this report, (which has the nature of a pilot study) we are first of all interested in magnitudes of cost estimates and, rather than subtleties of the cost calculations.
PART I

THE NATIONAL LEVEL
Chapter 2  THE ENERGY SECTOR IN ZAMBIA

2.1 Introduction

Energy crisis was one of the key-words for the world-wide economic development in the seventies. The drastic increases of oil prices in 1973/1974 (nearly 400 %) and in 1979/1980 hit the oil-importing developing countries the most. The 1980 oil price was 15-fold compared with that in 1972; 6.7-fold in constant US dollars prices (see figure 2.1). Many of these countries in Africa, Asia and Latin America were confronted with difficult choices: either they had to borrow funds to pay for the crude oil needed to maintain economic growth thereby greatly increasing their indebtedness to foreign banks, or they had to sacrifice economic growth.

The oil price development has negatively affected the whole world economy and led to recession and inflation and higher unemployment in many countries. The difficulties of the developing countries were worsened by the decline of the industrialized countries' ability to purchase the raw materials, generally the primary source of foreign exchange for most developing countries.

Shrinking petroleum resources and increasing prices for fossil fuel are only ONE aspect of the energy crisis. What is affecting most people even more directly is the increasing scarcity of traditional fuel resources: woodfuel.

Part I deals with national level energy supply and demand. Chapter 2 intends to outline the main aspects of national level energy supply and demand. Chapter 3 deals with the sector of farming households. In chapter 3 we will analyze in what respect the energy supply and demand of farming households differ from the overall patterns, as identified in chapter 2.

![Figure 2.1 Oil prices 1970-1987, expressed in US$/barrel. Source: "South", December 1987, p.12.](image-url)
The results of the case study of Magoye area (part II) must be seen within the light of the macro level analysis, as given in chapters 2 and 3. Paragraph 2.2 deals with the overall demand and supply of fuels in Zambia (i.e. the national level energy aims and tools). Main constraints that hamper existing energy supply possibilities are given in paragraph 2.3. This chapter ends with a short review of policy options in the energy sector. In chapter 7 these options are revisited. These are elaborated, in the light of the results of the Magoye case study, distinguishing between short, medium and long term options.

More details of national level energy supply are given in AKK 89, part C.

2.2 The overall pattern of energy supply and demand in Zambia

The last year of which full comprehensive data on energy demand and supply are available is 1986. These are to be published in "Zambia Energy Sector Strategy" (ZAM 88, Department of Energy).

In 1986 Zambia consumed about 4,222,300 toe (tonnes oil equivalent) of energy (= 176·10¹³ Joule see appendix B). Of this figure, 33.8 % was consumed in the form of modern fuels (coal, electricity, petroleum products) and 66.2 % in the form of traditional fuels (fuelwood and charcoal). In table 2.1 a comprehensive review of Zambia's energy balance for 1986 is given.

A) SUPPLY (see also figure 2.3).

Primary energy sources (table 3.1, row I) supply 99.5 % of the total energy (table 3.1, column 20) (the remaining 0.5 % are petroleum products). In order of importance: wood (74.7 % of total supply), hydropower (9.9 %), crude oil (9.2 %) and coal (5.6 %). Wood is the most important source of energy. Indigenous available energy sources are wood, hydropower and coal. All crude oil has to be imported, as Zambia has no known oil reserves.

B) CONSUMPTION BY FUEL (see also figure 2.3).

Traditional fuels are the most important fuel in energy end-use. Utilization of crop residues, bagasse and dung is thought to be small (ZAM 88). So in Zambia, traditional fuels are basically woodfuels (66.4 %, row IV). Woodfuel comprise wood (53.7 % of final energy consumption) and charcoal (12.7 %), which is produced from wood in kilns. In charcoal production from wood transmission losses occur (table 2.1, row III). In table 2.1 these are assumed to be about 75 %, which is a conservative estimate (losses in traditional methods are about 80-85 %, see AKK 89, part C.2.3). Conventional fuels are: petroleum products (12.2 % of the total energy for final consumption; these are mainly produced in refineries from the imported crude oil), electricity (12.8 %) and coal products (8.6 %).
## Zambia energy balance for 1986 (Source: ZAM 80, table 3.2)

| Unit: 1,000 toe (tonnes oil equivalent) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| PRIMARY ENERGY                         |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SOURCES AND FORMS OF ENERGY            |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| FUELS                                  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| OIL                                     | 403.4 | 600.5 | 26.6 | 20.9 | 629.5 | 6.0 | 1.0 | 6.0 | 2.5 | 1.4 | 0.4 | 0.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| COAL                                    | 603.4 | 600.5 | 26.6 | 20.9 | 629.5 | 6.0 | 1.0 | 6.0 | 2.5 | 1.4 | 0.4 | 0.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| WOOD                                    | -51.4 | -51.4 | 14.4 | 24.6 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 |
| TOTAL SUPPLY                            | -352.0 | -352.0 | 14.4 | 24.6 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 |
| TOTAL LOSS                             | -352.0 | -352.0 | 14.4 | 24.6 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 | 532.9 |
| DIST./TRANSM. LOSSES                   | 59.0 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 |
| TOTAL SUPPLY FOR FINAL CONS.           | 330.8 | 2362.3 | 2681.1 | 75.6 | 18.0 | 245.9 | 43.9 | 26.9 | 86.4 | 0.4 | 14.8 | 24.6 | 537.6 | 532.9 | 1608.9 | 4208.0 | 4208.0 | 4208.0 | 4208.0 | 4208.0 |
| ADJUSTMENT                             | -3.1 | 0.0 | 0.0 | -3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ADJUSTMENT IN % OF FINAL CONS.         | -0.9 | 0.0 | 0.0 | -0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| FINAL CONSUMPTION                      | 1855.9 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 | 4265.7 |

Notes:
(a) The utilisation of crop residues, dung, bagasse do not appear on the balance although they are used as fuels. However, very little information is available and the consumption is thought to be comparatively small.

(b) The final consumption of wood for "Agriculture and Forestry" and for "Industry and Commerce" are estimated to total 10% of consumption of wood for household energy use (both firewood and charcoal).

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**TABLE 2.1**

<table>
<thead>
<tr>
<th>PRIMARY ENERGY</th>
<th>SOURCES AND FORMS OF ENERGY</th>
<th>SECONDARY ENERGY</th>
<th>OTHER SOURCES</th>
<th>TOTAL</th>
</tr>
</thead>
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<tr>
<td>OIL</td>
<td>403.4</td>
<td>26.6</td>
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<td>COAL</td>
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<td>4265.7</td>
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</tbody>
</table>

Unit: 1,000 toe (tonnes oil equivalent): 1 toe = 41.656 GJ

---
C) CONSUMPTION BY SECTOR (see also figure 2.2).

Households form the largest consumer group (58% of final energy demand, table 3.1, row VI). Rural household supply is primarily met by firewood (95.5% of the households); charcoal is used by 87% of the urban households and 24% of the rural (ENE 85b, p.141; CHI 79, p.7).

Preference of charcoal vis-a-vis wood in urban households is associated with the diminishing access to firewood in the (semi-)urban areas and with its properties, such as ease of transport, smokeless burning and convenience. Selection of energy source in urban areas is clearly related to income: according to Chidumayo (CHI 79, p.10).

![Figure 2.2 Fuel consumption in Zambia per sector (1986). Source: Dept. of Energy.](image1)

![Figure 2.3 Fuel supply in Zambia (1986). a) supply of primary sources b) supply of final energy demand. Source: Dept. of Energy.](image2)
high-income households (> K 2400/year, in 1979 Kwacha, about US$ 3090, 1979) form 14% of the Lusaka population, using per household two times as much energy as the middle or lower-income households (K 1200-2400 and < K 1200, respectively, 1979). The predominant energy source for high-income households is electricity, while the lower income households use charcoal. Household electrification exists for about 38% of the urban households (ZAM 88), but is almost non-existent in rural areas (ENE 85b, p.150). It is unlikely that rural electrification will proceed fastly as the costs of extending power lines and placement of transformers are to be borne by individual households. Tables 2.2 presents data on fuel consumption by households.

The energy demand of the mining sector is met primarily by electricity (53%), coal (25%), and diesel/fuel oil (9%). Mining is the main consumer of electricity (73%), coal (54%) and fuel oil (73% of the national energy consumption).

Industry and commerce use coal and electricity predominantly. Also woodfuel is used, but in uncertain quantities. In table 2.1 it is assumed that these sector were responsible for 5% of the total woodfuel consumption.

Energy needs in the transport sector are dominated by petrol fuels: diesel oil (51%), gasoline (34%) and aviation fuel (14%), together 54% of the national energy demand for petroleum products.

Agriculture and government services do not use large quantities of (wood)fuel. In table 2.1 the final energy consumption for agriculture and forestry was assumed to be 5% of the woodfuel consumption for households.

Zambia’s net balance of energy trade is dominated by imports of petroleum products and, until recently, by the hydropower export sales (to Zimbabwe and Zaire). In 1981 the petroleum import bill was estimated at US$ 240 million, equivalent to 17.9% of the total imports and 19.4% of merchandise exports (ZAM 83, p.i).

---

<table>
<thead>
<tr>
<th>Petrol.prod.</th>
<th>Electricity</th>
<th>Fuelwood</th>
<th>Charcoal</th>
<th>Coal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>37,874 m3</td>
<td>422 GWh</td>
<td>160,000 t</td>
<td>332,000 t</td>
<td>17.56 PJ</td>
</tr>
<tr>
<td>households</td>
<td>2.5 PJ</td>
<td>1.5 PJ</td>
<td>2.56 PJ</td>
<td>11 PJ</td>
<td>17.56 PJ</td>
</tr>
<tr>
<td>Rural</td>
<td>no</td>
<td>234 GWh</td>
<td>3,210,000 t</td>
<td>55,000 t</td>
<td>54.02 PJ</td>
</tr>
<tr>
<td>households</td>
<td>data</td>
<td>0.8 PJ</td>
<td>51.4 PJ</td>
<td>1.82 PJ</td>
<td>54.02 PJ</td>
</tr>
</tbody>
</table>

TABLE 2.2 Fuel consumption by households for 1980 (PJ = pica joule, t = metric tonnes). Source: ENE 85b, table 4.16.
2.3 Constraints in energy sector in Zambia

Woodfuels

The Department of Energy estimates current sustainable yield of Zambia's woodlands at 14 million m³ (ZAM 88; AKK 89, part C.2.2, part D.1.1 elaborates on wood production and consumption estimates and their reliability).

Two main causes of deforestation in Zambia are:

a) wood consumption by (urban) households, estimated at about 14 million m³ (1986), of which 6.7 million m³ as firewood and 7.2 million m³ as charcoal

b) land clearing in chitemene agriculture. Loss due to chitemene may be a factor 3 higher than loss to woodfuel consumption, but is situated in the more sparsely populated areas of Zambia.

There is yet little evidence for a shortage of rural fuelwood on the national level. However, the consumption of wood demand is highly unequally distributed over Zambia, as charcoal demand is concentrated in the line-of-rail urban areas. Tree-cutting for charcoal production has caused deforestation of the peri-urban areas of the main cities in the line-of-rail provinces (Southern, Lusaka, Central and Copperbelt Provinces). This has resulted in localized shortages of fuelwood in the surrounding rural areas and confronted the urban population with rising charcoal prices.

According to ZAM 88 Northwestern, Western, Central, Eastern, Northern and Luapula Provinces produce more woodfuel than they consume. Copperbelt Province consumes 1% more woodfuel than it produces, Southern Province 23% and Lusaka Province even 300%! Last figures implicate that Southern and Lusaka Provinces import woodfuel from other provinces (hereby worsening supply shortages in other provinces) and/or deteriorate their own wood resources.

With present population growth rates maintained (1980-1988: 3.5%, rural: 1.9%, urban: 4.7%, respectively), pressure on wood resources will increase in the nineties. The Department of Energy has made projections of future woodfuel consumption (ZAM 88; AKK 89, part C.3) in 2006:

a) Assumption: Gross Domestic Product (GDP) remains static (1986-2006). This means a slight worsening as compared with recent economic performance, due to persistent foreign exchange shortages and weak copper prices.
   Demand in 2006: charcoal: 21.4 million m³ woodequivalent, firewood: 9.3 million m³.

b) Assumption: annual growth of GDP 3.5% (which is the highly optimistic growth target of the Government!):
   Demand in 2006: charcoal: 17.8 million m³ woodequivalent, firewood: 10.1 million m³.

The consequence is that the natural woodstock of Lusaka Province will be exhausted before 2000. Deforestation will grow sharply in Southern, Central and Copperbelt Provinces during the nineties, and lead to almost complete exhaustion of wood resources by 2006. The remaining provinces will suffer a net, though not extensive, deforestation by the early nineties. In addition to the severe woodfuel deficits in the line-of-rail
region, some smaller regions will also suffer from shortages: Mongu (Western Province), parts of Eastern Province and near some of the fish-smoking areas in North Eastern Province and Luapula Province.

The energy and also income situation of the urban poor will decline (shortages and/or higher prices of charcoal) in the coming decades. Shrinking of woodfuel resources is heavily concentrated in the line-of-rail area and spreading into neighbouring areas, so that the energy and income situation of the rural poor in these areas will decline also.

Conventional fuels

Demand for modern fuels (electricity, coal, petroleum products) will not surpass existing capacities of supply facilities in the coming two decades. The DoE has also made projections of energy demand of conventional fuels in 2006 (ZAM 88).

a) Assuming a zero growth of GDP, requirements in 2006 for:
- electricity will be 58% of the current hydropower capacity,
- coal will be 23% of the current capacity of the mines,
- crude oil will be 41% of the current capacity of the refinery.

b) Assuming a (high) annual growth of Gross Domestic Product of 3.5%, requirements in 2006 for:
- electricity will be 77% of the current hydropower capacity,
- coal will be 28% of the current capacity of the mines,
- crude oil will be 67% of the current capacity of the refinery.

Investments are therefore not needed in expanding the existing installed capacities. Investments are however necessary in:
- maintenance of the supply facilities,
- fuel substitution (see the next paragraph).

Such investments have a large foreign exchange component however. Persistent shortages of foreign exchange (causing lack of spare parts, raw materials) and of skilled manpower, may cause problems in maintaining present production capacity levels.

Balance of energy trade

Zambia's net balance of energy trade is dominated by two issues: petroleum imports (mid-eighties: US$ 90 million/year) and power export to Zimbabwe (peak year 1986: US$ 40 million/year, ZAM 88). Since 1987 power export declined to US$ 20 million. Beyond 1991 export sales of power are expected to decline. Over the period 1989-1993 petroleum import volumes are expected to rise with 2% per annum. Future prices are highly uncertain. A general consensus is that they will stabilize at the mid-eighties level (see figure 2.1), after the drop in the period 1980-86, but will rise again beyond the mid-nineties as increasing world demand soaks up the existing resources. In coal exports (US$ 1 million, 3000 tonnes, 1986/87) no increase is expected.

In short, the outlook for 1989-1991 is a widening energy trade deficit (of about US$ 70-80 million), with a further deterioration after the mid-nineties as petroleum prices will rise. Conservation and/or substitution of petroleum products play therefore an important role in the Zambian energy policy.
2.4 The Zambian energy policy

The major objective in the Zambia energy policy is (ZAM 88) "to satisfy demand for energy at the least economic cost in a way that is consistent with national development priorities, with the availability of resources, and with the long-term viability of energy supply organizations" (op.cit. ZAM 88). Translated into a number of sub-objectives, this means (ZAM 88, ZAM 83):
- providing sufficient, reliable and least-cost energy supply to the productive sectors of the economy,
- providing sufficient, affordable energy to households,
- without compromising the objective of least-cost supply, minimizing net energy imports to save forex,
- to strengthen the energy sector institutions.

A number of measures are considered necessary to reach the above-stated objectives. Of course, limited investment resources, both domestic and foreign exchange (see AKK 89, part A), will be the principal constraint. The flow of official aid and commercial lending has depressed. The level of domestic savings is extremely low. Over the next several years this picture of severe capital scarcity will remain.

The following measures are considered urgent:

A) CONSERVATION OF DEMAND AND IMPROVED SUPPLY MANAGEMENT:
- conservation of woodfuel by introducing more efficient charcoal production methods and more efficient charcoal stoves;
- to increase stumpage fees and strengthening their enforcement to bring plantation wood prices more in line with wood costs;
- encouragement of community and private sector reforestation efforts that do not require government finding;
- to reduce fuel losses and conservation of the use of petroleum products in the industrial and mining sector and the refinery itself;
- establishment of technical assistance programs to provide efficient and skilled energy manpower and managerial expertise and assistance in the conduct of energy audits in companies;
- rehabilitation of the Tazama oil pipeline
- increase of the efficiency and quantity of coal production;
- to improve the effectiveness of the power distribution system in urban and rural areas;
- to maximize net revenues from export of power surpluses;
- to improve the transport system, particularly the railways for carrying coal and petroleum products.

B) FUEL SUBSTITUTION
- fuel substitution of woodfuel by promoting coal briquettes as a substitute for charcoal as an urban household or industrial fuel and by extending the number of urban grid connections;
- promotion of fuel substitution by coal and/or electricity for petroleum products;
- to increase energy self-sufficiency by stimulating well-proven and relatively simple renewable energy technologies, especially those that are reliable and can be repaired in the field. The Energy Department considers solar water heating, solar drying, wind water pumping and biogas as the most viable;
C) RATIONALIZE ENERGY PRICING POLICIES to ensure that consumers make efficient decisions to what forms of energy and how much energy they use and to ensure the viability of energy supply organizations;

D) REORGANIZE ENERGY SECTOR INSTITUTIONS. Especially the position of the Department of Energy is advocated as a central institution, ultimately responsible for the planning and implementation of the production, conservation and pricing of energy. At present, the roles of various energy institutions overlap and co-ordination is lacking and so there is yet no clear energy strategy.

Two ways of fuel substitution are considered especially important: a) substitution of petroleum products by other modern energy sources, e.g. substitution in the mines for fuel oil by coal and electricity. b) substitution of charcoal by coal briquettes or electricity.

Electricity is financially competitive vis-a-vis charcoal for household use in urban areas (as we will see in paragraph 6.1.3). Recent performance of electricity substitution has been quite low however. In the period 1977-1983 2500 new households were connected annually. To keep pace with the existing rate of urban household formation the rate of new connections must reach 9500 per year (assuming 2 households share each connection). The Governments' objective of 50% urban electrification by 2006, would implicate a rate of 15,000 new connections!

Zambian coal in its raw state is unsuitable for direct burning. At the moment the National Council for Scientific Research (NSCR) is involved in research and development of coal briquettes for household use.

Coal briquettes and electrification will in most cases only be an alternative for woodfuel for urban households. Costs of extending the distribution network to rural areas (requiring large government investments) would be prohibitive in practice.
After discussing overall national energy demand (aims) and supply (tools) and impacts we focus on the sector of farming households in this chapter. The purpose of this chapter is to stress differences with the pattern sketched for Zambia as a whole in the preceding chapter, and elaborate on supply alternatives that have special possibilities in the rural areas.

We start with a short description of existing farming systems in Zambia (paragraph 3.1). Energy aims (demand), present tools (supply) and impacts (problems in energy supply) of farming households and problems therein are subject of paragraph 3.2. We end this chapter with a review of alternative tools (energy sources and conversion technologies) and their impacts. Some preliminary conclusions regarding applicability are given in paragraph 3.3. Many questions remain, on which part II tries to shed more light. Special attention is given to the so-called new and renewable energy technologies in AKK 89, part D: stage of development and future prospects for application in Zambian rural areas are discussed.

3.1 Characteristics of Zambian farmers

In terms of technical characteristics the farming sector can be divided into 4 categories (see table 3.1):

1) Large-scale commercial farmers; farms with more than 40 hectares under cultivation, using high input technologies and rely on hired labour.

2) Medium-scale farmers (or emergent farmers); farms of 5-40 hectares, which market practically all production. They still rely on family labour and use ADP (animal draught power) or sometimes mechanized power.

3) Small-scale farmers (or peasant farmers); farms of 1-5 hectares under cultivation, using some external inputs (fertilizer e.g.) and sell part of their production. They still rely on hand cultivation, but sometimes use ADP.

4) Traditional (or subsistence farmers); households which virtually produce mainly to meet their own needs, which do not use external inputs and rely on hand cultivation.

Development of farming differs greatly per region. A short review of farming regions is given in appendix F.1
3.2 Constraints in energy demand and supply of farming households

Official energy statistics in Zambia do not distinguish "farming households" as a separate sector. One could say that the sectors "rural households" and "agriculture", as given in paragraph 2.2 together form the sector "farming households". This is not quite true:

<table>
<thead>
<tr>
<th>Category</th>
<th>Traditional</th>
<th>Small-scale</th>
<th>Emergent</th>
<th>Large-scale commerce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main staple</td>
<td>Sorghum</td>
<td>Maize</td>
<td>Maize</td>
<td>Maize</td>
</tr>
<tr>
<td></td>
<td>Millets</td>
<td>Millets</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>Sorghum</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cassava</td>
<td>Cassava</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main inputs purchased</td>
<td>None</td>
<td>Fertiliser</td>
<td>Fertiliser</td>
<td>Fertiliser</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seed</td>
<td>Seed</td>
<td>Seed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pesticide</td>
<td>Pesticide</td>
<td>Pesticide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Herbicide</td>
<td>Herbicide</td>
</tr>
<tr>
<td>Main source of cash</td>
<td>Occasional</td>
<td>Production of</td>
<td>Production of</td>
<td>Production of</td>
</tr>
<tr>
<td></td>
<td>food surplus</td>
<td>cast crop; surplus</td>
<td>cast crop; surplus</td>
<td>cast crop; surplus</td>
</tr>
<tr>
<td>Production of new cash crops</td>
<td>None</td>
<td>Some</td>
<td>Some</td>
<td>Some</td>
</tr>
<tr>
<td>Power source</td>
<td>Hand; ox-hire; two teams of oxen; tractor hire; ownership</td>
<td>Several teams of oxen; tractor ownership</td>
<td>Possibly one or two teams of oxen; oxen; tractor hire; ownership</td>
<td>Possibly one or two teams of oxen; oxen; tractor hire; ownership</td>
</tr>
<tr>
<td>Hiring of labour</td>
<td>Family and communal</td>
<td>Family, casual and communal</td>
<td>Family, casual and possibly permanent</td>
<td>Permanent and casual, permanent</td>
</tr>
<tr>
<td>Size of farm (hectares)</td>
<td>0.25 to 1</td>
<td>1 to 5</td>
<td>5 to 20-40</td>
<td>&gt; 40</td>
</tr>
<tr>
<td>Definition (hectares)</td>
<td>&lt; 1</td>
<td>1 to 5</td>
<td>5 to 40</td>
<td>&gt; 40</td>
</tr>
<tr>
<td>Number of farms</td>
<td>462,600</td>
<td>121,406</td>
<td>21,350</td>
<td>730</td>
</tr>
<tr>
<td>Population</td>
<td>2,061,600</td>
<td>918,000</td>
<td>202,900</td>
<td>36,500</td>
</tr>
</tbody>
</table>

**TABLE 3.1** Broad characteristics of main types of Zambian farms.
New cash crops: cotton, sunflower, rice, wheat, tobacco.
Source: FO0 63 SOC, appendix II.
Farming households: energy demand and supply

Rural households also comprise non-farming families (rural wage-earners, craftsmen, shops, etcetera). In fact it is impossible to make a clear distinction between farming and non-farming households. Farming households have often secondary sources of income (beer brewing, fishing, crafts, wage work). Small craftsmen often own some land and produce a good deal of the food themselves. However, by far the majority of rural households are farming households, in the sense that major source of their income is agriculture (about 92%, 1982, own estimation based on figures from ZAM 85, table 3.1).

There is agriculture outside the farming household sector, on large (private and state estates), e.g. Nakambala Sugar Estate in Mazabuka.

In case of traditional, peasant and emergent farms one farm is associated with one household. A commercial (and sometimes and an emergent) farm usually accommodates several households, i.e. the owner or manager of the farm and his family, and hired permanent and casual labourers (with their families). In this report, when discussing energy in 'commercial farming households', is meant demand and supply in: a) consumption of the household of the owner/or manager, and b) production of the farm. Casual or permanent labourers are not regarded as farming households, but as wage workers.

Farming households are, in economical terms, involved in both production and consumption. Energy is consumed in consumptive and productive tasks. In the energy balance, presented in paragraph 2.2, energy demand in productive tasks correspond with the sector 'agriculture'; energy demand in consumption by farming households forms the larger part of the sector 'rural households'. We can therefore use the energy picture described in paragraph 2.2 as a basis for analysis of energy supply and demand in farming households.

The main fuel of farming households is firewood, mainly used in consumptive tasks, basically for cooking. Kerosene is used for lighting. In urban households selection of sources is clearly related to income (see paragraph 2.2). It is realistic to assume that higher-income rural households will consume more of conventional fuels (kerosene, electricity) than lower-income. Lower-income rural groups comprise a.o. subsistence, peasant and emergent farmers, craftsmen. Higher-income rural households comprise wage-workers, commercial farmers, of which many live in the vicinity of urban centres and have access to electricity supplying systems (grid, diesel-generated). As by far the majority of farming households are subsistence, peasant or emergent farmers one can conclude that these farming households almost exclusively rely on firewood as fuel for domestic purposes, i.e. cooking. Small quantities of paraffine are used for lighting purposes.

Fuel-use in agricultural production, the primary source of income of farming households is low, as is illustrated in table 2.1. Cultivation practices in agriculture are still mostly traditional and non-mechanized, hence not particularly fuel intensive. Fuel-use is restricted to commercial farmers, who use mainly diesel oil for tractors and transport vehicles. In tobacco curing also large quantities of firewood are used (5,080,000 tonnes/annum, ZAM 83, p.5, p.35).

In paragraph 2.2 we discussed the growing woodfuel shortage in the
peri-urban areas of Zambia, which will increasingly affect rural households. A reduction of firewood demand per capita of rural households is hardly possible, as this would mean a deterioration in quality of life. As the main use of firewood is for cooking, reduction of firewood demand would lead to:

a) reduction in the number of warm meals taken and/or reduction in the amount of food cooked.

b) application of other sources of biomass: crops residues, dung. These are now recycled in the farming system, as these are used as cattle fodder (residues, such as maize stover) or fertilizer (residues, dung). Extracting residues and dung (fertilizer) from the farming system, leads to soil erosion and other environmental damage and eventually, will disturb the whole ecological balance.

Urban and rural woodfuel problems cannot be separated, as rural and urban areas do not enjoy separate energy systems. Rural areas receive energy sources (electricity, petroleum products) through the urban-based distribution system. Urban areas receive charcoal from rural areas. Main cause of deforestation in the peri-urban areas is charcoal production. Clearly, one solution for the diminishing access to wood resources for rural households lies in finding alternative options for urban charcoal demand.

The shortage of traditional energy in rural areas has another dimension (apart from shortage of woodfuel), namely shortage of power in agriculture. In national level energy balances (such as the one presented in paragraph 2.2) usually only fuels are taken into account. Non-fuel energy sources, sunlight, and muscle power of living beings are not included, as these are freely available and/or not traded, and therefore hardly quantifiable. Yet, as already shortly discussed in paragraph 3.1, human and animal power and sunlight comprise the bulk of energy inputs in agricultural production!

Sunlight, is captured by photosynthesis and stored as biochemical energy in plants. The metabolism in humans and animals converts the energy stored in plants into muscle power.

The area that can be cultivated by a traditional farming household without energy inputs other than human labour, is rather limited, about 1 hectare. In Zambia about 64% are such traditional farmers (see table 3.1).

Application of animal power facilitates higher hectarages of cultivation. For peasant and emergent farmers animal power is the main source of power, besides human labour. Yet, cattle keeping is unequally distributed over Zambia, the main herds found in Southern, Western and Eastern Provinces (see appendix F.2). Application of animal power is the first step in the mechanization process of agriculture.

The next step is application of engine-powered equipment, which facilitates maximization of production. Diesel oil and electricity are main energy inputs in such a modern farming system. Maximization of production requires extremely high investments in engine-powered equipment and in inputs of conventional fuels. So, maximization is expensive, both from a consumer as well as national point of view. In Zambia only commercial farmers have sufficient financial resources to afford tractors and related equipment and use of conventional fuels. From the national point of view widespread application of engine power in agriculture is expensive in terms of foreign exchange costs. All oil products have to be imported, as well as tractors and about 90% of
tractor-drawn equipment. Generally it is not possible to maximize, but to optimize. That is to find the point which (taking all relevant facts into account) provides the most positive balance of positive and negative elements.

3.3 Prospects of substitution for traditional sources (firewood, charcoal, human power) in farming households. Relations with urban household energy supply

In the preceding paragraph was argued that the shortage of traditional energy sources available to farming households has two aspects:
- deforestation, which will lead to localized firewood shortages in the decades to come,
- shortage of power in agricultural production, as 64% of Zambian farmers rely almost entirely on human labour as source of power.

In this paragraph we will discuss alternatives for these traditional sources of energy, and evaluate impacts of introduction in rural areas. Paragraph 3.3.1 deals with conventional sources of energy, paragraph 3.3.2 discusses non-conventional sources. As main cause of deforestation is charcoal production for urban households, we will also include urban household energy options in the discussion, as indirect means to tackle rural fuelwood shortage.

3.3.1 Conventional energy sources

Electricity

The extension of the electricity grid has high priority in Zambia. In Zambia it is generated from the vast hydropower resources, a renewable source of energy. Electric energy is an important factor in modern life. Electricity is a clean and comfortable kind of energy, which has a broad range of utilization in modern households (cooking, lighting, refrigeration, ironing), in agriculture (to power implements), in large and small scale industry and in services. Yet, generation and distribution of large-scale electricity power requires expensive materials, which have a large foreign exchange component. Installation and control require skilled workers and good management. The laying of distribution systems over sparsely populated regions in Zambia with low consumption levels, causes excessively high investment costs. High capacity use makes the system more economic, but in the beginning stage capacity use is most likely to be relatively low (about 4-10%).

An alternative to electricity supply from the grid is generation by autogenerators. Capital cost of such supplies are lower than of those of
grid supplies, but fuel, operation and maintenance costs are higher. In Zambia large-size diesel generators are used to supply electricity to urban areas, remote from the national grid. Most of them are operated on diesel, resulting in high foreign exchange costs. Policy in Zambia is to replace the existing 14 diesel power stations by linking these up with the national grid.

Rural electrification is virtually non-existent. Past rural electrification programs have resulted in large operating losses (ZAM 83, p.39). Due to the extreme shortage of funds of ZESCO, rural electrification is not an option for the coming two decades.

Connecting urban households to the grid has high priority, but performance has been low (see paragraph 2.4).

Coal

Application possibilities in agriculture and households are quite low.

In agriculture coal is of low importance as it is not suitable to operate conventional combustion engines. Coal may be important in so far as by coal processing gaseous or liquid fuels can be extracted, which are used to power engines (steam engine!). Although such coal technology is well-known, it is not utilized in Zambia, apart from large-scale industries.

Zambian coal is (because of the high ash content) not suited to be used in raw state to operate engines or for cooking (in non-enclosed fires). The several impurities require that the fuel be burned in stoves with chimneys. Such a stove would cost about K 20,000 (Dover-type, adapted from CHE 79, p.170), quite prohibitive for the majority of households. There would also be gigantic problems of distribution and marketing: difficulties are to be expected in transferring coal from production to consumption sites, due to the perilous state of the transport sector.

Other possibilities are:
1) to use coal indirectly, for electricity generation, as is practised already in some thermal power plants in the country.
2) producing briquettes, by processing of coal with molasses from low-temperature carbonized coke, as a smokeless solid domestic fuel. Advantage of briquettes is that they can be produced exclusively from domestic resources (coal, molasses). Further people could use them in their traditional stoves and do not need to change cooking equipment and habits. Disadvantage of coal as fuel is that the end products of combustion cause more air pollution. Technical viability of producing briquettes is demonstrated in Japanese and German studies and testwork by NCSR. There has been no analysis yet on the economic viability at a commercial production scale. If viable, briquettes could be the alternative for urban households for charcoal.

Petroleum products

For farming (and urban) households petroleum products have the following uses:
- fuel for domestic tasks (cooking, lighting),
- fuel for internal combustion engines in motive and stationary power
applications or to generate electricity.

In the light of foreign exchange situation, government policy aims at conservation of consumption of petroleum products.

From the national point of view substitution for woodfuels by petroleum products is hardly a feasible option. Also from a private point of view as the conversion from cookers by traditional measures to cooking with kerosene or diesel requires high investments in new stoves, and cash money in operating expenditures on fuel.

For use in internal combustion engines (the conventional engine in motive and stationary power applications) there seems hardly to be an alternative fuel that has all the advantages of oil products as gasoline and kerosene.

3.3.2 Non-conventional energy sources

Especially the poor farmers are most difficultly reached by the urban-based distribution system of electricity and petroleum products. It is clear from the foregoing that conventional energy substitutes for traditional sources of energy (human power, firewood) are of limited importance, because these are not available and/or affordable to poor farmers.

Since the seventies, after the oil crises, research and development in the sector of non-conventional energy sources was intensified in the world. All kinds of non-conventional energies are characterized by the fact that they are renewable and thus potentially inexhaustible. Not all renewable energy sources are non-conventional energy. Wood and large-scale hydropower are examples of a renewable traditional and a renewable conventional source of energy.

Zambian renewable energy resources comprise (compare with table 1.1):

- a) biomass (wood, dung, crops, crop residues, etc.). These can be burned directly or be converted into an (other) usable form of energy (charcoal, tar, vegetable oil, woodgas, biogas, alcohol, muscle power).
- b) solar energy, which can be captured by solar collectors to be used as heat or in thermodynamic engines, or by photovoltaic cells.
- c) wind energy, for shaft power applications and/or electricity generation.
- d) hydro energy, for shaft power application, electricity generation.
- e) geothermal energy, for electricity generation.

In the following we will discuss the stage of development of renewable energy technologies and future prospects for application by farming and urban households. For more details the reader is referred to AKK 89, part D.

Biomass

In Zambia land is abundant. Labour is available and biomass production (being labour intensive) can contribute to employment creation. Examples of biomass production schemes are (large-scale) woodfuel plantations, village forestry and agroforestry.
Until the price paid by the urban consumer equals the retail cost of plantation wood, woodfuel plantations (for wood and/or charcoal production, primarily meant for urban consumption) will not be a viable proposition. The Government cannot afford to heavily subsidize woodfuel forestry. Urban forestry schemes are not a viable option on the short term, as long as transporting charcoal will remain cheaper. On the long term, charcoal prices may have risen such, that they will at least equal the price of wood or charcoal from large-scale plantations.

Raising stumpage fees (to make plantation wood more competitive) or higher levies paid by the urban retailer, would have a negligible effect, as 95% of the charcoal production is "illegal" (only 5% is produced by licensed producers). Pre-requisites for the implementation of higher stumpage fees are better control of tree cutting and effective enforcement of forest licensing regulations and/or control of traders at roadblocks. But even so, another questions remains: to what level should levies or duties be raised in order to make urban woodfuel plantations viable without creating hardships for the poor urban consumer?

Another strategy of making plantations more competitive is not to base plantations on the single end-use as woodfuel. For instance if timber trees are used, a first crop could be sold as industrial wood at a price that reflects full production costs while subsequent coppice wood could be harvested as woodfuel and sold at a cheaper rate.

Village forestry efforts are important to ensure a continued fuelwood supply in the rural areas, and may even serve as a promising alternative for large-scale urban plantations. Labour costs are lower and yields per hectare may be higher. Such schemes require effective tree care practices, nurseries to be established, extension services. Village forestry should be integrated with present agricultural extension work, requiring additional government funds to implement the forestry efforts succesfully.

Besides wood, other crops can serve as source of energy. On a village level for example in intercropping schemes. For example, crops used as energy source and food crop, being later-maturing together with early-maturing crops, wet with dry season plants, in such way that a reliable and year-round supply is guaranteed. Multiple cropping helps minimizing the inevitable periods of low productivity between the harvest of one crop and the establishment of an adequate leaf area on the succeeding crop generation. A careful reassessment of local traditions and factors as energy content, water supply and nutrient supply has to precede implementation of such cropping schemes. In the Zambian rural areas, however, crops will often have higher demand as food, fodder and/or cash crop. I think therefore energy cropping would not be accepted yet by the village population as an alternative for fuelwood.

No research and development work is done in the field of woodstoves, as a rural fuelwood crisis has not manifested itself as such on the national level. I believe, nevertheless, that such work should take a place in research activities. In the decades to come the rural fuelwood shortage will increase in view of a growing deforestation, especially in the line-of-rail provinces.

From the viewpoint of wood-use efficiency the end-use of wood, for cooking, is to be preferred to the use of charcoal. Only if improved charcoal stoves are introduced simultaneously with improved charcoal production, the wood-use efficiency of charcoal cooking may be larger.
than of cooking above the open fire (using aluminium pots). The wood-use efficiency of improved wood stoves is always better than charcoal cooking (see table D.3 for a review of efficiencies), and is to be preferred from this environmental viewpoint.

Charcoal will remain important however as fuel for the urban households. As charcoal consumption is one of the main causes of Zambian deforestation, introduction of improved charcoal stoves and improved charcoal kilns should have a high priority in an energy policy. Costly kilns will not be a viable means for the private producer; the Government has not the funds to finance large-scale projects. The key will be introducing more efficient versions of traditional techniques, together with effective producer training. The potential impact of an improved charcoal stove program can be considerable. Table 3.2 suggests that if 30% of the urban households would use an improved stove by 1996 and 90% by 2006, this would lead to a 30% reduction in charcoal consumption than without the program (ZAM 88).

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Without improved stoves</td>
<td>706</td>
<td>910</td>
<td>1,173</td>
<td>1,463</td>
<td>1,838</td>
</tr>
<tr>
<td>With improved stoves</td>
<td>706</td>
<td>863</td>
<td>1,036</td>
<td>1,197</td>
<td>1,342</td>
</tr>
<tr>
<td>Decrease (%)</td>
<td>0</td>
<td>5</td>
<td>9</td>
<td>16</td>
<td>27</td>
</tr>
</tbody>
</table>

TABLE 3.2 Potential impact of introduction of improved charcoal stoves on charcoal consumption. Unit: 1000 tonnes. Source: Dept. of Energy.

On the short term gasifier technology (yielding woodgas, also called producer gas) will have a low potential for application in Zambia: at the moment little or no research and/or extension is done in this field in Zambia. On the long term the technology could be feasible (which will be discussed in chapter 5). Introduction of gasifiers should go with establishment of (village or large-scale) forestry schemes, as not to aggravate pressure on existing wood resources.

Biogas technology in Zambia is still in the research and development stage. In those areas with a tradition of cattle-keeping biogas technology may be a promising one. An attractive point is that biogas is multi-functional: it can be used for cooking, lighting, shaft power applications and electricity generation.

Solar energy

In the short run photovoltaics cannot contribute essentially to the energy supply in rural areas of Zambia because of the high costs involved. This does not mean that the technology should be ignored. Ever since the first development of solar cells they have shown steep decreasing cost per peak Watt. This will continue if mass production of solar cells becomes more widespread. In Zambia further cost reduction could be obtained by developing the necessary technology and industrial
infrastructure in Zambia itself. This would save the country foreign exchange. Also an adapted government policy could make solar cell technology more viable: at the moment an important cost component of solar systems is formed by taxes and import duties. If prices of solar systems drop in the long term, they could be a solution for rural electrification, cooling, storage of products (medicines) and water pumping. Main advantage of solar systems is that they can be sized in modules (in proportion to the consumer's needs) and require little maintenance (important in today's Zambia with its chronic shortage of spare parts).

It is not my opinion that solar cookers will gain large-scale acceptance by rural households, as they demand considerable alterations in cooking methods. Maybe the first market for solar cookers/ovens is the commercial one: commercial food and beverage processing, e.g. bread-baking, beer-brewing.

Solar driers are superior as compared with wood drying, because of the substitution for fuelwood, and because of better product quality and less losses. Because fishing takes place the whole year round, this would make investment more attractive than e.g. investment in crop drying. Solar driers can either be used by individual families or by entrepreneurs at a village level. The economic feasibility will depend on designing driers for local production and minimal material costs (use of locally available materials).

Solar technologies of more of interest for rural health clinics rather than rural households are solar stills and solar refrigeration.

Wind energy

With large parts of Zambia having average annual windspeeds less than 3 m/s (in practice often the speed at which a windmill starts delivering power), the wind energy resource potential is quite low. Only a few areas have wind speeds exceeding 4 m/s (a rough estimate of the speed at which a windmill becomes economically viable) for more than 10% of the day. This does not totally exclude the exploitation of the wind resource. Experience has shown however that imported windmills are not a feasible option. Application will depend on finding a cost effective appropriate technology design. The first application has to be sought in water pumping: household water supply and irrigation for small-scale subsistence farmers.

Hydro power

Fabricating, operating and maintaining small-scale hydropower units (5-100 kW) is very well possible in Zambia. Sites with perennial streams and rivers with either high heads or high flows or both have highest potential. This restricts sites predominantly to northern (high rainfall) Zambia. To embark projects these sites have to be evaluated carefully, as well as the economics of the project. An advantage of hydro-power units is the relatively low maintenance costs (bearing, transmission belts require attention). Locally manufactured turbines have the advantage of greater spare parts availability.
Animal power

Employing animal power in agricultural production is important: power input level is increased drastically as compared with pure manual cultivation, leading to a larger output in production and thus increase in revenues for the farmer. Large-scale application of tractor power, the alternative for animal power, is constrained by a lack of foreign exchange. This restricts the numbers of tractors and spare parts it can import. In Zambia all tractors and about 90% of the tractor-drawn equipment has to be imported. The Department of Agriculture of MAWD has estimated that at any one time over 50% of the tractors in the country are inoperable due to lack of spare parts. This situation will continue in the foreseeable future. Many farmers are now looking at ADP as a replacement for tractor power, and even commercial farmers are looking to a power "mix" of tractor and ADP.

Also application of ADP is hampered by constraints, however. Major constraints are (source: various publications by MAWD):
- application of ADP is predominant in areas that have a tradition of cattle-keeping (see appendix F.2). Supply of ox-training facilities, quality of promotion of ADP and, sometimes, supply of oxen is inadequate in provinces that does not have a long tradition of ADP.
- supply of ox-drawn equipment is inadequate in terms of quality, quantity and regularity. The Department of Agriculture of MAWD estimates 40% of the number of ploughs are inoperable, due to lack of spare parts (foreign exchange) and local repair capacity. Ox-drawn equipment is manufactured within Zambia. Northland Engineering Ltd., Shonga Steel Ltd., and the parastatal Lenco are the main manufacturers. The agricultural equipment industry is however dependent on imported raw materials (steel) and spare parts. With strengthening of co-operatives (the main distributors at the provincial/district level), expansion of primary societies (at the grass-roots level) and programmes for training of village blacksmiths, rural distribution of implements should be further improved.
- supply of acaricides, prophylactics and other inputs against cattle diseases is inadequate and irregular.
- the amount of medium term credit available for oxen and/or equipment is generally insufficient.
- in the field of policy-making their is a lack of co-ordination of supply of inputs to farmers and artisans.

3.3.3 Application possibilities per type of farming households

Some preliminary conclusions regarding application of various energy sources in farming households are sketched here. In chapters 5 and 6 the financial feasibility of energy supply alternatives is elaborated. In chapter 7 these conclusions are complemented with the results of the Magoye case study, enabling to formulate a more definite opinion. For a review of presently applied energy sources in farming households one is referred to table 3.2.
32 Chapter 3

<table>
<thead>
<tr>
<th>Category</th>
<th>Subsistence</th>
<th>Peasant</th>
<th>Emergent</th>
<th>Commercial</th>
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</thead>
<tbody>
<tr>
<td>Traditional energy sources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>Cooking/heat</td>
<td>Cooking/heat</td>
<td>Cooking/heat</td>
<td>Tobacco/fish</td>
</tr>
<tr>
<td></td>
<td>Tobacco/fish</td>
<td>Tobacco/fish</td>
<td>Tobacco/fish</td>
<td>curing</td>
</tr>
<tr>
<td>Charcoal</td>
<td>Food prep.</td>
<td>Food prep.</td>
<td>Food prep.</td>
<td>--</td>
</tr>
<tr>
<td>Human muscle power</td>
<td>All tasks</td>
<td>All tasks</td>
<td>All tasks</td>
<td>All tasks</td>
</tr>
<tr>
<td>Animal muscle power</td>
<td>--</td>
<td>Crop production</td>
<td>Crop production</td>
<td>Occasionally (crop prod., transport)</td>
</tr>
<tr>
<td>Modern (conventional) energy sources</td>
<td>Occasionally</td>
<td>Lighting</td>
<td>Lighting</td>
<td></td>
</tr>
<tr>
<td>Paraffine</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Livestock husbandry, Tractor, Water lifting, Crop processing, Electricity generation, All tasks</td>
</tr>
<tr>
<td>Diesel/gasoline engines</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Electricity from the grid</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

TABLE 3. Presently applied energy sources in Zambian farming households per task.

All tasks: domestic (cooking, lighting, water supply) and production tasks (livestock keeping, crop production and processing, transport).

Definition of farm (household) categories as given in paragraph 3.2 and table 3.1.

-- no or very low application.

Subsistence farming households

Most new and renewable energy technologies (NRETs) require a certain capital outlay. As the name indicates, subsistence farmers have zero or very little cash saving possibilities. This practically excludes application of NRETs in subsistence farming households.

An exception must be made for animal power, which enables a farmer to expand its cultivated hectarage and thereby to get a regular cash income. In introducing ox power in subsistence farms, the following aspects are important:

1) Credit supply. Without adequate medium term credit facilities a (subsistence) farmer cannot afford the capital outlay for oxen and ox-drawn equipment. To lessen the need for the purchase of oxen and equipment, initiatives for hiring out of oxen and/or ox carts should be encouraged. In a ADP (animal draught power) project hiring is essential.

2) The unfamiliarity of the subsistence farmer with application of ox power in agriculture. Training facilities are thus important. Training of oxen must be done with the farmer and an ox-trainer in the village.

3) Supporting infrastructure: adequate supply and repair and maintenance facilities in the area; extension work.
Commercial farming households

Commercial farmers differ from the other groups of farmers in that most of them are connected to the electricity grid. From the private point of view these farmers do not face problems in energy supply. Application of non-conventional energy technologies is potentially important in two cases:
1) In farms that are not connected to the grid. Especially the question of feasibility of alternative electricity supplies (e.g. diesel-generated, biogas-generated, solar power) vis-a-vis a grid extension is important.
2) In water pumping applications (electric versus diesel, biogas or woodgas pumping).
3) In farms involved in tobacco production or fishing: the substitution of wood as source of heat in curing by solar driers.

Peasant and emergent farming households

Peasant farmers and emergent produce food crops for their subsistence needs and market the food surplus, and cash crops. This facilitates some cash saving possibilities and thus purchase of new (energy) technologies. Peasant and emergent farming households have no access to grid electricity. As rural electrification is not feasible at least for the coming two decades, these categories of farming households have great potential for application of non-conventional energy sources and technologies: village forestry, improved wood stoves, biogas technology, wood gasification, wind technology, solar power.
PART II

CASE STUDY OF MAGOYE AREA
4.1 Introduction

Part II (chapters 4, 5 and 6) the core of this report, comprising the findings of the Magoye case study. For an account of fieldwork and the method of data collection in general used in the case study of (farming households) in Magoye area, one is referred to paragraph 1.3.3.

This chapter starts with a general description of Magoye area. Paragraphs 4.3 gives a general introduction of types of farming systems and constraints that hamper Magoye farming. A motivation for the extensive description of the area and its farming is that such, regional, village level, information is hardly found in official documents or reports. Yet, such background information is a pre-requisite for the reader to have a good view on introduction of technologies and its possibilities.

In this chapter the following subjects are discussed:
- general description of the environmental and socio-economic characteristics of the area.
- energy supply and demand in the area.

Chapter 4 can be seen as an introduction to the next chapter 5, in which we focus on 'farming households' in Magoye area. In chapter 5 a description of various energy-consuming tasks is given, and suggestions for improvement of tasks by introducing new technologies is given. Such new technologies will effect adjustments in energy demand (energy aims in terms of the aims-tools-impacts methodology), and will need adjustments in energy supply. In practice the latter means improving energy infrastructure (energy tools). Impacts of energy tools studied are ability to meet energy aims, and their reliability and affordability.

The final findings of the case study are presented in chapter 6.

4.2 Description Magoye area

Location

Magoye Town is located in Mazabuka District of Southern Province along the tarmac road linking Livingstone with Lusaka. "Magoye area" is
FIGURE 4.1 Magoye area: agricultural camps and settlement schemes.
Sources: Survey Dept (MLNR, Lusaka); M. Hamoonda (Agricultural District Office, Land-use Branch, Mazabuka; SOU 75.

MAGOYE AREA

boundary Magoye Block
agricultural camp
settlements
farmac road
rail road
secondary road

Magoye Town
Magoye Block Hq.
Ngwezi
Ngwezi A
Ngwezi B
Ngwezi C
Muzuma D
Mbaya R
Ngonkola
Miss. Hosp.
Kavule R.
dam

north
camp headquarter
geriver
land tenure system

0 5 10 15 20 km

NACHENGWA
Magoye area

defined here as Magoye Agricultural Block and neighbouring settlement lands, as depicted in figure 4.1. The Magoye Block consists of 8 agricultural camps: Chivuna, Chijanwa, Magoye, Maunga, Munjile, Nachengwa, Ngwezi Block and Nkonkola. The inhabitants are mainly Plateau Tonga. Through the area run Magoye and Ngwezi Rivers.

**Land-use, topography, vegetation and soils**

Magoye Block is divided into a settlement area and a reserve area (see paragraph 4.3.1). Schultz (SCH 76) classifies the land-use system on the settlements as "semi-commercial ox-plough cultivation" and on the reserve area as "semi-permanent ox-plough cultivation". Farming methods are above the Zambian average and essentially related to ox-drawn equipment. Land is prepared for planting mostly by ox-ploughs; planting in the area is often done by hand following an ox-drawn plough. Weeding is done by cultivators and by hand. All crops are harvested by hand.

Soils are classified by FAO/UNESCO as Luvisol-Phaeozem (BOE 88, p.1). They may vary between reddish sandy clay loams (well drained) or grey-brown clay loams (poorly drained). Soil reaction is often slightly acidic. In virgin state these soils are very deficient in phosphorus and well supplied with potassium.

Most farmed land is flat to gently sloped. Slopes of more than 5% are rare and mostly occur on reserve lands. Erosion appears to occur on practically all sloping land. Farmers on those lands are quite concerned about this. Very few fields are effectively protected against erosion (BOE 88).

The characteristic vegetation in the area is Munga Woodland, typical for an area with flat topography. This is an open, park-like woodland or savanna with scattered or grouped emergents (up to 18 m high, SOU 75, p.50). Particularly characteristic species are Acacia, Combretum and Terminalia. Tall grasses, swept by annual fires, are also characteristic of Munga woodland.

**Climate**

Climatic recordings in the area are done by several stations in Mazabuka area: for example Mazabuka Boma, National Irrigation Research Station (Kafue Flats), Zambia Sugar Company (Nakambala Estate Mazabuka), Magoye Research Station. In appendix F.4 climatic data for Kafue Flats are given (together with a short description of the Zambian climate). Data from other stations differ, but not in a way indicative of climatic variation (BOE 88, SOU 75).

The climate is semi-arid, with a unimodal rainfall distribution. Mean annual rainfall is 780 mm. The area has three seasons, distinguished by rainfall and temperature differences: a cool dry season (April-August), a dry hot season (August-November) and a hot wet season (November-March). In the area there is water surplus between January and March. Although water is retained in the soil throughout the year, application of irrigation would favour increased plant growth.

**Agriculture**

Agriculture is the predominant cash-generating activity in the
area. The main cash crops are maize, sunflower, cotton and soyabeans. Subsistence crops are mainly groundnuts, sorghum, mixed beans, sweet potatoes, pumpkins, bambaranuts and cowpeas. Cattle is extensively grazed on communal land and plays an important role as traction power, for manure provision, as a form of savings and as a sign of wealth.

Roads and waterways

A hard sand feeder road connects the several agricultural camps in Magoye Block. Grading of this main road is done every year; the condition of the road can be described as good, at least in the dry season, but in the rainy season inaccessible without 4-wheel drive. Besides this road there is network of small roads and footpaths in the area.

The waterways, rivers and streams, fall dry or almost dry in the dry season and can therefore not be used for transport or hydropower.

Services

The Magoye Block area is catered by several services, as is in correspondence with the national policy to provide equal access to services in all parts of the country. Table 4.1 gives a review of services offered in 7 agricultural camps of Magoye Block.

The Multipurpose Societies are catering for smaller depots in the area. They are involved in storage of agricultural products and selling of inputs (fertilizer, seeds) and implements. Multipurpose Societies and depots are supplied by SPCMU (Southern Province Co-operative and Marketing Union) At present these are badly stocked with implements and spare parts, forcing farmers to go to Monze or Mazabuka to buy the items in more expensive private shops.

People living near Magoye Town go there to get necessities. People living further away have to go to the shops or groceries in their camp. Such retail shops (privately owned or attached to the depot) sell mainly non-food basic articles. Because of transport retail commodities in the rural areas are usually much more expensive than in townships. For example a litre of paraffine costs officially K 1.74, but is in Maunga or Chivuna sold for prices up to K 3.

In the area there are clinics in Munjile and Magoye Town. Those clinics do primary treatments only. Medicines have to come monthly from Mazabuka or Lusaka. Frequently shortages occur, especially in Magoye Clinic (where no storage occurs). The clinics have no facilities to transport people to hospitals in Monze or Mazabuka. No visits to patients are made. In Chivuna is a rural health centre (RHC), run by the mission post there. Tasks of RHC's are treatment of diseases and injuries, the supervision of community health workers and health education to the people in the catchment area. In the RHC patients are admitted In the RHC storage of medicines and vaccines is done. Most visits by patients to the RHC are done by foot, bicycle or ox-cart. If necessary transport is provided by the missionary to hospitals in the nearby towns.
In Magoye area various handicrafts are carried out (carpentry, smithery, shoemaking). Products range from shoes, furniture, agricultural implements (hoes), sculpture products. As tools are used hand-axes, chisels, nails, pens, knives, hammers, hacksaws. Raw material used are timber (carpentry), scrap metal (smithery) and leather. To give an indication of the number of craftsmen per camp: in Ngwezi A and B 3 blacksmiths are working, 3 carpenters and 1 carpenter/blacksmith. These figures do not necessarily represent a general picture for Magoye area, because of the proximity of Ngwezi to Magoye Town. The main problems craftsmen face is lack of raw materials and lack of tools. Other problems mentioned in the interviews were lack of capital and lack of means of transport. Demand for carpentry products seems to be more than production. Improved transport in the area could enlarge the market possibilities, but also mean more competition from urban artisans. In smithery demand for products exceeds production. Especially in the rain season for instance hoes sell like hot cakes.

The only larger scale industrial activity in the area is grinding of maize. SPCMU runs two hammermills, one in Munjile (powered by a diesel engine), one in Chivuna (powered by electricity).
4.3 Agriculture

4.3.1 Types of farmers

Within Magoye Block several types of farmers can be identified:
1) commercial farmers, with over 40 ha under cultivation,
2) settlement farmers, who can usually be identified as small-scale commercial (16-40 ha),
3) emergent farmers (5-16 ha),
4) peasant farmers (0-5 ha, also called traditional farmers),
5) institutions (e.g. schools, research station).

The category of subsistence farmers (table 3.1) is not identified as such by Magoye extension officers. The reason is that the category is virtually absent in the area, indicative for the above-average farming in the area.

There are 2 predominant land tenure systems:

a) settlement schemes. These are former commercial (i.e. colonial settlers) farms on State Land (adjacent to the line-of-rail). In Southern Province most of the commercial farmers, state ranches and large production estates can be found here. After Independence (and departure of most of the expatriate farmers) land has been reallocated: farms either fell into the hands of the government, parastatal bodies or settled by indigenous farmers.

In Magoye area the camps of Mbaya, Musuma and the Ngwezi Extensions cover settlement areas. Modern leasehold land right applies here. Farm size is 70 ha (bush, arable, grazing land) on average, with arable land varying between 10-20 ha (BOE 88, p.2). One farm accommodates 21 persons on average, due to polygamous marriages (see paragraph 5.2.7) (3.3 ha of

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>Land tenure system</th>
<th>Number of villages</th>
<th>Number of farm families</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ngwezi B</td>
<td>s</td>
<td>7 (1987)</td>
<td>130 (1987)</td>
</tr>
</tbody>
</table>

TABLE 4.2 Agricultural camps Magoye Block.

Abbreviations: HQ: head quarters,
s: settlement scheme on state land,
t: trust land
r: reserves

Source: Magoye Block supervisor.
land available per head)! The Ministry of Rural Development was responsible for initiating Ngwezi settlements. On behalf of the government Family Farms Ltd. (a non-profit company) works as a settlement agency. Mbaya and Musuma schemes were initiated in 1970. The Ministry sees settlement schemes as a means of upgrading farming. A peasant farmer from the reserve lands, who is well-doing, is offered land in the settlement scheme and sometimes loans for oxen. He has to make a certain production or otherwise he has to leave the scheme. After a certain period he will obtain full rights of his farm land.

b) reserve and trust land. These lands have never been touched by colonial administration and here traditional land right and inheritance laws still apply. Trust land is mainly under control of chiefs, but the government has certain rights in these lands. Reserve land is fully under "control" of chiefs and preserves the social structure of chief and headman and traditional law courts. On average there is 12.6 ha available per farm (bush, arable and grazing land). Mean family size is 8.4 persons (3.9 in active labour, 4.5 dependents, BOE 88, p.2; 1.5 ha of land available per head).

State land areas are considered the most developed in agriculture, a typical pattern in Zambia. Extension worker ratio is much higher as compared to reserve areas. On the other hand settlement farmers in Magoye area face shortage of farming and grazing land.

4.3.2 Extension work

There are 11 extension officers in the area based in the agricultural camps. Table 4.2 shows the number of farm households served and the average distance covered. Each camp is headed by an extension officer and divided into 8 zones. The extension workers pay regular visits to the various zones to train farmers and inform them on a range of topics. For each zones 10 farmers are elected by the farmers of that zone as contact farmers. Contact farmers are supposed to have a meeting with the extension officer every fortnight, meetings which also can be attended by the farmers they represent. Contact farmers are responsible for passing through information to them.

4.3.3 Crop production

Cash crops grown in the area are maize, cotton, soyabean, sunflower. Also commercial farmers grow groundnuts as cash crop. Other farmers grow groundnuts for informal trade. The higher the hectarage cultivated (per type of farmer), the higher total yield, but also the higher the yield per unit area. This is due to more efficient farming methods (e.g. higher application rates and a more optimal combination of fertilizer, seeds, chemicals; better land preparation). Crop production figures of the seasons 1985/86, 1986/87, 1987/88 are presented in appendix F.4.

Several problems hamper crop production in Magoye area:
1) The great loss of cattle in the last years due to corridor disease. Because of this loss farmers have not enough oxen anymore for ploughing and harrowing and are forced to hire oxen or a tractor from fellow farmers or companies (e.g. Lusume Services Ltd.).
2) Late planting, as a result of:
   a) the struggle to hire oxen,
   b) late distribution of seeds and fertilizer by SPCMU (Southern Province Co-operative and Marketing Union) depots,
   c) late approval of seasonal loans (for seeds and fertilizer) by the lending institutions.
   d) late payments of farmers for their produce by SPCMU. As a consequence they face difficulties in buying the necessary inputs in time for the next season.
3) Late opening of depots for the harvested crops. In the meantime uncollected maize is attacked by termites and ants.
4) Several farmers face budgetting problems: they are not capable of paying off the loan of the previous season. If they do not pay off the loan in time their request for a loan for the new season will not be approved.
5) SPCMU is supposed to provide implements also. At time of research the depots only provided ploughs and some spare parts. For other equipment farmers have to go to commercial shops in the nearby towns (Magoye, Mazabuka, Monze). In retail shops prices are higher than the SPCMU prices. Since most farmers do not have private transport means (except ox-carts) transport to those cities is always a problem.
6) Irrigation is generally not applied in the area. As water supply is inadequate, droughts (such as the one in 1987) continue to cause problems.

4.3.4 Animal husbandry

Almost all of Magoye farmers own cattle. During the day cattle are kept on grazing land. During the night cattle are kept in kraals as a protection against theft and to protect crops. Further a farming family usually keeps chicken. Also goat and pig keeping is common, but not every farmer owns these animals.

Table F.7 (appendix F.4) reviews the number of cattle in Magoye area in 1987 kept by emergent and traditional farmers.

Farmers face various problems in livestock keeping:
1) diseases,
2) scarcity of drinking water for animals during the dry season (May-November),
3) scarcity of grass for grazing of cattle during the dry season.

ad 1) The major disease affecting cattle is corridor disease, especially during the rainy season (December-April). During the rainy season the brown earticks causing corridor disease multiply more rapidly than in the dry season and hence pose a big threat to cattle. At this time of the year farmers are busy with cultivation of crops and they have spent most of their money on buying fertilizer and other crop inputs. Therefore, in many cases cattle are not dipped or sprayed with
Acaricides or cattle receive a very dilute mixture of acaricide which fails to kill ticks. A vaccin against corridor disease has not been developed so far. Once affected by the disease 80-95% of the cattle die.

Foot and mouth disease was a problem in and around Magoye area in 1987. The disease was eradicated however, due to a vaccination campaign carried out by the Veterinary and Tsetsefly Control Department and due to restrictions in the movement of cattle (imposed by the same department).

Other diseases that are found occasionally in Magoye area are skin disease and tickborne diseases such as anaplasmosis, heart water and bubesiosis.

ad 2) Scarcity of drinking water is another problem. As elsewhere in the region the many streams in Magoye area are seasonal. As soon as the dry season sets in they dry up. The longer lasting water sources are pools, captured by dams on which cattle tend to depend more in the dry season. Many cattle farmers take their animals to Kafue River where there is abundant water and grass supply. Unfortunately this is also the place where many cattle pick up tickborne and other diseases, since cattle are not (sufficiently) dipped or sprayed with acaricides.

ad 3) Also the grazing grass becomes scarce in the dry season. Due to a high population of cattle in Magoye area and the fact that grass concentration is low (because it is not cultivated or fertilized) the grass is soon overgrazed and cattle only survive on scanty grass resources and maize stover. Usually there is no other supplementary feeding.

Especially in the settlement areas overgrazing is a problem. In 1975 the average hectarage per animal was 2.1 ha, much less than the required minimum of 4 ha/animal (SOU 75, p.173). Although the settlements have individual paddock areas, these are nothing more than lines on maps as little fencing takes place. Costs of fencing materials are prohibitive. Even if they had money their first priority would be to fence arable land. So animals are still being grazed on a communal basis.

Corridor disease has a disastrous effect in the area. All respondents reported to have lost cattle (average: 46%, ranging from 18-71%). In 1975 the average number of cattle on the reserves was 24 per farmers (with an annual growth rate of 2.2%/annum, SOU 75, p.173); the average number per farmers on the settlement areas was 36 (of which 10 oxen). Table F.7 shows how averages have gone down since.

Figures of sales are very low. For example for the 1973/74 season 141 cattle were sold on the settlement areas (total number of cattle 6711) and 17 on the reserves (out of a sample of 992). Sales and slaughters are in a long way from commercial standards (SOU 75).

4.3.5 Agricultural organisations

The Decentralisation Act of 1980 was meant to transform the existing centralized decision structure into a more decentralized
structure with local authorities (district, ward) more in control over their own, including financial, affairs. Another reason was the bureaucratic and heavily subsidized operations of the parastatals. Provincial Cooperative Unions were created intended to take over the tasks of parastatal marketing organisations. In Southern Province the SPCMU (Southern Province Cooperative and Marketing Union) was formed. In 1986 it took over the marketing of crops from Namboard (except for cotton, which remains marketed by the parastatal Lintco). Currently SPCMU is engaged in:
- crop marketing,
- transport,
- supply of farm inputs and equipment,
- supply of consumer goods,
- small-scale milling,
- credit supply.
So far, traditional crops and vegetables had no access to the official marketing system. These are informally traded, together with some cash crops, amongst the rural population on a small scale. Traded quantities at local market places or farmgates are negligible.

A depot run by SPCMU or Multipurpose Society usually also provides implements and has a consumer shop, mainly selling essential consumption goods (soap, sugar, cooking oil, salt, blankets, paraffin).

All farmers in Magoye area are member of SPCMU. After paying a registration fee of K20 one becomes a full member.

Credit allocation in the area is in the hands of SPCMU, Lima Bank and commercial banks (Barclays Bank, Standard Chartered Bank) in Mazabuka. Seasonal loans are given mostly for buying seeds, fertilizer and in some cases chemicals. The loans have to be paid off in one year. An important condition for obtaining a loan for the new season is that the loan of the previous season has been paid off. Visits to farmers are made regularly to know his crop production and his ability to pay off the loan. The amount of money lended depends on the proposed hectarage of cultivation and the bank's judgement of the farmer's production possibilities.

Medium term loans (3 years) are provided for obtaining implements, oxen, tractor, again in accordance with the farmers financial position. Interest rates for seasonal and medium term loans were about 30% in early 1987 but have dropped to 18-20% (1987/1988, see also appendix A for information on interest rates).

The agricultural infrastructure is hit by several problems and constraints:
1) in the present marketing system mutual responsibilities and competences are obscurely defined. Coordination between Namboard and the provincial Cooperative Unions (PCUs) is still low. Unions still depend heavily on government funds. For example in the 1984/85 season government funds were not released in time with as a consequence that the PCUs could not pay farmers in time for their produce. Also the PCUs could not pay Namboard in time for delivered fertilizer and empty bags. As a reaction Namboard delayed deliveries of inputs for the cropping season 1985/86.
2) the maize haulage season is June-October, but is usually spilt over even to December. The Magoye picture is not different from the rest of Zambia: lack of transport possibilities and bad management at district
level lead to delayed crop haulage. Every year tonnes of maize (in some years even approaching 20% of the harvest) are wasted, because crop haulage is disturbed by the rainy season (in Magoye e.g. starting last year already in October). Lack of tarpauling capacity leads to tonnes of maize soaked in the depots and Multipurpose Society depots, before it is collected in the district centre.

4.4 Energy demand and supply Magoye area

4.4.1 Supply and demand of energy

The main sources of energy in Magoye area are:
- traditional sources (firewood, charcoal, human and animal power)
- conventional sources: - electricity,
  - petroleum products (diesel, gasoline, kerosene),

Traditional sources of energy

Firewood is the main source of fuel of the main group of consumers: (farming) households. Firewood is used for cooking food and water and space heating, usually used in an open fire.

Charcoal is produced in the area by traditional methods (as described in AKK 89, part C.2.3). The bulk goes to the nearby towns Mazabuka and Monze, and, and even to Lusaka Province. Use in the area itself is small, the main users being households (for baking) and smithery.

Magoye area, and Southern Province in general, has a tradition of using animal draught power (ADP) for transport and land preparation, which creates the base for the above-average character of Magoye farming. The interviewed emergent and settlement farmers usually possessed one or more of the following ox-drawn implements: plough, harrow, cultivator, planter, ox-cart and one even a trailer (see paragraph 5.3.2 and 5.4 for more details). The interviewed peasant farmers usually did not have a planter and sometimes not an ox-cart. Few farmers posses a tractor. Ownership of a tractor and associated equipment is restricted to commercial farmers and to a very few settlement farmers.

Conventional fuels

Magoye Town is connected to a 33 kV line of the national grid. Thus electricity is available in and around Magoye Town to higher-income households, services, institutions, shops, workshops, commercial farmers. An extension of the 33 kV line provides electricity in Chivuna (shops, the secondary school, the hammermill, the mission, the RHC). Usually farming households have no connection to the electricity grid.
Only commercial farmers, all situated around Magoye Town, can afford to be connected.

Petroleum products (diesel, gasolene, paraffine) are provided by the filling station in Magoye Town (run by Family Farms Ltd.). This causes supply problems to households living in the further-away camps (see map Magoye area). Although these products are made available in local retail shops. However, in retail shops prices are much higher. For example, costs of paraffine are K 1.74/litre (filling station Magoye, September 1988). However, people in the further-away agricultural camps find the prices of kerosene in retail shops much higher (K 3-4 per 1 litre bottle). Kerosene is the main fuel of lighting for most farming households. For lighting locally made lamps (tins) are used. More wealthy farmers use hurricane lamps. A problem with these lamps is to obtain spare glasses.

Constraints in energy supply

Increasing firewood shortage in the area is caused by charcoal production and by population pressure. Firewood shortage is considered a major constraint in the reserve lands of Munjile and Chivuna and on a few settlement areas (Magoye A, Ngezi A and C; BOE 88, own findings). Scarcity of fuelwood goes hand-in-hand with greater walking distances (3-5 km). Farmers in Munjile and Chivuna mentioned they had to go to the nearby settlement areas. The farmers there charge fees with a minimum of K 10 per tree. The interviewed settlement farmers seemed to be more aware of firewood nursery than farmers on the reserves. They stated they save a part of their plot for wood.

Since cattle keeping has recently been severely hit by several problems, these problems (mentioned in paragraph 4.3.4) have also affected application of animal draught power.

Other constraints are:
1) the quality of ox-drawn implements and ox-carts is generally poor. Respondants stated lifetimes of 3-5 years in the interviews for local (Zambian) made implements, as compared with more than 10-15 years for imported ones.
2) the majority of farmers require credit for purchase of oxen and ox-drawn implements. At present, especially after the recent losses of cattle and oxen, supply of medium-term loans for ADP is far below demand.
3) Local craftsmen and workshops in Magoye area do repair and making of mouldboards, spikes of cultivators, landslides, ox-carts. But the facilities are not sufficient to meet the demand for repairs of farming implements, a picture that is for that matter typical for the whole of Zambian rural areas. At present, supply by the depots of farm implements and spare parts is far below the required level. Only ploughs and plough spares are supplied by the depots. Depot officials stated that soon also cultivators would be supplied. To buy new implements or to get old ones repaired, farmers are forced to go to towns. In this cases transport always presents a problem, specially when one has to go to towns as Mazabuka or Monze. Lack of spares and repair facilities lead to a shortened lifetime of the implements and their underutilization. For example punctures in ox-carts tires pose a big problem and are the main cause of breakdowns leaving a cart unused for long periods. Punctures
are frequently caused by thorns on the road. Repair costs are expensive: about K 25 per puncture.

As a consequence of the disastrous loss of cattle last years some farmers are forced to hire oxen or tractors for the work to be done. Of the interviewed farmers 1 settlement farmer hired a tractor for ploughing and planting; of the 4 emergent/settlement farmers 3 hired a tractor for transport, 1 hired oxen plus ox-cart, 1 used his own means of transport (ox-cart and trailer). Of the 5 peasant farmers 4 used own means of transport (ox-cart), 1 hired a tractor from the settlements. For land preparation 3 peasant farmers responded to hire oxen.

4.4.2 Possibilities to improve energy supply in Magoye area and practical applications

In paragraphs 2.4 and 3.3.2 we discussed alternatives for current energy sources and technologies. Here we will elaborate on the possibilities of harnessing such sources in Magoye area, as an prelude to chapter 5.

1) greater efficiency in the production of traditional forms of energy and greater efficiency of traditional energy conversion methods.

Rural households use wood directly in open fires. Simple designs of wood stoves permit increasing the efficiency with which heat is used. Because charcoal production is cause of deforestation options for saving rural woodstock should include also urban household energy options. Introduction of improved charcoal stoves (reducing urban demand) and improved charcoal production methods contribute to conservation of wood stock in the Magoye area, an should therefore be included in a rural energy strategy as indirect means.

2) substitution of traditional energy sources by new 'modern' sources.

Options for (both nearby-urban and Magoye rural) households are:
- electricity, supplied from the national grid. Magoye lies at a 33 kV line. From this line a grid extension can be constructed to distribute electricity to households. Electricity can also be supplied by diesel-generators.
- kerosene can be used for cooking in special stoves.

3) substitution by 'renewable' sources of energy and new energy conversion technologies.

Options are:
- direct use of renewable sources of energy:
  - biomass: 1) woodgas (produced from wood in a gasifier), 2) biogas (produced in a digester from dung and crop residues);
  - solar energy, by employing solar collectors;
  - wind energy;
  - hydropower.
- electricity generation, by
  - photovoltaic systems
  - dual-fuel engines (on biogas, woodgas),
- windmill generators,
- hydropower.

**Improved wood supply**

In Mazabuka District, the Conservation Programme of Lusume Services Ltd. (a rural development non-governmental organization) is involved in soil conservation and agroforestry. The head office is at Magoye. With local shortages of firewood already manifested in the area agroforestry has a great multi-purpose potential. Besides tackling the fuelwood constraint, agroforestry serves to handle:
- soil erosion. Besides measures as digging contour ridges, greater plant density, intercropping (also with legumes), and application of manure, also interplanting of trees along contour lines helps to reduce erosion.
- storm damage. Thunderstorms are a frequent feature in the area, causing crop damage. planting trees in windbreaks tackles this problem.
- diet deficits of rural people. Using (indigenous and/or exotic) fruit trees will increase levels of nutrition.
- fodder shortage in the dry season. Evergreen fodder trees can provide fodder to cattle when not sufficient grass is available in the dry season.
- land fencing. Only very few farms are presently fenced with barbed wire, as costs are prohibitive. Many farmers (also on the reserves) have a desire to mark boundaries and to fence fields. Cause for this desire is most likely the frequent crop damages by stray cattle, and on the settlements, disputes over boundaries.

In Magoye area are farmers, who already have some experience with tree planting, though planting of trees for other reasons besides fruit, vegetable leaves and shade (mostly around the homestead) is not very common. Most farmers have not started planting fuelwood trees. A major bottleneck in fuelwood tree planting is the availability and the right choice of fuelwood species in the past. The Forest Department has supplied Eucalyptus trees in great numbers in the past (to rural schools and to farmers). Survival rates were very poor however. This was due to the fact that the necessary inputs (Dieldrin/Aldrin Borate against boron deficiency and fertilizer) were not provided, while farmers were not informed that Eucalyptus planting would fail without these. Another important bottleneck is that farmers are reluctant to invest in tree planting, because it does not yield (cash) profit on short term.

**Other sources of renewable energy**

No efforts are presently undertaken in the area to introduce wood-saving cooking methods, improved charcoal production methods, or other biomass conversion technologies, such as biogas or woodgas technology.

The cultivation of soyabean, sunflower offers possibilities to enhance oil extraction. Vegetable oil has a multi-purpose use as cooking oil, or also as fuel. By its tradition of cattle keeping Magoye area has a great potential for biogas technology.
Magoye area enjoys a high annual average solar influx of about 2283 kWh/m²/year (or 6.25 kWh/m²/day), with an annual average number of 8.4 sunshine hours per day. Monthly averages vary between 5.40-7.50 kWh/m²/day, and 5.7-10.1 sunshine hours per day. This makes Magoye area an ideal candidate for solar power application.

The winds that dominate this part of Zambia have low energy characteristics. The average annual windspeed is 2.4 m/s. Seasonal variation in windspeeds occur, with a minimum in February (1.3 m/s) and a maximum in September (3.4 m/s). Wind potential is low therefore. Generation of electricity is excluded as windmill generation systems require cut-in speeds of 2.5-3 m/s.

Some windmills are in use in the area for waterpumping (on farms and schools). In the colonial days several expatriate farmers had installed windmills. After they left these windmills were neglected so allmost all have perished. In the eighties Family Farms Ltd. was involved in installing windmills. After a heavy storm the windmills got damaged however and the project was not continued.

Application of small-scale hydropower in the area is practically excluded as Magoye area has a flat topography, and rivers and streams (almost) fall dry in the dry season.
Chapter 5 ENERGY DEMAND AND SUPPLY OF FARMING HOUSEHOLDS IN MAGOYE AREA

5.1 Introduction

Chapter 5 starts with a qualitative analysis of energy consumption of typical Magoye farming households (paragraph 5.2). A description is given of various energy-consuming tasks, and current technologies (referred to as energy end-use equipment) employed in these tasks (together referred to as 'energy aims'). Possible alternative technologies are identified.

Before discussing the supply side ('tools': energy sources and conversion technologies) an analysis is made of income and expenditure levels of Magoye farming households. Knowledge of the financial means of households is essential when evaluating the feasibility of technologies.

In this report 'groups of farming households' are defined (see table 5.0), corresponding with the 'groups of farmers' identified in paragraph 4.3.1:

a) peasant farming households,

b) emergent farming households (on reserves and settlements),

c) commercial farming households.

Here the words 'farm', 'farmer', 'farming household' are used interchangably, as for peasant and emergent farmers holds that one household works on one farm. For commercial farms this is not true: also permanent labourers and their families derive income from the farm. In this report households of wage labourers are not studied (in accordance with the convention adopted in chapter 3). A 'commercial farming household' is defined as the owner of the farm and his family, or, in case the farm is owned by a (private or state) firm, the manager and his family, and his farm.

Emergent farmers can be divided in emergent farmers on the reserves and settlement farmers. Settlement farmers could be regarded as a separate group (see paragraph 4.3.1). Too little information was available to maintain a clear division between reserve and settlement farmers throughout the report, so are treated as one group: 'emergent farmers'.

In paragraph 4.4 the supply side, energy resources in Magoye area, was shortly reviewed. Paragraph 5.4 confronts supply and demand side by looking how each (current and alternative) energy tool can match energy demand of each (current and alternative) technology employed in the identified tasks.

In the paragraphs 5.5 and 5.6 impacts are analyzed and quantified in view of the energy aims. Effects studied here are the ability of energy tools to match energy demand, and their profitability/feasibility and reliability. Impacts are evaluated in the next chapter 6. In this chapter conclusions regarding energy supply in farming households and Magoye area in general are formulated, and recommendations to improve energy infrastructure are presented.
### Table 5.0  Broad characteristics of main types of Bagoye farming households.

The table gives a summary of main characteristics discussed in the paragraphs 4.3.1 and 5.2. Sources data: own findings, Bagoye Block supervisor, BOE 88.

<table>
<thead>
<tr>
<th>Category</th>
<th>Small-scale (peasant)</th>
<th>Emergent</th>
<th>Large-scale (commercial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic staple</td>
<td>Maize</td>
<td>Maize</td>
<td>Maize</td>
</tr>
<tr>
<td>Subsistence crops</td>
<td>Sorghum</td>
<td>Sorghum</td>
<td>Sorghum</td>
</tr>
<tr>
<td>Cash crops (main)</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Cotton</td>
</tr>
<tr>
<td>Source of cash + maize</td>
<td>Sunflower</td>
<td>Sunflower</td>
<td>Sunflower</td>
</tr>
<tr>
<td></td>
<td>Soyabean</td>
<td>Soyabean</td>
<td>Soyabean</td>
</tr>
<tr>
<td></td>
<td>Groundnuts</td>
<td>Groundnuts</td>
<td>Groundnuts</td>
</tr>
</tbody>
</table>

| Main inputs purchased         | Fertilizer #          | Fertilizer # | Fertilizer |
|                               | Seed                  | Pesticide/   | Pesticide/insecticide/   |
|                               |                       | insecticide* | herbicide               |

### Energy/powers:

**TRADITIONAL:**
- wood: cooking/heating
- charcoal: baking
- human power: cooking/heating, domestic tasks, domestic tasks, transport, transport, transport, transport, crop production, crop production, crop production, and processing, and processing, water lifting, water lifting
- animal power: transport, transport, land preparation, land preparation, (one or two teams), (several teams if oxed, ox hire), oxed

**CONVENTIONAL (MODERN):**
- paraffine: lighting
- diesel/gasoline engines: occasionally, (maize sheller/waterpump, tractor (transport, land preparation, planting), (maize sheller, pump, tractor hire), engines (e.g. pump or maize sheller/grinder, cooking/lighting/other household appliances).
- electricity (from the grid)

### Hiring of labour

<table>
<thead>
<tr>
<th>Average area cultivated</th>
<th>3.5 hectares</th>
<th>10 hectares</th>
<th>50 hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition (hectares)</td>
<td>&lt; 5</td>
<td>5 to 40</td>
<td>&gt; 40</td>
</tr>
<tr>
<td>Number of farms</td>
<td>210 (reserve land)</td>
<td>300 (settlement)</td>
<td></td>
</tr>
<tr>
<td>Percentage total number</td>
<td>86.4%</td>
<td>12.9%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Estimated household size</td>
<td>8.2</td>
<td>10.5 (reserve land)</td>
<td>n.a.</td>
</tr>
<tr>
<td>per farm (reserves 4.4; settlement 21)</td>
<td>21 (settlement)</td>
<td>16 (average emergent)</td>
<td></td>
</tr>
</tbody>
</table>

---

n.a.: not appropriate: see definition of 'household' and 'farm' given in the text (paragraph 5.1).
5.2 The structure of energy consumption in a farming household

5.2.1 Introduction

Two main groups of tasks performed in a farming household can be distinguished, in economical terms:
- consumption: (domestic) tasks, e.g. food preparation
- production: crop production, crop processing, livestock maintenance.

Figure 5.1 gives a conceptual scheme of energy use in tasks performed by a farming household. These tasks are interlinked by energy flows.

Energy flows into the agricultural production component in the form of work (human, animal, machines, consuming fuels), fertilizer (chemical, dung or crop residues) and solar energy for growing. Part of the crop and crop residues are recycled in the household system in the form of food, cattle fodder, and crop residues as fertilizer.

Energy flows into the livestock component in the form of human labour, fodder. Outputs are dung, cattle products, animal labour.

Energy flows into domestic component in the form of food and fuels. Human labour is energy input in the other components.

A farming household is not energy self-sufficient. Energy inputs are received from communal lands (wood), other households (e.g. labour or oxen hiring), or the market (fertilizer, fuel).

In the following sections of this paragraph we will look into detail at these energy-consuming tasks. A description of technologies used, and their energy inputs is given, differentiating between peasant, emergent and commercial farmers. Livestock maintenance is not discussed separately here, as this was already discussed in the paragraphs 4.3.4 and 4.4.1.

Tasks can be divided according to economical terms (consumptive or productive tasks). Another way is dividing tasks according to the end-use form in which energy is consumed in a particular task. The following table gives a breakdown of farming household tasks, according to economical terms, and according to the end-use form of energy applications require heat, light or electricity as end-use form of energy):

<table>
<thead>
<tr>
<th>End-use form</th>
<th>Consumption</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat, light</td>
<td>cooking, lighting</td>
<td>crop drying</td>
</tr>
<tr>
<td>Motive power</td>
<td>transport</td>
<td>transport</td>
</tr>
<tr>
<td>Stationary power</td>
<td>domestic water supply</td>
<td>land preparation, planting, harvesting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>irrigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>crop processing</td>
</tr>
</tbody>
</table>

Note: domestic water supply is defined here (for practical reasons) as: water supply for human and livestock consumption, and garden watering.
5.2.2 Description of domestic energy-consuming tasks

Major (fuel-consuming) domestic tasks in a household are:
- food consumption and preparation,
- space heating,
- cleaning and washing,
- lighting,
- water procuring (see paragraph 5.2.4),
- firewood collection (see paragraph 5.2.4),
Energy demand and supply of farming households in Magoye area

Food consumption and preparation

Typical Magoye peasant and emergent farming households cook over open fires, using wood. Cooking is done outside, as smoking fires inside the hut would be irritating and dangerous. Baking (e.g. bread, oil-buns) is done employing brick-made stoves, which are heated using charcoal or wood. Interviewees stated that they could not bake regularly due to shortage of flour.

On an average people have at least two meals per day, at midday and the second one in the evening. The staple food in Magoye area is *nshima*, served with relish. *Nshima* is maize meal, cooked with water into a thick porridge. The relish may contain vegetables (ocra, groundnuts, rape, peas, beans, pumpkins), fish, meat, mushrooms, or combinations thereof. Content of relish depends on the season, with consequences for food intake levels. Especially from January to August intake levels in peasant and emergent households are lowest and dietary practices are nutritionally inefficient.

It takes about 1 hour to cook a meal of *nshima*, but varying with the relish content.

The open fire is the least efficient cooking method from an energy point of view. As long as firewood is abundant this may not pose a big problem. But with the beginning firewood scarcity in the area, a strong case can be made for introduction of wood-saving stoves or alternative fuels. In the Magoye context potential alternative fuels could be electricity, biogas, petroleum products.

Lighting

For lighting predominantly paraffine is used by peasant and emergent farming households. Lighting devices for the poorer households are "can & wick" lamps, made from tins. More wealthy farmers have hurricane lamps (which cost about K 150). A problem with these lamps is to obtain spare glasses.

Illuminance of these lighting methods is very poor. The basic unit of light intensity is the lumen (lm), which combines a physical measure of the light level, with the response to this by the human eye. Illuminance refers to the effective light level per unit area (unit: lumen/m²). In the developed countries the following standards have been developed:

- passageways, relaxation, recreation 110 lumen/m²
- reading 320
- handwriting, study 750

Illuminance of a can & wick is about 5.4 lumen/m², of a hurricane about 32 lumen/m². A 60 W incandescent electric bulb gives a light intensity of 430 lumen/m². Using improved kerosene lamps (e.g. a pressure-type lantern), electric bulbs, biogas or solar lanterns would improve quality of lighting in a farming household.

Other domestic energy end-uses: use of electricity

For space heating in the cold season the open fire is usually used. A respondent stated that all one needed extra was 1 or 2 blankets.

Hot water supply is luxury few have heard of. Generally it is considered that the climate does not necessitate the use of hot water. Almost all commercial farming households are connected to the...
electricity grid. Only these households, supplied with electricity, consume substantial amounts of fuel for uses other than cooking and lighting. Major demand is for refrigeration and air conditioning, with minor amounts for TV, radio, ironing and electric power tools.

5.2.3 Description of energy-consuming tasks in production

Land preparation
Growing of a crop starts with land preparation, in which a number of tasks are carried out: land clearing, land grading and soil preparation.

Land clearing and land grading have to be carried out only once in principle. Especially in the case of irrigation application land grading is important. Traditionally these tasks (clearing and grading) are carried out manually. The use of ox and tractor power is more efficient and gives a better result.

Soil preparation
a) Quality and quantity of the harvested crop is determined by the extent to which ploughing is performed. The least effective method is manual ploughing (by a hoe). Ox-ploughing (peasant and emergent farmers) is a considerable improvement, though depending on plough quality and skill of the farmer. Best results give tractor ploughing (commercial farmers).

b) Harrowing and cultivation are performed after ploughing. It can be done manually, animal traction (peasant and emergent farmers) or by a tractor with a sophisticated harrow and cultivator.

c) Ridging is performed to make later tasks (weeding, fertilizer application, harvesting) easier. Ditching is required to dispose of excess water, but few farmers in Magoye area put this into practice. Tasks are performed manually (hoe), by animal traction (ridger, peasant and emergent farmers) and a tractor (commercial farmers).

Planting
Planting is performed manually using a hoe, or by a mechanical planter (hand-operated, ox-drawn or tractor-drawn). Generally, Magoye farmers plant manually; settlement farmers employ ox-drawn planters, commercial farmers tractor-drawn. The advantage of mechanical planters is that seeds are sown in lines with constant depth.

Seeds can be local varieties, which are removed from the mother plant. In the case of cash crops however (see table 5.0), usually hybrid seeds are bought.

Fertilizer
Application of fertilizer depends on the nutrient removal of the specific crop and of the fertility of the soil concerned. Usually dung is applied before ploughing and collected from the cattle kraals. Peasant and emergent farmers use chemical fertilizer, but almost exclusively on maize. In principal it is recommended for every crop, by extension officers. Fertilizer is applied twice, as basal dressing (with
Crop protection

The traditional method of weeding is with help of a hoe. Magoye peasant and emergent farmers usually do not employ herbicides. Some interviewees stated however the need for herbicides. Especially during the growing phase plants are vulnerable to attacks by ants and termites. Insekticides cannot be afforded by peasant farmers however. Some emergent farmers use insekticides on maize.

Cotton needs frequent and intensive spraying, because of the many pests. Pesticides are therefore used by all cotton-growing farmers. Use of pesticides on other crops is hardly occurs however.

Farmers perform chemical spraying with knapsack sprayers, which are shoulder-carried and continuously pumped by a hand lever. Tractor spraying is only economical on large plots.

A general picture is that commercial farmers apply seeds, fertilizer, and chemicals above recommended levels, emergent farmers at about these levels, and peasant farmers below these levels.

Harvesting, storage, processing and transport of crops

In the area harvesting is performed manually. The traditional method is cutting the crop manually (by using a scythe, reaper, brush cutter or knife). Cotton is harvested by picking, which is very labourious. It begins 4 months after sowing, and lasts for two months, during which period picking has to be done every week to prevent staining.

The main on-farm crop processing activity is maize shelling. Before the maize is sold to SFCMU the grain has to be removed from the cob. The traditional method in the area to achieve this is beating maize on raised racks. A more efficient method is using shellers (hand- or engine-powered). Settlement and commercial farmers farmers in the area own or hire such shellers.

Other crop processing activities in the area are not common. These are discouraged by the unfavourable pricing policy of the government. This makes small-scale rural processing (e.g. maize grinding, oil extraction from soyabean or sunflower, grading and ginning of cotton) not competitive against subsidized parastatals.

Before crops are stored (whether on-farm or in depots) drying is essential to prevent germination and growth of bacteria and fungi. Sun-drying is the traditional method, and causes no problems as this activity takes place in the driest months.

Crops retained for home consumption or informal trade are stored (peasant and emergent farmers). The maize retained is stored unshelled in locally built storage bins, called butala. These are built of mud bricks with spaces left between them to allow ventilation. Pests and termites pose a big problem. Storage bins require spraying prior to loading them. As pesticides are expensive this is generally not done. One interviewed farmer stated that 50-75% of his stored maize was spoilt last year.

Transport of crops is discussed in the next paragraph.
5.2.4 Transport

Trips can be divided:
- "on-farm", in domestic activities (firewood collection, water procuring) and in agriculture (movement of small loads of in- and outputs from farm to the fields). Firewood collection (peasant, emergent farmers) is one of the most time-consuming activities in domestic transport. If loads are not too large and distance not too great most of the trips are by walking, otherwise by ox-cart. With a growing firewood shortage, distance will form a constraint. In the dry season water fetching is added as an important time-consuming activity, as many hand-dug private wells fall dry and water has to be fetched over larger distances. About 15-20 litre can be carried per person, with a walking speed of about 1.5 km/hour (KOL 87, p.52).
- "off-farm", in domestic activities (personal trips to clinics, shops, social contacts) and in agriculture (movement of goods from farm to the market, depot, road, etc. or vice versa). In Magoye area most farming households rely on walking, cycling or using ox-carts for nearby personal trips. Only a commercial farmer can afford a private vehicle. For transport to nearby towns people rely on public transport or private vehicles (the latter often charging about K 10 per person).

Transport in agriculture is related to the crop calender, as peaks occur when use of farm inputs is sensitive or yields have to be transported.

**Transport means** can be subdivided in:
- human-powered (human porterage, wheelbarrows/handcarts, pedalled vehicles),
- animal-powered,
- motorized.

**Human porterage** (headloading, shoulderloading, backloading) is the most simple form of transport. Typical loads in developing countries are in the range of 20-30 kg. It is quite arduous work physical work, that over a longer period can result in damage of the spine, joints, muscles of the limb and trunks and internal organs. Headloading is in most cases a female task, requiring considerable skill.

**Wheelbarrows and handcarts** are a very useful transport means both for on- and off-farm transport. Maximum loads vary from 100 kg (western-type wheelbarrow) to 1000 kg (large handcart pushed by several people). Handcarts are not known in the area, to my knowledge.

Use of **bicycles** in the area is constrained by the high price (about K 1200, 1988 price; K 790, mid 1987 price), the deplorable quality, and absence of spare parts. Punctures pose a big problem. Strenghened bicycles to carry loads are not known in Magoye area. The weak construction of ordinary bikes prevents them being used for load carrying.

**Ox-carts** play an important role as transport means in Magoye farming households. In the area ox-carts are constructed by:
- local craftsmen,
- Lusume Services Workshop (at Magoye Town, about K 6000-7000, end 1988 prices)

The most common type has 2 wheels, frequently axles and tyres from scrap vehicles are used, in otherwise traditional design. Such a cart can carry about 500 kg. More sophisticated types about 1000 kg. A 4-wheel
5.2.5 Mechanization of power applications

In agricultural production systems one can differentiate between a traditional, transitional and modern system. This systems more or less correspond with the farming systems as distinguished in paragraphs 3.2 and 4.3.

A traditional system (traditional or subsistence farmer, see table 3.1) is characterized by a very low degree of commercial inputs. Main energy input is human labour, so tasks are non-mechanized. A transitional system (peasant, emergent farmers) starts using purchased inputs (chemical fertilizer, seeds, chemicals), fields are prepared by draught animals. Sometimes (part of) the tasks are motorized (mostly hired). In a modern system (commercial farmer) all tasks are motorized as far as possible or feasible. Input of fertilizer, seeds and chemicals are at least at recommended levels.

Positive aspects of mechanization are:
- increase of yields,
- intensification of land-use,
- wider cropping system (multiple instead of single),
- reduced labour requirement,
- less dependency on hired services,
- work time reduction and less fatigue,
- increase of image.

Negative aspects are, however:
- costs of mechanization (investment and operating costs),
- requirements of higher skills of the farmer,
- higher risks,
- dependency on spare parts, repair and maintenance services.

Tasks in agricultural production are not mechanized at the same stage. Operations first to be mechanized are soil preparation and transport. The right time of sowing and planting has a great influence on ultimate crop yield, and it is important that these tasks are done as quickly as possible. Mechanization helps to guarantee such a quick land preparation and relieve man and animal of the strains during peak labour.

Next steps in the process is mechanization of harvesting and weeding (combine harvesters, tractor sprayers). However machines used,
- are very specialized,
- can only be used in a very limited period,
- have large capacities.
Therefore use is restricted to large plots, or to contractors, co-operatives.
5.2.6 Water management

Water resources of Magoye farming households (human consumption, cattle and garden watering) are lifted and surface water. Lifted water is from hand-dug wells. Commercial farms get their water from boreholes. In some areas (e.g. Chivuna) communal pumps are in use. Surface water is streams, rivers. Source of power in lifting water is human power (using rope and buckets). Water supply is hampered in the dry season, as streams dry up and hand-dug wells dry out.

A first way of improving water supply is casing of wells. This prevents collapse and caving, and thus allows wells to be dug deeper, giving higher drawdowns (and thus yield). As materials masonry and brickwork are used, or in less stable grounds (low tensile strength, unequal pressure) concrete. Also bacteriological quality of such wells is better than of traditional wells or surface water, which are often the focus of parasitic and bacterial diseases.

Water yields a traditional wells can deliver are limited. Boreholes (drilled wells) are the invariable choice, when:
- large quantities of water are required, and the well diameter would have to be so large as uneconomical as compared with a borehole.
- there is a impervious layer that prevents further penetration by digging.

In a modern system mechanization also enables to have two crops per year, short time after another, without post- and pre-harvest work overlapping each other. This is only possible if climate conditions are favourable and water supply is guaranteed.

The natural way of water provision is by rainfall. Adequacy of rainfall is determined by:
- the average annual rainfall
- the distribution of rainfall. Supply has to match demand and both vary throughout the year.

Crop production in Magoye area is frequently hampered by critical water shortage in the dry season. The 1987 drought brought many farmers in financial problems and in some cases even starvation.

An adequate water supply is thus an important aspect of crop growing, not only to expand production, but also to reduce risks. Surface water is not available in the dry season. Thus primary source for irrigation in Magoye area is pumped water from boreholes. This makes large investments in a (engine-powered) pumpset necessary and thus irrigation a very costly affair. Only above-average commercial farmers seem to be able to afford irrigation.

Two types of irrigation are important:
- sprinkler irrigation,
- gravity irrigation.

In gravity irrigation water is transported in furrows, ditches, which are excavated in combination with land preparation practices.

In sprinkler irrigation water is transferred by a piping system to sprinklers, which spread the water over the field. Sprinkler irrigation is more expensive than furrow irrigation.

Pumps can be classified according to mechanical principles:
I Displacement pumps. The most widely used pumps under this heading are
reciprocating plunger pumps, in which water is moved by the direct push of a plunger piston.

1) hand- or engine-powered pumps, in which the cylinder is above ground as part of the pump's body (up to 5-6 metres depth).
2) hand-, engine or wind-operated deep well pumps, where the cylinder is in the well/borehole.
3) rotary pumps (hand- or engine-powered).
4) chain & bucket systems, such as the traditional rope and bucket, or chain-bucket pumps. Especially the latter type is suitable for animal-powered pumping.

II Velocity pumps.

5) engine-powered centrifugal and turbine pumps, driven either from the surface or by a submersible electric motor.
6) jet pumps, engine-powered from the surface

III Others, e.g. air-lift pumps, hydraulic rams.

5.2.7 Activities by sex; nutrition

In peasant and emergent farms most farming activities are carried out by the household members themselves. Hiring of labour (permanent or casual) is not common (only commercial farms usually employ permanent and casual hired labour). For laborious tasks as weeding and harvesting one usually relies on friends or relatives. Female farmers do have to hire labour however, especially for heavy jobs as ploughing, harrowing.

The cultivation of traditional subsistence crops is usually in the hands of women. Both men and women are equally involved in cash crop cultivation, although cash crops are under supervision of men. Specific male tasks in cash crop cultivation are:
- arranging tractors or oxen for transport and field preparation,
- application for loans,
- receiving payments,
- purchase of crop inputs.

Women assist in all other agricultural activities. Domestics tasks (water fetching, firewood procuring, cooking, washing, raising of the children) are carried out by women or children.

Since the husband controls the financial affairs this leaves women in a vulnerable position. Often they face budgetting problems in getting diversified meals for the children, soap, clothes, paying school fees and uniforms and getting commodities.

The Tonga people have a tradition of polygamy. Often you find the more prosperous farmer has 4 or 5 women (esp. on the settlements), resulting in a large household size. Even in this category of farmers malnutrition occurs (despite the relative high cash income, compared with peasant farmers). Because of the large number of children per family they do not get a diversified meal. The usual meal is nshima with some relish (mainly ocra and groundnuts). If there is meat it is reserved for the adults. Nutrition problems are aggerivated in the dry season: due to lack of water households face problems in keeping a vegetable garden. Polygamy is one of the reasons of land shortage in the settlement areas as each plot was originally meant for 1 family (1 man, 1 woman and children) only.
5.3 Financial position of farm households

Under specific assumptions direct costs and revenues related to the cultivation of a certain crop per unit area can be calculated. Confronting seasonal expenditures with cash revenues a "gross cash income from crops" can be computed. In the calculations of this paragraph marketed surpluses are used instead of actual production. The difference between actual production and marketed production forms the production retained for home (subsistence) consumption. If adding subsistence consumption a "gross income" (cash + non-cash) could be calculated.

Here this is not done as the first interest in this survey goes to cash flows, and the annual cash balance of households. Furthermore a problem would be whether to use official marketing prices in valuing

<table>
<thead>
<tr>
<th>Base data</th>
<th>MAIZE</th>
<th>COTTON</th>
<th>SUNFLOWER</th>
<th>SOYAEBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average hectarage under production</td>
<td>1.5</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Average sales/production per hectare *)</td>
<td>11 bags</td>
<td>470 kg</td>
<td>6 bags</td>
<td>5 bags</td>
</tr>
<tr>
<td>Use of fertilizer per hectare</td>
<td>300 kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Use of seeds per hectare</td>
<td>15 kg MN603/4</td>
<td>40 kg</td>
<td>6 kg hybrid</td>
<td>45 kg</td>
</tr>
<tr>
<td>Use of chemicals per hectare</td>
<td>-</td>
<td>300 ml Fastac</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Seasonal expenditures (in 1987 $)

<table>
<thead>
<tr>
<th></th>
<th>MAIZE</th>
<th>COTTON</th>
<th>SUNFLOWER</th>
<th>SOYAEBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeds</td>
<td>82</td>
<td>17</td>
<td>18</td>
<td>106</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>480</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chemicals</td>
<td>-</td>
<td>66</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>562</td>
<td>105</td>
<td>18</td>
<td>106</td>
</tr>
<tr>
<td>Revenues</td>
<td>880</td>
<td>1410</td>
<td>540</td>
<td>1085</td>
</tr>
</tbody>
</table>

Cash balance

<table>
<thead>
<tr>
<th></th>
<th>MAIZE</th>
<th>COTTON</th>
<th>SUNFLOWER</th>
<th>SOYAEBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditures crops</td>
<td>X 793</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td>X 143</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>X 936</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revenues</td>
<td>X 3918</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INCOME</td>
<td>X 2992</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Income per person per month: X 29.60
(at 6.4 persons per family)

TABLE 5.1 Calculation of the "gross cash income from crops" of the average peasant farmer, cultivating 3.5 ha.

*) Maize: average production 17.5 bags/hectare, but a total of 15 bags is retained for home consumption. Other crops: production = sales.
Producer prices: maize X 80/90 kg bag, cotton X 3/kg, sunflower X 90/50 kg bag, soyabean X 217.50/90 kg bag.
Seed prices: 50 kg MN603/4 X 183/50 kg, cotton X 12/20 kg, sunflower X 107/25 kg, soyabean X 196/50 kg.
Fertilizer, maize X 80/50 kg, Fastac: X 0.625/ml.
Cost estimates are exclusive ox-hiring for land preparation or transport
(X 100/hectare: X 2-3/bag)
the subsistence part or cost prices (plus a profit margin) or at consumer prices (which are much lower due to government subsidies).

Calculation average cash income farmers

In this paragraph the cash income position is calculated of the three groups of farmers:
- peasant farmers,
- emergent farmers/settlement farmers,
- commercial farmers.

A "gross cash income from crops" for the three farm categories is estimated in tables 5.1, 5.2 and 5.3.

We can immediately see from the tables that apparently cash crops as cotton and soyabean are very profitable, while maize is not. This is

<table>
<thead>
<tr>
<th>Base data</th>
<th>MAIZE</th>
<th>COTTON</th>
<th>SUNFLOWER</th>
<th>SOYABEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average hectarage under production</td>
<td>5.6</td>
<td>2.3</td>
<td>1.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Average sales/production per hectare</td>
<td>22.7 bags</td>
<td>700 kg</td>
<td>10 bags</td>
<td>10 bags</td>
</tr>
<tr>
<td>Use of fertilizer per hectare</td>
<td>400 kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Use of seeds per hectare</td>
<td>20 kg NM603/4</td>
<td>50 kg</td>
<td>8 kg hybrid</td>
<td>60 kg</td>
</tr>
<tr>
<td>Use of chemicals per hectare</td>
<td>160 ml Fastac</td>
<td>350 ml Fastac</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Seasonal expenditures (in 1987 X):

| Seeds | 410 | 69 | 55 | 118 |
| Fertilizer | 3584 | - | - | - |
| Chemicals | 560 | 431 | - | - |
| TOTAL | 4554 | 500 | 55 | 118 |
| Revenues | 11430 | 2100 | 1440 | 1082 |

Cost balance

| Expenditures crops | X 5227 |
| Interest | X 942 |
| TOTAL | X 6169 |
| Revenues | X 16058 |
| INCOME | X 9889 |

Income per person per month: X 45.80
(at 18 persons per family)

TABLE 5.2 Calculation of the "gross cash income from crops" of the average emergent farmer, cultivating 10 ha.

*) Assumed maize production is 27.5 bag/hectare, of which 27 bags are retained for home consumption. Producer prices: maize X 80/90 kg bag, cotton X 3/kg bag, soyabean X 217.50/90 kg bag.

Seed prices: 50 kg NM603/4 X 103/50 kg, cotton X 12/20 kg, sunflower X 107/25 kg, soyabean X 196/50 kg.

Fertilizer, maize X 80/50 kg, Fastac: X 0.625/ml.

Costs are exclusive tractor-hire for transport (X 3-5/bag)
not surprising as the producer price of staples is kept low in favour of the urban consumer.

The gross cash income from crops only includes seasonal revenues and expenditures on cash crops. Other sources of income are cattle sales and secondary sources (non-farm income, informal trade of crops, chicken and egg sales, beer brewing). Other farm expenditures are fixed costs of implements, maintenance costs of implements and building materials, expenditures on cattle. We then arrive at a net income which can be spend 'freely' by a household (e.g. on consumer goods).

Other sources of income (informal trade of crops and vegetables at marketplaces or farmgate, beer brewing, fishery, selling of chicken, non-farm income) are difficult to estimate. The income generated is small compared with the formal cash income (according to MAR 79 about 8% and 2% of the cash farm income of peasant, emergent farmers respectively).

Fixed costs comprise depreciation on farm implements (ploughs,}

---

### TABLE 5.3 Calculation of the "gross cash income from crops" of the average commercial farmer, cultivating 50 ha.

<table>
<thead>
<tr>
<th>Base data</th>
<th>Maize</th>
<th>Cotton</th>
<th>Sunflower</th>
<th>Soya bean</th>
<th>Groundnuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average hectarage under production</td>
<td>20</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Average sales/production per hectar</td>
<td>40 bags</td>
<td>1100 kg</td>
<td>20 bags</td>
<td>11 bags</td>
<td>6 bags</td>
</tr>
<tr>
<td>Use of fertiliser appl. per hectar</td>
<td>450 kg</td>
<td>140 kg</td>
<td>120 kg</td>
<td>110 kg</td>
<td>120 kg</td>
</tr>
<tr>
<td>Use of seeds per hectar</td>
<td>20 kg</td>
<td>60 kg</td>
<td>6 kg hybrid</td>
<td>60 kg</td>
<td>60 kg</td>
</tr>
<tr>
<td>Use of chemicals per hectar</td>
<td>160 ml Fastac</td>
<td>300 ml Fastac</td>
<td>150 ml</td>
<td>150 ml</td>
<td>100 ml</td>
</tr>
</tbody>
</table>

**Seasonal expenditures (in 1987 K):**

| Seeds    | 1460 | 540 | 642 | 2110 | 4650 |
| Fertilizer | 14400 | 2010 | 385 | 515 | 1050 |
| Chemicals | 2000 | 2610 | 280 | 485 | 500 |
| TOTAL     | 17860 | 5360 | 1307 | 3110 | 6160 |

**Revenues**

| 64000 | 49500 | 5400 | 13920 |

**Cash balance**

| Expenditures crops | K 33797 |
| Revenues           | K 144780 |
| INCOME             | K 110983 |
harrors, cultivators, hoes, ox-carts, knapsack sprayers). A review of annual financing and maintenance cost of equipment is presented in table 5.4.

An important variable cost is dipping of cattle against ticks. Let us suppose 'Supona Super' (manufactured by Shell Chemicals (Z) Ltd.) is used. For effective tick (and also fly) control treatment should be carried out every week (in cases of severe tick infestation or during the rains, this should be increased to once every 5 days). Per treatment per animal about 2 ml cattle dip (on 4 litre water) is used. Costs of 'Supona Super' is K 134.30 per 0.5 litre. We assume that 60 treatments per year are done, so annually 120 ml per animal is used. Annual costs:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Peasant farmer</th>
<th>Emergent farmer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plough, at K 400</td>
<td>1 X 159</td>
<td>3 X 477</td>
</tr>
<tr>
<td>Harrow, at K 314</td>
<td>1 X 125</td>
<td>1 X 251</td>
</tr>
<tr>
<td>Cultivator, at K 430</td>
<td>1 X 171</td>
<td>2 X 342</td>
</tr>
<tr>
<td>Fidger, at K 340</td>
<td>1 X 136</td>
<td>3 X 471</td>
</tr>
<tr>
<td>Ox-cart, at K 4000</td>
<td>1 X 1360</td>
<td>1 X 1360</td>
</tr>
<tr>
<td>Planter, at K 1200</td>
<td>0</td>
<td>1 X 400</td>
</tr>
<tr>
<td>ULV sprayer, at K 577</td>
<td>1 X 167</td>
<td>1 X 167</td>
</tr>
<tr>
<td>Building materials</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 2118</td>
<td>K 5672</td>
</tr>
</tbody>
</table>

TRACTOR-DRAWN EQUIPMENT (commercial farmer):

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Annual costs (in K 1987 kwacha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor, at K 130,000</td>
<td>1 X 31336</td>
</tr>
<tr>
<td>Mould-board plough, at K 12,000, n=10, m=7%</td>
<td>1 X 3230</td>
</tr>
<tr>
<td>Disc harrow, at K 12,000, n=10, m=7%</td>
<td>1 X 3595</td>
</tr>
<tr>
<td>Cultivator, at K 5000, n=10, m=5%</td>
<td>1 X 1245</td>
</tr>
<tr>
<td>Planter, with fertilizer attachment, at K 4000, n=12, m=7%</td>
<td>1 X 1020</td>
</tr>
<tr>
<td>Trailer, at K 20,000, n=10, m=5%</td>
<td>1 X 4980</td>
</tr>
<tr>
<td>Annual fuel cost (500 hours/yr, 12.34 litre diesel/hr (37 kW tractor), K 1.743/litre)</td>
<td>K 10750</td>
</tr>
<tr>
<td>Annual lubricant cost (.7% per litre diesel, K 14.16/litre)</td>
<td>K 610</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 56,755</td>
</tr>
</tbody>
</table>

TABLE 5.4 Annual cost estimates of farm equipment (in mid 1987 Kwacha).

Prices based on: AGR 81, AV Tarry Ltd (Lusaka), SPCMU, Lenco, Northland Eng. Ltd. (Ndola), Turning & Metal Ltd., Lusume Services Workshop Magoye.

Annual costs comprise:
- annual financing costs (at equal annual instalments, rate 15%)
- annual maintenance costs (estimated at m% of the initial investment).

n: estimated lifetime.
K 32 per animal. A sprayer for animals costs about K 540,-. If we assume
a peasant farmer to have 10 cattle, and a emergent farmer 25 cattle,
costs of cattle-keeping can now be estimated:
- sprayer (at lifetime of 5 years) K 108,
- dipping: peasant farmer K 320, emergent farmer K 800.
By selling one animal per year, a farmer can afford dipping and thus
save the remainder of the animals.

Due to the irregular pattern quantification of household
consumption expenditures is difficult. The expenditure groups can be
identified:
- essential consumer goods (food and non-food: clothes, blankets,
  paraffin)
- personal transport (public, private)
- education (school fee K 57 per year per pupil, school uniforms, books)
- medical care (medicines)
- durable and luxury consumer goods (radio, crafts; beer).

According to KOL 87 (p.306) a household spends about K 140-160 on
food (sugar, salt, cooking oil) and K 200 on clothes (1987 prices).
Marter & Honeybone (MAR 79, p.45-58) give consumption expenditure
estimates for Choma District, near Magoye area. Assuming prices of
non-durable consumption having risen 7-fold since then (and expenditure
pattern has not changed), we come to the following estimates (based on
the figures mentioned in MAR 79):

<table>
<thead>
<tr>
<th></th>
<th>Peasant</th>
<th>Emergent</th>
</tr>
</thead>
<tbody>
<tr>
<td>essential consumer goods</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K 670</td>
<td>K 2780</td>
</tr>
<tr>
<td>education (assuming 4 pupils peasant farmer, 12 pupils emergent farmer, K 57/year):</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K 230</td>
<td>K 910</td>
</tr>
<tr>
<td>durable goods/beverages/miscellaneous:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K 250</td>
<td>K 840</td>
</tr>
<tr>
<td>payments and gifts from relatives:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K 90</td>
<td>K 430</td>
</tr>
<tr>
<td>TOTAL cash consumption expenditure</td>
<td>K 1240</td>
<td>K 4960</td>
</tr>
</tbody>
</table>

We can now compile the following cash balance: (PF: peasant, EF: emergent, CF: commercial farmer, *: not studied):

<table>
<thead>
<tr>
<th></th>
<th>P.F.</th>
<th>E.F.</th>
<th>C.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross cash income from crops</td>
<td>K 2980</td>
<td>K 9890</td>
<td>K 110,980</td>
</tr>
<tr>
<td>Other sources of income</td>
<td>K 300</td>
<td>K 300</td>
<td>K *</td>
</tr>
<tr>
<td>FARM CASH RECEIPTS</td>
<td>K 3280</td>
<td>K 10190</td>
<td></td>
</tr>
<tr>
<td>Expenditures implements</td>
<td>K 2120</td>
<td>K 3870</td>
<td>K 56,750</td>
</tr>
<tr>
<td>Expenditures cattle-keeping</td>
<td>K 330</td>
<td>K 910</td>
<td>K *</td>
</tr>
<tr>
<td>Labour expenditures</td>
<td>-</td>
<td>-</td>
<td>K *</td>
</tr>
<tr>
<td>FARM EXPENDITURES</td>
<td>K 2450</td>
<td>K 4780</td>
<td></td>
</tr>
<tr>
<td>NET FARM CASH INCOME</td>
<td>K 830</td>
<td>K 5410</td>
<td></td>
</tr>
<tr>
<td>Cash expenditure consumption</td>
<td>K 1240</td>
<td>K 4900</td>
<td>K *</td>
</tr>
<tr>
<td>Cattle sales</td>
<td>K 1600</td>
<td>K 1600</td>
<td>K *</td>
</tr>
<tr>
<td>CASH BALANCE</td>
<td>K 390</td>
<td>K 2110</td>
<td>(K 54,230)</td>
</tr>
</tbody>
</table>

Cattle is not sold in the area at certain numbers per year, but are
an extra source of income in times of cash shortness or illness. Here it
is assumed that 2 animals are sold. It has to be stressed that
'consumption expenditures' only comprise cash expenditures, and not the
subsistence part (which was also not taken into account in the 'receipts').

Peasant farmers have very modest net incomes. Consumption is not very much above subsistence needs, depending on the sales of cattle, and actual investment in equipment. Not all farmers have an ox-cart for example. Supposing the average peasant farmer has no ox-cart, expenditures on implements drop to K 760. Expenditures on ox-cart hiring have to be included then however, which are estimated in paragraph 5.5 at K 90/year. The cash balance then becomes 390+760-90 = K 1060. As not to be dependent on other farmers in times of peak demand for transport, and not risking delays in transport of in- and outputs ox-cart ownership is preferred to hire. According to several key-informants many farmers face budgetting problems. The seasonal pattern of cash income is highly irregular, and positive only after after receiving the money for their produce. Often a great share of it is spent immediately (beer, commodities). At the same time a household has to set aside a certain amount to finance transport for bags (maize, fertilizer, seeds). In anticipation of an eventual limited credit disbursement for the next season's crop inputs a household has to save some money. Droughts (such as the one in 1987) and delayed payments for crops and delayed approval of loans add to the budgetting problems.

Net income levels of emergent farmers begin to approach levels available for urban employment. Their cash balance provide opportunities for savings for emergent farmers. Tonga farmers often invest savings in cattle, as this regarded more profitable than compared to returns obtainable from depositing their savings in a bank (MAR 79, p.58). However, especially before the outbreak of corridor disease this has resulted in annual increase in cattle population, and as a result, overgrazing (especially on settlement schemes, where the wealthier farmers can be found).

Due to lack of information a cash balance of a commercial farm/farming household could not be constructed. Here, only income from crops, and expenditures on equipment are calculated.

Many peasant farmers find themselves in a vicious circle. Once their usual consumption and investment requirements are met, they are unable to afford much investment in expansion of their farm. Some interviewed farmers stated for example that they did not apply higher rates of fertilizer and chemicals because sufficient short-term credit was not available. Medium-term credits for implements are hard to get for the average peasant farmer. The capacity of emergent farmers to invest out of personal funds and still remain with relatively large cash balances suggests that (short and medium term) loan allocation should be directed more towards peasant farmers.

Inflation

Table F.8 in appendix F gives prices of 1987/88 and 1988/89 season of crops and crop inputs. With the use of these figures, and with the same assumptions made in table 5.1, the following crop expenditures and revenues for a peasant farmer have been calculated for the 1988/89 season:
Total income (1988/89 season) is then K 4170, as compared with K 2980 (1987/88 season).
For the peasant farmer this means an income increase of 40%. We can compare this income increase with for example the trend of consumer price inflation for low-income groups in Zambia (in 1986/87, 1985/86 and 1984/85 resp.: 40%, 52%, 37%. Such official inflation figures are based on official prices, and do not reflect black market prices (in other words shortages of commodities). The inflation for 1988/89 is expected to be 35% by the Government, but by most observers estimated between 60 and 70%, about the same as the real inflation for 1987/88. So, we must conclude that rural incomes will deteriorate further in the next season, in view of the expected income increase from crops of 40%.

5.4 Matching energy demand and supply

One can say that no single energy tool can meet all the energy requirements of a farming household. There will have to be a mix of sources and conversion technologies, of which each component should be designed to match (a) specific task(s). Matching (leading to an optimum energy mix) is carried out by:
- assessing local energy requirements of a farming household,
- assessing locally available resources,
- selecting those energy systems which best fit requirements, that are reliable and affordable.

In the preceding paragraphs of this chapter we discussed the energy demand side. Energy-consuming technologies, that are presently employed or have a potential for improvement, with their energy inputs (heat, light, muscle electric or machine power). In paragraph 4.4 the energy supply side was reviewed: traditional and alternative energy sources, available in Magoye area. Table 5.5 gives a comprehensive review of the possibilities to harness a specific energy source for a specific task, as carried out by a farming household.

Energy tools (sources and conversion technologies) must me able to meet energy aims (present and future demand). Introducing new technologies (energy-consuming and energy-converting) means changes in energy demand and supply are required.

Changes in energy demand are achieved by the changed activities themselves. Adjustments may be a change in magnitude of demand, or a shift from one form of energy to the other, or both.

Changes in the supply side are similar to improving the energy
Energy demand and supply of farming households in Magoye area

Changes in energy demand are influenced by the following variables:
1. the size of the farming household (number of people),
2. household income (related to the size of the farm),
3. costs and performance of energy-consuming equipment,
4. climatological factors (e.g. temperature),
5. cultural factors (diet practice, cooking habits, farming practice),

Supply variables comprise:
1. price and/or availability/reliability of the primary source of energy,
2. cost and performance of the conversion technology, converting the primary source into a usable form of energy,
3. urban, semi-urban, rural location. Differences in location are closely related to points 1. and 2.,

<table>
<thead>
<tr>
<th>Human power</th>
<th>Animal power</th>
<th>Wood</th>
<th>Charcoal</th>
<th>Kerosene (paraffine)</th>
<th>Kerosene (paraffine)</th>
<th>Kerosene (paraffine)</th>
<th>Coal</th>
<th>Kerosene (paraffine)</th>
<th>Kerosene (paraffine)</th>
<th>Kerosene (paraffine)</th>
</tr>
</thead>
</table>

DOMESTIC/HEAT APPLICATIONS
- cooking/heating
- lighting
- refrigeration

STATIONARY POWER APPLICATIONS
- water pumping
- crop processing: maize shelling

MOTIVE POWER APPLICATIONS
- land preparation
- planting
- weeding
- harvesting
- transport

TABLE 5.5 Applicability matrix. The table only indicates the potential applicability of energy technologies, without indicating the actual technical or economical feasibility in view of Magoye farming households. Crosses (X) indicate which cases are studied in this chapter. Crosses (x) indicate cases in which supply is possible but not studied in this chapter.
4. less easily defined variables, such as:
- time and 'effort' devoted to energy procuring,
- cultural and socio-economic factors (labour division, gender division in decision-making).

In the following two paragraphs comparison are be made between present and alternative energy tools, and their impacts are elaborated. Two impacts have the attention of this report:
- the ability of an energy tool to meet demand sufficiently. This impacts is quantified by capacity calculations of the energy tool concerned.
- the affordability of tools, vis-a-vis each other and as compared with farmer's income and expected benefits. Quantification is done by cost calculations of the energy tools.

In quantifying impacts the following procedure is followed:
1) First an estimate of daily energy consumption per task is made for an average Magoye farming household. This is important as to determine whether capacity of of energy system is sufficient to match demand. Hereby is taken into account that supply and demand patterns fluctuate seasonally and monthly. It is important that capacity is not oversized, not undersized, but sized according to peak demand.
2) The economics of energy conversion devices is determined in order to estimate costs of energy, delivered by the device, per unit of energy.
3) Per task annual costs of energy tools and costs per unit of energy are estimated.
4) Costs are confronted with benefits (productive tasks) and/or farm cash incomes, as estimated in paragraph 5.3 (consumptive tasks). This enables identification of financially feasible options. Finally results are itemized to the distinguished groups of farmers.

For practical reasans the energy-consuming tasks, given in table 5.5, are divided in two groups:
- tasks with motive shaft power, in which energy sources are restricted to human, animal power and petroleum products: paragraph 5.5.
- domestic tasks (consuming energy in the form of heat and light) and tasks with stationary shaft power as energy end-use input (in which a whole range of energy sources are available): paragraph 5.6.

Cost elements taken into account in the costing procedure of this chapter are:
- capital cost of the technology (annualized over its economical/technical lifetime, using equal yearly instalments at a interest rate of 15%, see appendix A),
- annual costs of maintenance and operation,
- annual costs of fuels and lubricants.
A final figure derived is the unit cost: the cost per energy output. This allows the costs of power output of different systems to be compared. The unit cost of capacity is derived by dividing total annual cost by annual power capacity; the unit cost of generation/consumption is derived by dividing total annual cost by actual annual generation/consumption of power. Both unit costs are equal if the system is not underutilized. Actual deviation of consumption from capacity may result from seasonal/monthly changes in consumption, in energy supply or both.
Total costs (somnation over the three cost elements) can be confronted quantitatively with:
- household income.
- benefits generated by introduction of the system of energy(-consuming and -converting) technologies.

In the case of household domestic application (which are consumptive) income level of a households must be sufficient to cover investment and operating costs of technologies. In the case of application in production the surplus generated must be higher than total costs of technology introduction. This surplus is determined by subtracting benefits in the 'with'situation (situation with applying the energy(-related) technologies) from the 'without' situation.

5.5 Motive power applications

Land preparation, capacity estimates

The area that can be cultivated by a farming household (without additional power inputs as animal power) is rather limited, about 1-1.5 hectares depending on the number of family members, actively involved in work). It requires about 500 man-hours for ploughing and planting (Source: appendix F.4, AGR 78, NAN 83, p.77) of one hectare. Land preparation and planting is done in the period that stretches from before the first rains (October) to the end of December. Assuming the number of effective working days in this period is 60 days, at 5 working hours per day, then the hectareage that can be prepared by one person is about 0.6 hectare.

The use of ox power facilitates a much larger hectareage to be cultivated. The theoretical capacity of ox power for land preparation and planting can be calculated as follows. Using 1 pair of oxen the time taken per hectare for the following tasks is (source: OXD 83, Lusume Services Ltd., Magoye):
- ploughing 15 hours
- harrowing (2 sections) 7
- ridging 10
- cultivating 7
- planting 10.

So, 1 pair of oxen needs about 50 hours (10 days). It is assumed that a farmer will start land preparation in November (until mid-December, exclusive fertilizer application). At a working day of 5 hours, assuming 40 effective working days available, then the hectareage that can be cultivated by 1 pair of oxen is 4 hectares. This estimation is more or less in accordance with the average hectareage cultivated by a Magoye peasant farmer, about 3.5 hectare. This also helps to explain why the group of 'subsistence farmers' is virtually absent in Magoye area, as almost all farmers employ ox power and are thus able to cultivate an
area larger than 1 hectare (the definition used by the MAWD). Emergent farmers employ several pairs of oxen (usually more than one plough, cultivators, harrow, etc.; own observation; table 5.4; MAR 79, p.47,). Their average hectarage cultivated is larger therefore, about 10 hectares.

The hectarage that can be cultivated by a tractor is much larger. Time requirements for a tractor as hired out by Lusurne Services Ltd. (a 65 HP Farmwell 645 tractor) are:
- ploughing 4 hours
- harrowing (disc harrow) 1.5 hour
- planting 3.5 hour

With a working day of 6 hours, thus 1.5 day is required to prepare 1 hectare. Again assuming 80 working days available (more days are available, because fertilizer application can be combined with planting, and also other operation periods, e.g. weeding can be shortened), the hectarage cultivated is about 53 hectares. This estimate corresponds with the hectarage cultivated by the average commercial farmer, which is about 50 hectares.

Although the potential power deliverance of a tractor is higher than of oxen (30-60 kW versus 800 W, pair of oxen), this does not result in a proportional decrease in time requirements. This is due to effects management, distance tractor-workplace, soil, clogging up of machinery, fuelling and daily maintenance, etcetera.

**Transport capacity estimates**

The theoretical capacity of an ox-cart pulled by two for transport of outputs is estimated as follows.

**Base data:**
- Loading capacity of an ox-cart is 900 kg.
- A pair of oxen is expected to pull a load of 1000 kg at 2.5-3 km/hr for distances as far as 30-40 km; source: Lusurne Services Ltd.
- Distance farmgate-depot is 5 km, so 4 hours are needed per trip (excluding loading and unloading), here we assume 1 or 2 trips per day can be made.

**Peasant farmer:** total output (of all the marketed crop production, see table 5.1): 30 bags, 2290 kg. Three trips have to be made in 3 days.

**Emergent farmer:** total output: 180 bags, 14,300 kg (see table 5.2). Sixteen trips have to be made, requiring 8 or 16 days, depending on the number trips per day made.

Loading capacity of a tractor-trailer combination is about 3000 kg. At an average speed of 10 km/hr, this means that to transport 3000 kg (1 trip) 1 hours is needed (exclusive loading and unloading).

Especially settlement farmers stated to hire tractors for transport, as this facilitates a faster transport. To transport the output of an emergent farmer thus only 5 hours are needed (excluding loading and unloading).

To transport the output of the average commercial farmer (97,590 kg, table 5.3) 11 hours are needed (excluding loading and unloading).
Cost estimates of hiring and ownership of ox-drawn and tractor drawn-equipment

Most Magoye farmers own cattle. Cost estimates of ox-drawn equipment were already presented in paragraph 5.4, when determining income levels of farming households. In these estimates the capital cost of cattle was not included, as farmers do not sell or buy cattle on a regular basis (for the purpose of draught power).

Price of cattle depends on liveweight (about K 4/kg). As indigenous cattle have a liveweight of about 400-900 kg (males) and 300-500 kg (females) prices (1988) of cattle vary between K 1600-2700 (males) and K 1200-2000 (females). Productive life of cattle is 12-15 years. Mortality rates of traditionally managed cattle are quite high however (20-50%, especially in recent years due to corridor disease).

Many farmers face problems due these recent losses. Those farmers have to hire oxen from fellow farmers. Rates mentioned were:

- **land cultivation**, about K 10/day. Assuming a pair of oxen need about 10 days for land preparation per hectare, annual costs are K 100/cultivated hectare (1987/88 season).

- **transport** (K 2-3/bag, 50 or 90 kg bag), not depending on distance. Annual costs of hiring oxen for transport of inputs and outputs (units: 50 or 90 kg bags) are (assuming all inputs and outputs are transported by hired oxen-ox-cart combinations):
  - emergent farmer: 132 bags (90 kg), 177 bags (50 kg). Total cost: K 750.

Problem with depending on ox-hire from fellow farmers is that these farmers of course give priority to their own cultivation and transport activities. Therefore farmers have to put considerable effort in obtaining oxen for hire. Interviewed ox-hiring farmers complained of overlap of post- and pre-harvest work.

Rates for land preparation with tractors were K 100/hour (Ford Company Lusaka, 1987/88 season) and K 140/hour (1988/89 season, Lusume Services Ltd.). One can tentatively conclude that these rates are somewhat below the estimated economic cost per hour of K 114 (but in the latter case was assumed that only one farmer uses the tractor; cost reduction can be achieved if that farmer hires out his tractor, and thus utilization is better). Nevertheless, cost of tractor hiring for land preparation are high. As it takes about 9 hours to cultivate 1 hectare, costs are about K 900/hectare.

Tractor-hire for transport is more profitable. Annual costs for transport of an average emergent farmer hiring a tractor for transport of all his inputs and outputs are (132 bags of 90 kg at K 5/bag, 177 bags of 50 kg at K 3/bag): K 1190. This is somewhat cheaper than annual costs of an ox-cart (about K 1300, see table 5.4).

Total costs of an average emergent farmer hiring tractors for both land preparation and transport are thus K 1020.

It is interesting to confront annual cost of tractor power vis-a-vis ox power in view of the hectarage covered. Annual costs of animal draught power of an emergent farmers cultivating 10 ha are, assuming 5 oxen available for draught power (K 1500/ox, productive life of 12 years)
5 oxen (productive life 12 years, \(i=15\%\), equal annual instalments) 
- supplementary feeding in the peak season 
  (100 days, 2 kg/animal/day at K 1.60/kg, OXD 83) 
- ox-drawn equipment (table 5.4) 

\[
\begin{align*}
\text{TOTAL} & = \text{K 1384} \\
& + \text{K 1600} \\
& + \text{K 3872} \\
& = \text{K 6860}
\end{align*}
\]

We can derive the following estimates of costs of power per hectare cultivated:
- animal draught power: K 390/hectare (equipment only), 
  K 690/hectare (animals, feeds, equipment), 
  (based on the average emergent farmer, 10 hectare).
- tractor power: K 1140/hectare 
  (based on annual cost K 56,800 for the average commercial farmer, 50 hectares, see 5.4).

We conclude that the annual costs/hectare of ox-drawn equipment is much below annual costs of tractor-drawn equipment. It has to be stressed however that, employment of tractor power does not only lead to a quantitative increase in yield, but also a qualitative, due to better quality of land preparation. Thus, cost/hectare are larger, but also benefits/hectare. The latter are hard to quantify however.

Almost all ox-drawn equipment is manufactured in Zambia itself, while almost all tractor-drawn equipment is imported. This makes cost of tractor-drawn equipment relatively higher due to higher cost of labour (abroad) and cost of international transport, and to a very high foreign exchange component.

Ownership of tractors and related equipment is restricted to commercial farmers. Annual costs of tractors and tractor-drawn equipment are quite high (here estimated at about K 56,800, see table 5.4, or about K 1140/hectare). Experience in Magoye area has shown that settlement farmers cannot afford tractors. Only a few settlement farmers still own a tractor. Many tractors have been taken back as farmers could not pay off the loans provided.

Costs of hiring tractors (e.g. from Lusume Services Ltd.) is not much cheaper than ownership (K 1020/ha hiring; K 1140/ha ownership (commercial farmer). In practice costs of tractor ownership per hectare would be much higher for the emergent as compared with a commercial farmer, because of the smaller hectarage cultivated and thus underutilization of tractor capacity (45 kW tractor and related equipment; 10 hectare: K 5680/ha, 20 hectare: K 2840/ha).

Clearly, tractor ownership is only feasible for commercial farmers. At present use of tractors in other categories is limited to tractor hiring for transport by emergent farmers.
5.6 Domestic tasks and stationary power applications

5.6.1 Basis for cost comparison

The following main domestic tasks (with heat, light, electricity as energy input) and tasks with stationary power applications are studied in this paragraph (given with potential energy inputs, see table 5.5):

a) domestic tasks:
   - cooking (wood, charcoal, kerosene, biogas, electricity),
   - lighting (kerosene, biogas, electricity)
   - other energy-consuming tasks. Here we will study refrigeration as an example (biogas, electricity).

b) waterpumping (human power, animal power, diesel or dual-fuel engine, wind power, electricity)

c) maize shelling (human power, diesel or dual-fuel engine, electricity).

On the supply side the following energy sources are available with their related conversion technologies:

- wood (direct burning in open fire or various types of stoves) and its derivatives:
  - charcoal (direct burning in mbaula's or improved stoves, produced by traditional or improved methods),
  - woodgas (used in dual-fuel engines and in electricity generators, produced in gasifiers),
- biogas (direct burning in stoves, lanterns and flame-operated refrigerators; dual-fuel engines; dual-fuel generators),
- solar power, converted by photovoltaic cells into electricity, or by solar collectors in heat. Of the latter we will study solar thermodynamic pumps as possible applications.
- wind power, used for water pumping.
- extension of the electricity grid.

Grid extension differs from other technologies in that it cannot be implemented on a household level, but rather on the camp or area level.

As basis for comparing alternative energy tools, energy consumption per task is estimated in appendix E.1. These estimates are used for determining the required size of the energy supply system (e.g. a biogas plant, or a diesel engine). Then unit costs of the supply systems are calculated (expressed in K/kWh). At their turn unit costs of supply systems are (in combination with the estimated energy consumption per task) used to determine total costs of end-use equipment (as e.g. a waterpump). The details of these calculations are given in appendix E.2.

Figure 5.2 and table 5.6 give a summary of the base data, calculated in appendix E, on which estimates of total costs of technology per task are based. Note that calculations are not yet itemized per category of farming households. The cost estimates are presented in the next sections:

paragraph 5.6.2: household domestic alternatives: domestic tasks as cooking, lighting and refrigeration; domestic water supply.
<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Stationary Power Applications</th>
<th>Domestic/Heat Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- hand pump (2 elevation heads, 10, 30 m)</td>
<td>- cooking (7.92 kWh/household/day)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- animal-powered pump (16 and 36 m head)</td>
<td>- open fire (efficiency 7%)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- wind-powered pump (16 and 36 m head)</td>
<td>- woodstoves (eff.10-25%)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- electric pump, 0.75 kW (16 and 36 m)</td>
<td>- charcoal stoves (eff. 15-25%)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- diesel/dual-fuel engine, 2.1 kW (16, 36 m)</td>
<td>- biogas stove (eff.55%)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- irrigation (30 m elevation, 25 ha)</td>
<td>- paraffine stove (eff.40%)</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- electric pump, 11.2 kW</td>
<td>- diesel/dual-fuel pumpset, 11.9 kW</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- hand sheller</td>
<td>- maize sheller</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- engine-powered sheller</td>
<td>- engine-powered sheller</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- stellina</td>
<td>- solar thermodynamic (kaleen) engine</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- irrigation (48 panels)</td>
<td>- diesel - direct fuel</td>
</tr>
<tr>
<td>Wood - &quot;Tree&quot;</td>
<td>- domestic power supply (61 panels)</td>
<td>- national electricity grid (s extension)</td>
</tr>
</tbody>
</table>

**FIGURE 5.2** Base for comparison of energy technologies in domestic/heat applications and stationary power applications (waterpumping and maize shelling). The crosses (X) indicate which energy (conversion) technology is used to supply a specific energy-consuming tasks in the cases studied in this chapter.
Energy demand and supply of farming households in Magoye area

FUELS (in 1987 Kwacha per kW energy of fuel):

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Financial Cost Price</th>
<th>Present Retail Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village forestry wood</td>
<td>0.066 (cost of production)</td>
<td></td>
</tr>
<tr>
<td>Plantation wood</td>
<td>0.089 (estimated retail price)</td>
<td></td>
</tr>
<tr>
<td>Charcoal, free wood</td>
<td>Traditional produced 0.058</td>
<td>Oil drum method 0.076</td>
</tr>
<tr>
<td>Village forestry wood</td>
<td>0.104</td>
<td>0.109</td>
</tr>
<tr>
<td>Plantation wood</td>
<td>0.257</td>
<td>0.184</td>
</tr>
</tbody>
</table>

(estimated retail prices, see table E.5)

PHASED COSTS (in 1987 Kwacha per kW delivered by engine):

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Cost of Capacity</th>
<th>Cost of Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel engine</td>
<td>2.2 kW engine (table E.19)</td>
<td>11.9 kW (table E.21)</td>
</tr>
<tr>
<td>- economic retail price diesel</td>
<td>1.60</td>
<td>1.29</td>
</tr>
<tr>
<td>- dual-fuel engine, biogas</td>
<td>1.62</td>
<td>1.52</td>
</tr>
<tr>
<td>- woodgas (will forestry wood)</td>
<td>2.16</td>
<td>1.41</td>
</tr>
<tr>
<td>- case 1 (indigenous repair)</td>
<td>1.88</td>
<td>1.41</td>
</tr>
<tr>
<td>- case 2 (imported spare parts)</td>
<td>2.92</td>
<td>2.46</td>
</tr>
</tbody>
</table>

GRID ELECTRICITY (energy charges per kWh):

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Economic Cost +</th>
<th>Present Charge +</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct grid connection</td>
<td>0.18</td>
<td>0.07</td>
</tr>
<tr>
<td>extension, rural 100% load (50 km from grid) 10% load</td>
<td>0.625</td>
<td>0.515</td>
</tr>
<tr>
<td>extension, urban 100% load 10% load</td>
<td>4.65</td>
<td>4.52</td>
</tr>
<tr>
<td>extension, urban 10% load</td>
<td>0.407</td>
<td>0.297</td>
</tr>
<tr>
<td>extension, rural 10% load</td>
<td>2.45</td>
<td>2.34</td>
</tr>
</tbody>
</table>

(Economic costs grid + econ. cost extension + econ. cost extension, see table E.3)

ELECTRICITY (cost per kWh generated by energy conversion device):

<table>
<thead>
<tr>
<th>Energy Conversion Device</th>
<th>Unit Cost of Capacity</th>
<th>Unit Cost of Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>photovoltaics - domestic irrigation</td>
<td>10.31 6.62</td>
<td>11.84 (par. E.2.6) 12.00 (par. E.2.6)</td>
</tr>
<tr>
<td>diesel-generated, retail price</td>
<td>3.5 kW generator</td>
<td>50 kW generator 1.2</td>
</tr>
<tr>
<td>- economic retail price diesel</td>
<td>2.07 2.36</td>
<td>1.41 (table E.15)</td>
</tr>
<tr>
<td>woodgas-generated (7 kW generator)</td>
<td>3.03 (case 1)</td>
<td>1.65 (case 2, table E.6)</td>
</tr>
<tr>
<td>biogas (67 m3 plant, 11.2 kW generator)</td>
<td>1.69 (see table E.10)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 5.6 Comparison of prices and costs of fuels, electricity and shaft-power. The method of calculation of costs is presented in appendix E.4.
paragraph 5.6.3: irrigation,
paragraph 5.6.4: maize shelling,

Figure 5.2 indicates:

a) on the demand side: characteristics of energy demand and/or technology employed per task. Main assumptions made:
- domestic (heat, light, electricity) tasks:
  household size: 8.5 members, assumed energy consumption: cooking: 7.92/kWh/day, lighting: 0.96/kWh/day, refrigeration: 0.631 kWh/day (see figure 5.2).
  (real daily energy consumption can be calculated by multiplying above energy consumption estimates by the efficiencies given in figure 5.2, for details see appendix E.1.1)
- domestic water supply:
  average daily water consumption per family: 1.68 m³ (human and cattle consumption, garden watering, details: appendix E.1.2).
- irrigation: plot of 25 ha, with 6 crops, total annual water consumption 134,250 m³ water (details: appendix E.1.2).

b) on the supply side: characteristics of energy sources and conversion technologies that are able to meet demand.
The crosses indicate which combinations (energy tool - task) are studied here. Table 5.6 give a review of the estimated unit costs of energy for fuels, electricity and unit costs of power delivered of shaft power engines.

5.6.2 Cost comparison of rural household energy alternatives

Cooking

In a peasant or emergent farming household expenditures on cooking form the larger part of the household energy consumption. Also in a modern household (i.e. using petroleum products or electricity for cooking) expenditure on cooking remains relatively large.

In estimating the cost to the consumer of household fuels for cooking requires the knowledge of the following parameters:
- comparative fuel prices,
- purchase cost of appropriate devices and estimation of their useful lives,
- combustion efficiency of each device;
- cost of auxiliary equipment (e.g. electrical wiring in the house),
- energy required for cooking.

In appendix E.1.1 the annual energy consumption on cooking is theoretically estimated at 2890 kWh per household, for an average household size of 8.5.

Table 5.7 compares options of energy supply for cooking:
1) costs of alternative energy tools per unit energy are given in column II,
2) costs of fuel per useful energy (taken into account the end-use efficiency of the cooking device; column III),
3) annual fuel expenditure for cooking per household, column IV)
### Energy demand and supply of farming households in Magoye area

<table>
<thead>
<tr>
<th>I Fuel, stove (efficiency)</th>
<th>II Cost fuel per unit energy ($kWh)</th>
<th>III Cost fuel per useful energy ($kWh)</th>
<th>IV Annual fuel expenditure ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free plantation wood</td>
<td>Village forestry wood</td>
<td>Free plantation wood</td>
</tr>
<tr>
<td>FIREWOOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>open fire-clay pot (7%)</td>
<td>0.0868</td>
<td>0.0667</td>
<td>0.127</td>
</tr>
<tr>
<td>open fire-aluminium pot (11%)</td>
<td></td>
<td></td>
<td>0.150</td>
</tr>
<tr>
<td>mud/clay oven (10%)</td>
<td>0.1865</td>
<td>0.1265</td>
<td>0.150</td>
</tr>
<tr>
<td>brick oven (15%)</td>
<td>0.2590</td>
<td>0.1820</td>
<td>0.200</td>
</tr>
<tr>
<td>portable metal stove (25%)</td>
<td></td>
<td></td>
<td>0.303</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHARCOAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- traditional production</td>
<td>0.0580</td>
<td>0.3567</td>
<td>0.1037</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAPAFFINE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pressure stove (10%)</td>
<td>0.2600</td>
<td>0.1340</td>
<td>0.1700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRID ELECTRICITY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cooker (70%)</td>
<td>0.0635</td>
<td>0.0378</td>
<td>0.0940</td>
</tr>
<tr>
<td>grid extension 100% lead</td>
<td>0.2577</td>
<td>0.1477</td>
<td>0.2707</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELECTRICITY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cooker (70%)</td>
<td>0.1072</td>
<td>0.0644</td>
<td>0.1400</td>
</tr>
<tr>
<td>pvcoptovoltaics</td>
<td>11.84</td>
<td>11.84</td>
<td>11.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOMASS (stove, 5%)</td>
<td>0.104</td>
<td>0.0580</td>
<td>0.1400</td>
</tr>
</tbody>
</table>

### INVESTMENT COSTS COOKING EQUIPMENT

<table>
<thead>
<tr>
<th></th>
<th>Mid 1987 price</th>
<th>Lifetime (yrs)</th>
<th>Annual cost (i=15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>maize</td>
<td>200</td>
<td>2.65</td>
<td>130</td>
</tr>
<tr>
<td>portable metal wood stove</td>
<td>32.50</td>
<td>2</td>
<td>20.00</td>
</tr>
<tr>
<td>paraffine pressure stove</td>
<td>220</td>
<td>6</td>
<td>58.10</td>
</tr>
<tr>
<td>electricity: - single hot plate (62% efficiency)</td>
<td>370</td>
<td>6</td>
<td>97.80</td>
</tr>
<tr>
<td>- cooker (70% efficiency)</td>
<td>2580</td>
<td>8</td>
<td>577</td>
</tr>
<tr>
<td>- 3-plate cooker/oven (75% efficiency)</td>
<td>3050</td>
<td>12</td>
<td>563</td>
</tr>
</tbody>
</table>

### TABLE 5.7 Energy cost estimates of cooking fuels and devices in Zambia (1987 prices) for a household.

Annual fuel expenditure = annual fuel consumption x cost of fuel per useful energy.

Cost of fuel per useful energy = cost fuel per unit energy / stove efficiency.

Annual fuel consumption: 2890 kWh/household (see paragraph 6.2.1).

Prices of fuels are based on (see also summary table 5 6):
- woodfuels: plantation wood: estimated price (urban consumption): K 24.69/6J (see table 5.5)
- village forestry: production price (rural consumption): K 2.27/6J (see table 5.5)
- charcoal: prices: table 4.10. Note: 1 kWh = 0.00366 J.

4) annual financing costs cooking equipment.

For rural households the cheapest alternative for the use of "free", but scarcer, wood is:

a) wood provided by community/farm forestry projects (open fire K 340 per year), even more if combined with introduction of (improved) wood stoves (K 95 per year).

b) biogas, K 560 - 780.

Annual expenditures on fuel for cooking differ for peasant and emergent households, because of differences in household size. Combining the average household sizes given in table 5.0, with annual expenditures given in table 5.7 (household size 8.5) we find:

- peasant farmer (household size 8.2, annual expenditure 2788 kWh):
  - village forestry, open fire, K 325,
  - village forestry, portable metal stove, K 112.
  - biogas (10 m³ plant) K 887.

- emergent farmer (household size 16, annual expenditure 5440 kWh):
  - village forestry, open fire, K 656,
  - village forestry, portable metal stove, K 199.
  - biogas (10 m³ plant) K 1750.

In view of the cash saving possibilities estimated in paragraph 5.3, village forestry is a financially feasible source of energy for cooking for peasant and emergent farmers. Biogas is only feasible for the (above-average) emergent farmer. A household of a commercial farmer generally cooks electrically.

Lighting/Refrigeration

Data on annual expenditures on fuel and equipment are presented in tables 5.8 and 5.9. It is assumed that a household uses 4 bulbs of 60 W or equivalent.

Illuminance of the present lighting methods (kerosene: can & wick, hurricane) is low. In view of cash saving possibilities of an average peasant farming household (estimated at K 390) there is no feasible alternative however for lighting by can-&-wicks and hurricane, as direct grid connection is practically excluded. Higher income groups (such as emergent farmers) have as possibilities for improving lighting to make use of energy infrastructures as biogas plants, grid or diesel-generated electricity, if those are already present, and if they can be afforded.

The initial capital outlay for refrigeration is quite high, and cannot be afforded by the average peasant or emergent farming households (compare with income estimates given in paragraph 5.3). Only a commercial farming household can afford it.

Domestic watersupply

In appendix E.1.1 a daily water consumption of 1.68 m³ per household is taken as base data for cost calculation. In Zambian rural areas many households use get their drinking water from hand dug wells. In the dry season cattle watering often poses a problem and hand dug wells fall dry. In this paragraph we will look at the economical feasibility of the following alternatives for improving water supply:

a) handpump/cased deep well combination, providing water for a few
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Fuel price</th>
<th>Fuel consumption/year</th>
<th>Annual costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLUMINANCE: 240 W equivalent (4 bulbs of 60 W, 430 lm/m² each)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas (4 lanterns, 60 W eq)</td>
<td>K 1.09/m³ (10 m³ plant)</td>
<td>876 m³</td>
<td>K 955</td>
</tr>
<tr>
<td></td>
<td>K 0.64-1.02/m³ (60 m³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electricity (4 bulbs):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- grid</td>
<td>K 0.07 - 0.18/kWh</td>
<td>350 kWh</td>
<td>K 25 - 63</td>
</tr>
<tr>
<td>- extension 100% load, urban</td>
<td>K 0.297 - 0.407/kWh</td>
<td></td>
<td>K 104 - 145</td>
</tr>
<tr>
<td>- extension 10% load, urban</td>
<td>K 0.515 - 0.625/kWh</td>
<td></td>
<td>K 180 - 219</td>
</tr>
<tr>
<td>- diesel-generated</td>
<td>K 1.2 - 2.07/kWh</td>
<td></td>
<td>K 420 - 722</td>
</tr>
<tr>
<td>- woodgas-generated</td>
<td>K 1.65 - 3.03/kWh</td>
<td></td>
<td>K 578 - 1064</td>
</tr>
<tr>
<td>- biogas-generated</td>
<td>K 1.69/kWh (60 m³ plant)</td>
<td></td>
<td>K 592</td>
</tr>
<tr>
<td>- solar (6 lanterns 40 W)</td>
<td>K 6.48/kWh</td>
<td></td>
<td>K 2268</td>
</tr>
<tr>
<td>Paraffine (5 pressure)</td>
<td>K 1.743 - 2.519/litre</td>
<td>350 litre</td>
<td>K 610 - 884</td>
</tr>
<tr>
<td><strong>TRADITIONAL METHODS PARAFFINE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can &amp; wick, illuminance 5.4 lm/m² (at 1.743/lit)</td>
<td></td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>Hurricane, illuminance 32.0 lm/m²</td>
<td></td>
<td></td>
<td>17.5</td>
</tr>
</tbody>
</table>

**TABLE 5.8** Fuel cost estimates of lighting. in 1987 Kwacha. assuming an illuminance of one bulb 430 lm/m² (4 are used). Illuminance levels of present devices are much lower: can & wick 5.4 lm/m², hurricane 32 lm/m². Source fuel data as mentioned under table 5.7

---

**Annual financing cost 0.2 m³ refrigerator**
(assuming n=15, i=15%, retail price: K 15,000) K 2465

<table>
<thead>
<tr>
<th>Energy cost</th>
<th>Rate</th>
<th>Annual expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas (876 m³/annum)</td>
<td>K 1.09/m³ (10 m³ plant)</td>
<td>K 955</td>
</tr>
<tr>
<td></td>
<td>K 0.64/m³ (60 m³ plant)</td>
<td>K 561</td>
</tr>
<tr>
<td><strong>Electricity (767 kWh/annum):</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- direct grid</td>
<td>K 0.07 - 0.18/kWh</td>
<td></td>
</tr>
<tr>
<td>- urban extension 100% load</td>
<td>K 0.297 - 0.407/kWh</td>
<td></td>
</tr>
<tr>
<td>10% load</td>
<td>K 2.34 - 2.35</td>
<td></td>
</tr>
<tr>
<td>- rural extension 100% load</td>
<td>K 0.515 - 0.625/kWh</td>
<td></td>
</tr>
<tr>
<td>10% load</td>
<td>K 4.52 - 4.63</td>
<td></td>
</tr>
<tr>
<td>- solar power</td>
<td>K 10.31 - 11.84</td>
<td></td>
</tr>
<tr>
<td>- diesel-generated</td>
<td>K 1.20 - 2.07</td>
<td></td>
</tr>
<tr>
<td>- woodgas-generated</td>
<td>K 1.65 - 3.03</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 5.9** Household appliance: cost analysis of refrigeration as an example.
Electricity rates: as given in table 5.6 and 5.7
### Cast Energy Costs ($/kWh)

<table>
<thead>
<tr>
<th>Power source</th>
<th>Cost energy</th>
<th>Costs per m³ delivered water</th>
<th>Costs per household</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(X/kWh)</td>
<td>16 m head 36 m head</td>
<td>16 m head 36 m head</td>
</tr>
<tr>
<td>Electricity:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- direct grid</td>
<td>0.07&quot; - 0.18&quot;</td>
<td>0.29 - 0.30</td>
<td>0.89 - 0.22</td>
</tr>
<tr>
<td>- extension, 100% load</td>
<td>0.51&quot; - 0.625&quot;</td>
<td>0.35 - 0.36</td>
<td>1.02 - 1.06</td>
</tr>
<tr>
<td>- extension, 90% load</td>
<td>4.52&quot; - 4.65&quot;</td>
<td>0.89 - 0.91</td>
<td>2.25 - 2.29</td>
</tr>
<tr>
<td>- solar power</td>
<td>6.37&quot; - 7.36&quot;</td>
<td>1.14 - 1.25</td>
<td>2.61 - 1.11</td>
</tr>
<tr>
<td>- woodgas-generated electricity</td>
<td>1.65&quot; - 3.03&quot;</td>
<td>0.50 - 0.69</td>
<td>1.37 - 1.79</td>
</tr>
<tr>
<td>- diesel-generated electricity</td>
<td>1.20&quot; - 2.07&quot;</td>
<td>0.44 - 0.56</td>
<td>1.23 - 1.50</td>
</tr>
<tr>
<td>Diesel engine</td>
<td>1.60 %</td>
<td>0.63</td>
<td>1.65</td>
</tr>
<tr>
<td>- dual-fuel engine: biogas</td>
<td>1.62 %</td>
<td>0.70</td>
<td>1.80</td>
</tr>
<tr>
<td>Solar thermodynamic:</td>
<td>12.30</td>
<td>36.80</td>
<td>7540</td>
</tr>
<tr>
<td>Wind (incl. storage)</td>
<td>51.7&quot; - 277&quot;</td>
<td>6.83 - 40.56</td>
<td>8.79 - 52.15</td>
</tr>
<tr>
<td>Human power</td>
<td>0.51 (10 m)</td>
<td>2.58 (16 m)</td>
<td>341</td>
</tr>
<tr>
<td>- deep well</td>
<td>0.32 (8 m)</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>Animal power</td>
<td>0.16</td>
<td>0.64</td>
<td>894</td>
</tr>
</tbody>
</table>

Cost estimates of storage tank (example based on BEU 81, p.H-5):

- Concrete tank (cement, stones): $1,300/m³ storage capacity
- Annual financing cost (n=30 yrs, i=15%): $197/m³
- Maintenance (at 3% of initial investm.): $39/m³
- Annual total costs: $236/m³
- Asumes: 2 days storage, 3.4 m³ per family.
- Annual costs: $790/family

### Table 5.10


- households (cost analysis sketched in table E.16),
- b) handpump/borehole combination (table E.16),
- c) animal-powered pumping (table E.17),
- d) windpumping, providing water for one household, (paragraph E.2.7)
- e) engine-powered pumping, providing water for a (few) village(s) (table E.18 electric pumping, table E.19 shaft-powered pumping).

For details of the cost calculations one is referred to appendix E.2.
In table 5.10 summarizes the results of the calculations for the alternatives a) - e). Costs per m³ water delivered and annual costs per household are given, for the two different elevation heads. It is assumed that water is lifted from a depth of 10, respectively 30 metres. In cases c), d) and e) it is assumed further, that the pumped water is stored; in the calculation an additional head of 6 m is assumed. Costs of a storage tank is not included in the costs figures given in table 5.10 (excl. wind power), but mentioned separately. We see that costs of a storage tank are quite exorbitant, adding K 790/family (assuming a two-day storage capacity per family). Especially storage facilities makes options c), d) and e) expensive, unless some other less expensive storage method is used.

Costs of a shed or pumphouse for electric or diesel pump sets, installation and overhead costs are not taken into account. In the case of wind-powered or communal engine-powered pumping an operator would be required in practice. This further increases costs of such pumps.

Conclusion is therefore that the combination handpump - improved deep well poses the least annual expenditure to the household, followed by handpumping from a borehole.

For peasant farming households the following options seem feasible:
- a communal cased well (using bucket and rope), K 82/annum/household.
- a communal cased well with handpump, K 215/annum/household (at an elevation head of 8 m).
- a communal borehole with handpump, K 341/annum/household (at an elevation head of 10 m).
- private cased well (using bucket and rope), K 410/annum (i.e. the same well as the communal, but now privately owned).

For emergent farming households the same options are feasible, supplemented by:
- private cased well with handpump, K 1076/annum.

Private ownership of a borehole/pump is too expensive.

Commercial farms, directly connected to the grid, have usually water provided from a borehole by means of electric pumping.

5.6.3 Cost comparison of pumping options in borehole irrigation

Irrigation enables intensification of production by raising production per hectare, and by the possibility of having two crops per year. As surface water is not available during the dry season, water has to be pumped from boreholes. Wells are excluded for irrigation, as their capacity would not be high enough to supply the demand.

At present (borehole) irrigation is only applied by some commercial farmers. The preliminary conclusion can be drawn that apparently other farmer do not apply borehole irrigation because it is too expensive for them (i.e. costs of irrigation are larger than benefits generated). To found this conclusion we will calculate costs and benefits of a plot of 25 hectare (of an above-average settlement farmer).

Main assumptions made (details see appendix E.1.2):
- plot of 25 hectare, with as crops maize, cotton, sunflower,
soyabean, groundnuts, and as new crop in the dry season, wheat.
- elevation head of pumped water: 30 metres.
- the capacity of the pumpset is sized such that water requirements
  in the month of peak demand (in this case August: 28 m$^3$/hectare/day)
  can be met.
Annual water consumption of the plot is estimated at 134,250 m$^3$.

Alternative energy technologies are:
- human power,
- animal power,
- diesel or electric pumpsets,
- wind pumpsets.

Water requirements for irrigation are at least one order higher
than for domestic purposes. According to my estimations (appendix E.2.9)
the hectareage that can be irrigated by means of (assuming a 10 m
elevation head!):
- human-powered pumping (one person) is about 0.10 ha,
- 2 pairs of oxen, about 1 hectare,
- windmill (diameter 7 metres), about 0.2 hectare (in the month of
  lowest monthly mean windspeed, March, see appendix E.2.7). In the case
  of borehole irrigation (the case under study here) this excludes them as
  practicable sources of power for peasant, emergent and commercial farmers.

The outcome of the cost analysis is presented in table 5.11. If we
compare total (= financing and energy) annual costs of each pumping
method we see that electric pumping is cheapest, i.e. if direct
connection to the grid is possible. In this case annual costs of lifting
irrigation water are K 19,500-23,300. If such possibility is not

<table>
<thead>
<tr>
<th>Power source</th>
<th>Cost energy (K/kWh)</th>
<th>Cost per m$^3$ delivered water</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- direct grid</td>
<td>0.07&quot; - 0.18&quot;</td>
<td>0.14 - 0.17</td>
<td>K 19,500 - 23,300</td>
</tr>
<tr>
<td>- extension, 100% load</td>
<td>0.515&quot; - 0.625&quot;</td>
<td>0.26 - 0.29</td>
<td>K 34,750 - 38,500</td>
</tr>
<tr>
<td>- extension, 10% load</td>
<td>4.52&quot; - 4.63&quot;</td>
<td>1.28 - 1.31</td>
<td>K 171,700 - 175,500</td>
</tr>
<tr>
<td>- photovoltaics</td>
<td>6.37&quot; - 14.79&quot;</td>
<td>3.14 - 5.73</td>
<td>K 234,950 - 522,950</td>
</tr>
<tr>
<td>- diesel-generated</td>
<td>1.20&quot; - 2.07&quot;</td>
<td>0.78 - 1.18</td>
<td>K 58,200 - 87,950</td>
</tr>
<tr>
<td>- woodgas-generated</td>
<td>1.65&quot; - 3.03&quot;</td>
<td>0.95 - 1.62</td>
<td>K 73,550 - 120,750</td>
</tr>
<tr>
<td>- biogas-generated</td>
<td>1.69</td>
<td>0.77</td>
<td>K 57,700</td>
</tr>
<tr>
<td>Diesel engine</td>
<td>1.29&quot; &amp; - 1.52&quot; &amp;</td>
<td>0.86 - 0.91</td>
<td>K 63,850 - 67,700</td>
</tr>
<tr>
<td>Dual-fuel engine - biogas</td>
<td>1.41&quot; &amp; - 1.71&quot; &amp;</td>
<td>0.88 - 1.02</td>
<td>K 65,720 - 76,230</td>
</tr>
<tr>
<td>- woodgas</td>
<td>1.41&quot; &amp; - 2.46&quot; &amp;</td>
<td>0.87 - 1.37</td>
<td>K 65,210 - 102,050</td>
</tr>
</tbody>
</table>

TABLE 5.11 Cost comparison of energy technologies in waterpumping for irrigation of a
plot of 25 ha.

The data presented compiled from the tables E.3/E.20 (grid), E.15/E.20 (diesel-generated),
(dual-fuel and diesel engine).
Legenda: * present retail price fuel, } economic (retail) price fuel, \ unit cost of
capacity energy conversion device, $ unit cost of consumption energy conversion device.
% unit cost of energy delivered; woodgas: & case 1, * case 2.
available, the options are:
- electrical pumping, with as power source electricity from a grid extension or a diesel-generator.

If grid electricity is provided at economic costs (i.e. economic costs of the grid + extension costs) costs ranges between K 38,500-175,500 (100%, resp. 10% load factor).
Cost ranges using diesel-generated electricity are:
K 58,200-87,900.
- use of diesel engine. Estimated costs are K 63,900-67,700. That employing diesel power yields about the same cost range as employing diesel-generates electricity might seem surprising. This is due to the fact that electric pumps are standard systems, with high efficiency (and as such available on the Zambian market). Diesel pump sets efficiency is less, and furthermore maintenance costs are higher.
- use of a dual-fuel engine (on biogas or woodgas). Annual costs are estimated at K 65,950-78,000 (biogas) and K 65,200-102,000 (woodgas).

ZESCO will be willing to make an extension if costs are borne by the farm families to be connected. With a charge dependent on the load utilization, cost competitiveness of grid extension, against diesel or diesel-generated electricity depends on the load factor.

Cost-benefit analysis

In our case study of irrigation of a 25 ha plot more financial

<table>
<thead>
<tr>
<th>IRRIGATION OF THE 25 HA PLOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical extra yield due to application of irrigation:</td>
</tr>
<tr>
<td>bags per hectare</td>
</tr>
<tr>
<td>maize</td>
</tr>
<tr>
<td>cotton</td>
</tr>
<tr>
<td>sunflower</td>
</tr>
<tr>
<td>soyabean</td>
</tr>
<tr>
<td>groundnuts</td>
</tr>
</tbody>
</table>

Income estimate new crop of wheat (25% of hectarage):
Costs: - seeds (100 kg/ha, K 142/50 kg) | K 1775 |
- fertilizer (K 200/hectare) | K 1250 |
- chemicals (100 ml Fastac, K 0.625/ml) | K 90 |
TOTAL | K 3415 |
Revenue (high yielding variety, 4500 kg/ha, K 165/90 kg) | K 51560 |
Income from wheat | K 48145 |

Total additional income: | K 59048

TABLE 5.12 Benefits of irrigation of our example of a plot of 25 ha.
Benefits are expressed by the additional income. This is be calculated by:
- determining the increase in crop yield per hectare (and value) of the crops already cultivated,
- determining cash income from cultivation of the new crop, wheat.
Source data: appendix E.2, AGR 81 (yields under irrigation).
insight is obtained in the viability if benefits are confronted with costs. The situation "with irrigation" has to be compared with the "without" situation, i.e. the additional income generated by applying irrigation must at least equal the costs of irrigation.

In table 5.12 this additional income is calculated, under certain assumptions made. The additional income is estimated at K 59,000. It is assuming that other input factors (levels of fertilizer, improved seeds, chemicals application) are optimal, i.e. application rates are the same as of the average commercial farmer. This income is somewhat below annual costs of irrigation by means of diesel and dual-fuel engine (biogas) pump sets. Profitable is irrigation only in case a direct connection to the grid is possible.

Conclusively, electric pumping is most attractive. Reliability of electric pumping is higher than of diesel pumpsets (AW Tarry Ltd., p.c.), and is to be preferred when possible. In most cases such a direct grid connection is not possible. Grid extension seems feasible financially. In practice, ZESCO will only consider such extension when a group of farmers is willing to connect and finance the extension. Final feasibility will then depend on the load factor of the extension.

The next cheapest options (for 30 m borehole pumping) are pumpsets with internal combustion engines (diesel, biogas) or electric pumpsets (diesel-generated). According to this analysis costs are somewhat above the additional income, for an area of 25 hectare. One could say that these are not feasible options for (even above-average) emergent farmers. Difference between total costs and benefits (table 5.12) is not large however. Feasibility of irrigation for an above-average emergent farmer (about 20 hectares), by means of engines (diesel, or biogas) would thus depend on the actual depth from which the irrigation water has to be lifted.

Of the renewable energies biogas is competitive against diesel, provided that a dual-fuel engine is marketed at the same price as a comparable diesel engine. The required plant capacities are quite large however. For irrigation of a 25 hectare plot (at 30 m water elevation) this means that a farmer needs about 225 cattle (assuming additional use of crop residues as feedstock), to produce enough dung!!! Viability of biogas-powered irrigation thus depends on:
- the number of cattle owned,
- the fodder availability. If fodder has to be bought especially to feed the large amount of cattle this will increase the costs of biogas.

Already some parts of Magoye area are overgrazed. By fencing, fertilizing grasslands their productivity could be increased, but costs would increase too.

Economics of scale are important. For technologies as pumps, diesel engines/generators, solar power or biogas holds that the larger the power capacity of the technology the lower the investment cost per unit of power. The larger the plot irrigated the lower the unit cost per m³ water delivered, the lower unit costs per hectare.

We can extrapolate the above results taken into account economics of scale. This is illustrated by the following figures:
- TS1 diesel engine 4.5 kW, costs K 5800/kW.
- HL6 diesel engine 51 kW, costs K 2550/kW (table E.14).
- KSB submersible pumps: 0.75 kW, costs K 16,600/kW.
- 1.5 kW, costs K 9700/kW (Source data: A.W.Tarry Ltd, Lusaka).
Economics of scale implicates that similar options that are not feasible in emergent farms are certainly not feasible in peasant farms. Conclusively, borehole irrigation (at a 30 m elevation) is not a feasible option for peasant farms.

For commercial farms economics of scale implicate that diesel or biogas-powered pumping become feasible, because of the larger hectarage irrigated. Of course, electric pumping, in case of direct grid connection, is always cheaper.

5.6.4 Maize-shelling

Table 5.13 gives a review of time requirements to shell the mentioned quantities of maize. Compared with cooking and irrigation, fuel consumption for maize shelling is small. Total energy requirement in shelling of the 127 bags of maize (emergent farmer) is 20 kWh and 130 kWh in shelling of 800 bags (emergent farmer), in case of the engine-powered sheller mentioned in the table. Compare, e.g. cooking: about 5400 kWh/year. Demand concentrates however in a small period, a couple of days.

In view of costs of shellers, and of the time requirements, the following options seem feasible to me:
- peasant farmer: small handsheller,
- emergent farmer: large or pedal-powered sheller, small engine-powered,
- commercial farmer: medium/large engine-powered sheller.

Whether farmers actually will employ a sheller, depends on other factors. Where family labour is available to do the job, traditional shelling methods is likely to be preferred by a household.

<table>
<thead>
<tr>
<th>Base data</th>
<th>Peasant</th>
<th>Emergent</th>
<th>Commercial</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize production per year</td>
<td>22 bags</td>
<td>127 bags</td>
<td>800 bags</td>
<td></td>
</tr>
<tr>
<td>Time requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HAND SHELLER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small (150 kg/hr, X 660)</td>
<td>13 hr</td>
<td>76 hr</td>
<td></td>
<td>X 144</td>
</tr>
<tr>
<td>Large (300 kg/hr, X 2300)</td>
<td>4 hr</td>
<td>23 hr</td>
<td></td>
<td>X 504</td>
</tr>
<tr>
<td>Pedal-powered (1300 kg/hr, X 3300)</td>
<td>1.5 hr</td>
<td>9 hr</td>
<td>55 hr</td>
<td>X 723</td>
</tr>
<tr>
<td><strong>ENGINE-POWERED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small (750 kg/hr, 1.3 kW, X 3200)</td>
<td>15 hr</td>
<td>96 hr</td>
<td></td>
<td>X 701</td>
</tr>
<tr>
<td>Medium (2500 kg/hr, 4.5 kW, X 14,900)</td>
<td>4.5 hr</td>
<td>29 hr</td>
<td></td>
<td>X 3263</td>
</tr>
<tr>
<td>Large (4000 kg/hr, 7.2 kW, X 28,000)</td>
<td>3</td>
<td>18 hr</td>
<td></td>
<td>X 6132</td>
</tr>
</tbody>
</table>

**TABLE 5.13** Maize shelling, time requirements per type of power input.
Source data: SHA 84; AW Tarry Ltd., Lenco.
Annual cost are estimated, assuming lifetime 10 years, and operating cost 3% of initial investment.
This chapter presents the final stage in the aims-tools-impacts cycle on energy in Magoye farming households. In chapters 4 and 5 we discussed energy demand (aims), present and alternative energy technologies (tools) and impact identification (capacities, costs of energy technologies). This chapter deals with impact evaluation: the possibilities of (alternative) technologies to match (present and future) energy demand of farming households sufficiently, in a reliable and affordable way. The evaluation culminates in an attempt to formulate policy recommendations for improving energy supply in Magoye area.

6.1 Conclusions Magoye area

6.1.1 Characteristics of Magoye area and its farming systems

Magoye area cannot be regarded as an area representative for Zambia. The unique features comprise:
1) the farming in the area is far above-average. This is due to:
a) high fertility of the soils,
b) employment of animal draught power,
c) fair accessibility.

Farming in Magoye area is, with the Tonga tradition of cattle husbandry, related to the use of oxen and ox-drawn implements.
Magoye area is located along the tarred road Livingstone-Kafue-Lusaka. This guarantees adequate possibilities for supply and transport of agricultural in- and outputs from/to other parts of the province/Zambia. Recent problems in inputs provision and marketing are therefore not due to inaccessibility, but to problems in the organizational infrastructure.
2) location in the line-of-rail area. The area itself is relatively densely populated (esp. on the settlement schemes), as compared with other rural areas. The vicinity of urban centres (Mazabuka, Monze, and even Kafue, Lusaka) has made deforestation due to charcoal production manifested itself also in Magoye area.

Types of farmers

The three main farmer types in Magoye area are:
- small-scale (peasant) farmers (1-5 ha of cultivated area, 87.4% of the
farmers in Magoye area). Average household size is 8.4 people. Average cash income from crops of a peasant farmer, cultivating 3.5 ha (maize, cotton, sunflower, soyabean) is estimated at about K 2980 (1987 Kwacha) per year. If secondary sources of income, depreciation of implements are taken into account, we come at a net farm cash income of K 830. This is a very modest income, implicating that (after subtraction of cash consumption expenditures) cash saving possibilities are about K 400 (actual figure depends on revenues from sales of cattle; the reader should note that this figure is only a rough estimate, giving the order of magnitude of cash savings possibilities).

Note that 'subsistence farmers' (not involved in cash crop farming) are not identified as a separate group by Magoye extension workers. Their number in the area is negligibly small. 

- emergent/settlement farmers (12.9%), cultivating 5-40 ha. (Re)settlement farmers can be categorized as group between emergent and commercial farmers. Settlement schemes are located near the main streams (Magoye, Ngwezi) that do not fall dry completely during the dry season. The Tonga have a tradition of polygamy and characteristic is the large family size of a settlement household (about 21 persons/family). On one hand family labour is thus abundantly available, on the other hand, allocated plots are becoming too small to accommodate such large families. Average cash income from crops of a household in this category, cultivating 10 ha (maize, cotton, sunflower, soyabean) is estimated at about K 10,000 per year (1987 Kwacha). Again, including other farm revenues and expenditures (e.g. depreciation of implements) net farm cash income is about K 5000. Cash savings depend on actual cash consumption expenditures and cattle sales, and are here estimated at about K 2100. Again the reader should note this is a rough estimate, merely indicating the order of magnitude.

- commercial farmers (about 0.7%), cultivating over 40 ha. They generally have private means of transport, tractor(s) and are connected to the electricity grid (Magoye Town and immediate surroundings lie at a 11 kV power line). Cash receipts from crops of the average commercial farmer are estimated at about K 111,000 and expenditures on implements at K 56,000. Other expenditure (e.g. wages for casual or permanent workers, consumption expenditures of the household of a commercial farmer) or revenue items were not studied in this report.

Thus, farm income of the majority of farmers (peasant farmers, about 87%) hardly allows expenditures other than essential consumption goods (food items, blankets, pots & pans, medicines, school fees, etc.). In recent years prices of consumer goods and farm inputs have risen (in accordance with the depreciation of the Kwacha). Producer prices of crops have increased, though not at the same rate. In real terms income situation of farming households have declined therefore.

Profitability of a food crop as maize is much lower than of non-food crop as cotton. Producer prices of staples are being kept low in favour of the urban consumer. More economic producer prices would bring purchase of goods more in reach of peasant and emergent farmers. This would lead to an increasing ability to extend cultivation and an increasing standard of living in general.
6.1.2 Constraints and options in energy supply of farming households

The following group of energy-consuming tasks, carried out by a farming household, can be identified:
- domestic tasks (w.u. cooking, lighting, transport of firewood and other commodities, domestic water supply),
- agricultural tasks (crop production and processing, transport of farm in- and outputs),
- animal husbandry,
- water management (domestic water supply, irrigation).

Tables 6.1 (peasant farming households) and 6.2 (emergent farming households) give a summary of feasible options for improving the energy infrastructure of farming households. These options were identified in chapter 5, and are evaluated in this paragraph. A similar summary of options for Magoye commercial farms/households is not given. Generally, farms in this category are connected to the electricity grid, have a borehole for waterpumping, and employ engine power (diesel engine; tractor). Therefore, these do not face important problems in energy supply. The only energy question important in this category, is whether there are cheaper alternatives for electricity (domestic and productive tasks) and/or diesel power. In the case of grid electricity the answer is negative.

1) Fuelwood scarcity: domestic (energy-related) technologies

Households form the main group of consumers of fuel in the area, and cooking is the task by far requiring most fuel. Except households that are connected to the national grid (commercial farmers, wage workers in and round Magoye Town or Chivuna), households rely exclusively on firewood as source of fuel for cooking and heating.

Fuelwood scarcity is considered a constraint in some agricultural camps in Magoye area. Deforestation increases as a consequence of population pressure in the area itself, and due to charcoal production for (near-by) urban areas, as Magoye Town, Monze, Mazabuka, Kafue and even Lusaka. This will result in longer haulage distances, and an increased burden on women and children, who are mostly responsible for fuelwood procuring. Generally, it will lead to a deterioration in quality of life, and to environmental damage (soil erosion).

Other use of fuel in domestic tasks is for lighting. Farming households use paraffine, in selfmade 'can & wick's, or in hurricane lamps. Illuminance of these lighting devices is poor, as compared with modern standards. Of course, only households that are connected to the grid use electric lighting.

For peasant and emergent households the cheapest alternative for cooking (for the use of 'free' (but scarcer) wood) is wood produced in village forestry woodlots. For peasant households it is the only affordable one. Annual costs are K 95-340, depending on end-use efficiency. On assumption that an improved woodstove would cost the same as an improved charcoal stove, (about K 15) then it is clear that a village forestry project should go together with stove dissemination. Such stoves can be made artisanally in the area itself. Both village forestry and woodstove introduction require government funding in
### Annual expenditure

**SUMMARY LEAST-COST ENERGY TECHNOLOGIES, AVERAGE PEASANT FARMING HOUSEHOLD:**

**Annual cash saving possibilities (see paragraph 5.3)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Present</th>
<th>Constraint</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking (8.2 household members, annual energy consumption 2788 kWh)</td>
<td>x 0</td>
<td>x 326</td>
<td>- 'free' wood, portable metal stove x 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- village forestry, open fire x 170</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- village forestry, brick oven x 112</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(cost estimates inclusive annual cost cooking device, based on table 5.7)</td>
</tr>
<tr>
<td>Lighting (see table 5.8)</td>
<td>x 14</td>
<td>x 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(low illuminance level; present lighting devices)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALTERNATIVE: no feasible option, except substitution of can-à-wicks by hurricane</td>
</tr>
<tr>
<td>Refrigeration: not feasible.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waterpumping, domestic water supply:</td>
<td>x 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(hand-dug wells dry out in the dry season)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALTERNATIVES:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- communal cased well (using rope &amp; bucket) x 82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- communal cased well (with handpump) x 215</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- communal borehole/handpump (10 m head) x 341</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- private cased well (using bucket &amp; rope) x 410</td>
</tr>
<tr>
<td>Maize shelling:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALTERNATIVE: small hand sheller x 144</td>
</tr>
<tr>
<td>Irrigation: not feasible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motive power applications (production: land preparation, transport):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALTERNATIVE: no feasible options</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>COMPLEMENTARY MEASURES: dipping of cattle against diseases (X 32/animal/year),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>improvement of technical infrastructure in the area for repair of equipment,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>improved water supply.</td>
</tr>
</tbody>
</table>

**TABLE 6.1 Summary of feasible options in improving the energy infrastructure of peasant farming households.**
SUMMARY LEAST-COST ENERGY TECHNOLOGIES. AVERAGE EMERGENT FARMING HOUSEHOLD:

Annual cash savings possibilities (paragraph 5.3): X 2200

Cooking (16 household members, annual energy consumption 5440 kWh):
PRESENT: 'free' wood, open fire X 0

CONSTRAINT: increasing deforestation

ALTERNATIVES:
- 'free' wood, portable metal stove X 20
- village forestry, open fire X 656
- village forestry, brick oven X 314
- village forestry, portable metal stove X 195
- biogas stove X 1736

(cost estimates inclusive annual cost cooking device assuming annual costs of biogas lantern to be the same as a paraffine pressure stove, X 55: based on table 5.7)

Lighting:

PRESENT: hurricane (paraffine) X 30

CONSTRAINT: low illumination levels

ALTERNATIVE: 1 biogas lantern (60 W eq 4 hours/day) X 235

(exclusive costs lantern)

Refrigeration: not feasible.

Waterpumping: domestic water supply:

PRESENT: hand-dug well X 0

CONSTRAINT: hand-dug wells dry out in the dry season

ALTERNATIVES:
- communal cased well (using rope & bucket) X 82
- communal cased well (with handpump) X 215
- communal borehole/handpump (10 m head) X 341
- private cased well (using bucket & rope) X 410
- communal borehole, animal-powered pump (10 m head) X 850-900
- private cased well (with handpump) X 1076

Maize shelling:

PRESENT: beating maize on raised racks or hand sheller

CONSTRAINT: none important

ALTERNATIVE:
- large hand sheller X 504
- pedal-powered sheller X 720
- small engine-powered sheller (excl. fuel costs) X 701

Irrigation: see text

Motorpower applications (production: land preparation, transport):

PRESENT: oxen and ox-drawn equipment; hiring tractors for transport

of farm outputs, personal transport: walking, ox-cart, hiring

CONSTRAINT: cattle diseases; repair and maintenance, quality equipment

ALTERNATIVE: no feasible options

personal transport: bicycle X 236

COMPLEMENTARY MEASURES: dipping of cattle against diseases (X 32/animal/year), improvement of technical infrastructure in the area for repair of equipment, improved water supply.

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TABLE 6.2 Summary of feasible options in improving the energy infrastructure of emergent farming households.
research and development and extension activities.

**Biogas** as household domestic fuel seems to be feasible for the emergent farmer. It has the advantage that it has a multipurpose function, as fuel for cooking, lighting, refrigeration and to drive engines. Annual cost expenditures on biogas (assuming a 10 m³ plant) would be:

- cooking K 1750, lighting K 240/lantern.

Total annual costs of a biogas plant (10 m³) are estimated at K 4000,- (only affordable by the above-average emergent farmer). To match daily biogas needs for cooking and lighting (1 lantern) only, a smaller plant size, of 5 m³, would be sufficient. A 5 m³ plant would cost about K 11,800 (see table D.6, retention period 55 days). At a lifetime of 20 years, interest rate 15% and operating costs, estimated at 5% of initial investment, annual cost of such a smaller plant are K 2475,-.

**Rural electrification** by grid extension is only a long term option, given constraints in government expenditures. If a grid extension would be constructed, and if load utilization would be high (above 50%), electricity from such an extension would be cheap and comfortable source of energy for households. But the large capital outlay required (600 families connected, annual financing cost K 3.5-4.0 million) excludes for the coming decades grid extension to rural households by government investment. Also load utilization factor of rural grids are expected to be small in the first period after construction (1-14% is the experience in other developing countries). ZESCO would only be willing to extend the grid if cost were borne by the households themselves. Such an extension cannot be afforded by peasant or emergent farming households (annual financing costs K 5700-6500 per household) however.

Grid extension (at a load utilization of 100%) is the cheapest option in rural electrification. As already this option is not feasible for peasant and emergent farming households, other options in rural electrification (diesel/biogas/woodgas-generated, photovoltaics) are not feasible as well.

Conclusively, one can say that, at present income levels, and thus cash saving possibilities, rural electrification is not feasible for peasant and emergent farmers. Therefore, luxury household appliances such as electric lighting, fans, refrigeration are beyond reach of most rural households, also because of the initial capital outlay that household appliances require (e.g. refrigerator, annual financing cost K 2560).

For lighting in peasant and emergent farming households, this means there will be hardly any alternative for the present use of kerosene, except biogas (emergent farmers).

2) **Water supply for human and cattle consumption and garden watering**

Water is necessary for household and cattle consumption. The poor availability of water in the dry season is a big problem, as stream and rivers (almost) fall dry and hand dug wells dry out.

This means larger distances farm-water source. Furthermore, drying out of wells further inhibits watering of homestead vegetable gardens. Such gardens would be an important step in diversification of the imbalanced diet many peasant and emergent farming households have in the dry season.

The only waterways in the area that do not dry up are Magoye and
Ngwezi Rivers. Dams in these rivers are the only water resources in the late dry season. This has resulted in a situation of overgrazing near these places. Many farmers take their herd to distant grazing lands, but this trekking has negative aspects:
- it reduces the availability of oxen as source for draught power,
- animal manure cannot be collected. Manure is important as fertilizer,
- cattle pick up tickborne diseases, especially in Kafue Flats area the notorious corridor disease. Cattle watering in the area itself would thus be a major improvement.

Only commercial farmers have privately owned boreholes (electric pumping).

**Options** that can be afforded by *peasant* households, and, can meet water demand for domestic purposes of a (group of) household(s), are:
- communal cased well (using rope & bucket, annual costs K 82/household, 5 families),
- handpump/communal cased well (annual costs K 215/household, 5 families),
- handpump - borehole (annual costs K 340-1750/household, depending on elevation head, 10-30 m; nine, three families respectively). Only at low elevation heads (about 10 m) is this option feasible for the average peasant farming household.
A private cased well (using bucket and rope) would cost K 410 annually, only feasible for above-average peasant farmers.

Options that can be afforded by *emergent* households, are:
- options mentioned under peasant households,
- private cased well (with handpump, annual costs K 1076).

Here, the government should assist in digging deeper wells and, casing of wells, and installation of handpumps. With credit facilities the initial capital outlay of a handpump/deep well combination lies within the financial possibilities of a farming household, if facilities are shared. Private ownership of a borehole/handpump combination is above cash savings possibilities of the average emergent farming household.

Village level water supply by diesel, biogas, woodgas or electric pumpsets is in practice too expensive (range K 270-800/family annually at a 10 m elevation head), for the peasant farming household. Especially because such supply systems would also require a storage tank (adding K 790/family to the annual costs) and an operator (with additional labour costs).

Small-scale man-operated pumps have the advantage that these can be produced locally from locally available materials. This is an important feature. At the moment lack of spare parts has a result that if a pump is broken, it may last weeks until a deficit can be repaired. Such local-material pumps are in Zambia still in the research and development stage. There is no experience with animal-powered pumping in the area.

Annual costs of animal-powered pumping (serving a group of families) are estimated in this report at about K 900-2590/household (10 or 30 m elevation, inclusive investment cost cattle), or K 850-2490 (exclusive investment cost cattle). In case of 10 m elevation animal-powered borehole pumping is feasible for emergent farming households, if facilities are shared with other emergent farming households.
3) Some social aspects of introducing household domestic technologies in peasant and emergent farming households

**Water supply systems**

Ultimate goal of a water supply project is improvement of the living conditions of the target group. It will implicitly cause social changes: the project participant will earn more money and/or get more food and gain in status; he could sell water to other households in times of surplusses, placing households in a dependent position.

Private small pumps have the advantage that it makes families more autonomous and less management is required. Private ownership of a water supply device might be discouraged as neighbouring farmers might make use of it as well, without contributing to the cost. A private borehole might be too expensive for a small farm family, depending on the depth of the water table.

Such a family can profit (because of economics of scale) by co-operation or joint ownership. Working in co-operations is not traditional in the society, however. Also, homesteads are (traditionally) situated far apart in the area. Thus problems may be the site of the pumping device, and the day-to-day division of water.

**Family decision making**

Feasibility of introduction of household domestic technologies in peasant and emergent households will require a change in social attitudes.

Household activities, cash cropping activities, and subsistence cropping activities are traditionally sex-related. As cash cropping and cattle husbandry are under supervision and responsibility of men, women are not in a position to generate a cash income by farming. Other (female) income generating activities (e.g. beer brewing) are limited, and/or earnings are added to the household budget. Extension of cash cropping might only make female tasks heavier, as women are expected to contribute to extend cash cropping and simultaneously expected not to reduce household activities. Therefore, in the transition from traditional to emergent farming, it will be the men who benefit most from this process.

Improvements in the efficiency of household tasks (such as construction of a near-by well, purchase of a household appliance or a time-saving means of transport, such as a bicycle) contribute to lighten female tasks. A positive effect of time savings also would be more attention and care for the children. Such improvements will generally have low priority, however:

- opportunity benefits of lightening of female tasks are hard to quantify and does not generate direct financial revenues;
- such opportunity benefits are generally not included in the decision-making on expenditures for farming purposes, as financial affairs are under the responsibility of men.

Cattle is not sold regularly by peasant and emergent farmers. Simple improvements (such as village forestry, a cased well or even a biogas plant, dipping of cattle) could be afforded if farmers would sell some cattle on a more regular basis. The Veterinary Department can play an important role in commercialization of cattle husbandry in the area.
4) Agricultural production, transport

Except for commercial farmers (using fuels for tractors), the main energy input in production is muscle power, human and ox power. The other main energy input is sunlight needed for growing of plants, and for drying of harvested crops.

Mechanization of tasks

Tasks requiring motive power application are:
- land preparation, planting, harvesting,
- transport of farm commodities.

Tasks requiring stationary power application are:
- water pumping for irrigation,
- crop processing (maize shelling).

In a traditional system main source of power is human labour. Traditional farming (in which a household produces mainly for subsistence needs) is almost absent in Magoye area, unlike the average Zambian rural area. Transitional farming systems are characterized by mechanization of tasks (employing animal power), production and marketing of cash crops, and use of purchased inputs. Peasant and emergent farmers are in such a transitional stage. Commercial farms are modern systems, characterized by further mechanization (employing engine power) in an "optimal" combination of human and animal labour, engine power, purchased inputs and cropped area.

To a farmer mechanization of power application in tasks becomes interesting when:

a) it leads to an increase in cultivable area and/or cropping intensity, and such an increase by expanding existing power sources is not possible or feasible.
b) existing sources of power are not reliable or unavailable, especially in times of peak requirements.

Agricultural tasks first to be mechanized are:
- land preparation, planting and transport
- irrigation.

Crop growing and transport

Land preparation, planting and transport have to be carried out in a limited period of the year, i.e. just before planting and immediately after harvest. Generally, Magoye peasant and emergent farmers use animal power to perform these tasks, while other tasks (weeding, harvesting, maize shelling) are carried out manually. Only commercial farmers can afford tractors and tractor-drawn equipment. Costs of equipment for crop cultivation (land preparation, transport) are estimated:
- K 380 per hectare (ox-drawn equipment), K 670 (inclusive value of animals, annual cost of supplementary feeds),
- K 1140/hectare (tractor and tractor-drawn equipment).

Hiring of labour is not common in the area. Only female-headed households have to depend on hired labour or relatives. Farmers that have been afflicted by corridor disease and are faced with a shortage of ox power, have to hire oxen for (partial) land preparation and transport of farm in- and outputs. This forms an extra burden on the farm budget. Emergent farmers sometimes hire tractors for transport of outputs. Tractor hire for land preparation is not profitable. Present rates of
Chapter 6

hiring of land preparation and transport for a plot of maize are estimated at:
- ox-hiring K 115/hectare (from fellow farmers, land preparation K 100/hectare; transport K 75, average 46 bags of 10 hectare at K 3/bag),

These figures confirm the picture that tractor hire is not profitable for (peasant and emergent) farmers. Rates for tractor hire seem to cover economic costs of tractor and tractor-drawn equipment, according to the analysis of this report. Even for above-emergent farmers cost of private tractor ownership is prohibitive in practice. Only on large plots (say of the average commercial farmer, about 50 ha) use of tractors becomes economical.

Irrigation

Irrigation protects the farmer against the unpredictability of the climate elements. Drought is a recurring phenomena. The drought that hit the 1986/87 season led to maize damage. Average production was 9 bags/farmer, as compared with 20 bags in the 1987/88 season.

Furthermore, irrigation would facilitate a farmer to have two crops a year, and thus to increase his income.

Energy requirements in irrigation (of plots larger than 0.1-1 ha) are such that employing human or animal power is excluded. Irrigation is capital-intensive requiring large investments in pump sets (pump and engine) and operation costs (maintenance, fuel). At present only few commercial farmers irrigate (part of) their fields.

In chapter 5 the example of irrigation of a plot of 25 ha was studied, on which 6 crops are cultivated in a 3-year crop rotation (maize, cotton, sunflower, soyabean, groundnuts, with wheat as new crop grown in the dry season). Irrigation leads to increase in income due to:
- increase in crop yields/hectare of the existing 5 crops.
- income from cultivating the new crop wheat.

Additional income is estimated at K 59,000, assuming optimal supply of other input factors (seed, fertilizer, chemicals applied as in the average Magoye commercial farms).

In this example irrigation is only profitable in case of electric pumping with a possibility of direct grid connection (annual K 23,000 at economic costs grid). Application of a diesel or dual-fuel powered pumping is slightly loss-making, but is expected to give a positive result in case of irrigation on plots larger than 25 ha (generally: commercial farmers), due to economies of scale. Again, biogas is competitive against diesel power.

Peasant and emergent are not connected to the electricity grid however. One can tentatively conclude that for them irrigation is not a feasible option. Such a conclusion is premature however. Much would depend, on:
- actual depth from which the water has to be pumped up (here 30 m is taken as an example).
- actual farming practice. In practice optimal results are not achieved immediately after introduction of irrigation, as there is a learning process.
- crop price development. At present producer prices of staple crops are kept below economic cost price. Clearly, more remunerative prices, and thus a higher farmer's income, would make investments in agriculture more profitable.
Nevertheless, the analysis in this report confirms a general picture that borehole irrigation is not necessarily the most appropriate solution in improving living conditions of small-scale farmers. Borehole irrigation is a costly affair and in combination with lack of skills of the farmer in operation and maintenance, unfamiliarity with irrigation practices in general, a failing maintenance infrastructure, may make irrigation uneconomical. A step-by-step approach is more appropriate then: first increasing levels of in- and outputs by erosion control, water saving activities, supply of high yielding varieties, fertilizer and pesticides, followed by a change in farming practices, with realisation of infrastructural improvements as irrigation thereafter.

Multiple use of engines
An important characteristic of applying renewable energy sources (in irrigation) is the large difference between energy cost of consumption and unit cost of generation or capacity.

One reason is that sun and wind are variable sources of energy, one has to size capacities of the energy technology concerned to the lowest levels of solar irradiation and windspeeds in the month of peak demand (if demand is critical) or in the critical month of supply. Day to day irradiation and wind velocities are unpredictable, making expensive storage facilities (batteries or water tanks/ponds) necessary to overcome sunless and windless periods.

A second reason is the underutilization of irrigation equipment, during those months that rainfed water supply is sufficient. Diesel fuel differs from renewable energy sources in the sense that the consumer decides to procure it according to demand, while in the other case supply is fixed and underutilization of energy capacity has to be paid for. Lower costs per unit consumption of energy can be achieved by multiple-use of the engine in other months than the peak month. Costs then can be divided proportionally over different activities. Possibilities are:
- to use a tractor instead of an engine to drive an irrigation pump,
- to use an engine that drives a pump, for other purposes as well, in times when water demand is less, e.g. for maize shelling.

5) General problems in cattle husbandry and supply of farm inputs

Major constraints in ADP (animal draught power) and cattle keeping are:
1) lack of water and grass in the dry season. A related problem is the great loss of cattle in recent years, due to corridor disease, has had a deteriorating effect on the use of ADP (animal draught power), and thus agriculture of peasant and emergent farmers. Loss of cattle in itself means destruction of capital, as cattle are a form of capital. Afflicted farmers are forced to hire oxen from fellow farmers. The great demand for ADP concentrates in ploughing and harvesting time, leading to a shortage of ADP available in these periods, resulting in increasing fees for ox-hiring and late starting of necessary agricultural activities. Occurrence of cattle diseases (tsetse fly in the past, tickborne diseases now) goes in conjunction with inadequate and irregular supply of acaricides and prophylactics. On the other farmers often give cattle too
dilute mixtures.

2) supply of (acceptable) ox-drawn equipment. Supply is inadequate in terms of quality, quantity and regularity. The core of the problem is a breakdown in the raw material/manufacturing/distribution chain in Zambian equipment supply industry (foreign exchange!). Only a few companies in Zambia are involved in importation and manufacturing, (others have no access the necessary inputs) and have virtually a monopoly, with the effects of supply of poor quality tools at high prices. Magoye farmers complained e.g. about the low quality ploughs. Spare parts are unobtainable (resulting in effects as households having more than one plough, because spares for the old one are scarce) and cannot be locally repaired.

3) Depots run by SPCMU and the Societies do not have the financial reserves to guarantee a regular and adequate supply of (a wide range of) implements and spare parts.

4) repair and maintenance facilities. Repair facilities in the area at village level are inadequate or non-existent, yet are important to fill the present gap between demand and supply. The artisan sector lacks training, raw materials, and credit facilities.

Besides power and water, other input factors play a crucial role in agricultural production. Without adequate and timely supply of hybrid seeds, fertilizer and chemicals efficiency of cultivation (whether by oxen or tractor power) is seriously reduced. At the moment an optimum co-ordination between periods of ox-ploughing and availability of inputs leaves much to be desired.

SPCMU has only recently been given responsibilities for tasks previously handled by the parastatal Namboard. The management has not been developed as to deal successfully with the newly given responsibilities. Furthermore, competency problems at national level between Namboard and the PCUs have resulted in delays in collection of agricultural output and in distribution of inputs.

The output has to be transported before the start of the rainy season. Especially transport from collection points in the area to the district centre poses problems. One heavy shower damages maize, stored in the open air in bags, totally. The start of the wet season is always uncertain (November to mid-December).

Logistical problems in inputs supplies that selling points (depot run by the Primary Societies) face, have as a consequence that farmer receive their inputs late, after the ploughing period has started already.

A more intensive utilization of inputs by peasant (and to a lesser extent emergent) farmers (seeds, fertilizer, chemicals) by application of inputs at higher rates or on more crops, is inhibited by:
- inadequate purchasing power,
- limited availability of credit facilities,
- motivation (influenced by traditions, past experiences).

For an efficient use of ox power in Magoye agriculture an adequate infrastructure is paramount. Especially extension of activities by the Veterinary Department to eradicate corridor disease should have top priority.

Problems in farm inputs supply and output marketing (that depots and SPCMU face, can partly be identified as the aftermath of the inefficient centralized infrastructure of agricultural institutions in
the past, and of the recent changes therein (decentralization, shifting responsibilities of institutions on national and local levels).

Partly these problems are conditioned by the deteriorating national economic situation in the eighties, that has resulted in severe cuts in expenditures by national and local governments. The economic crisis has manifested itself also in acute shortages of foreign exchange, which are responsible for the growing problems, the Zambian manufacturers of ox-drawn equipment face today. As long as the economic crisis persists, limited government budgets will remain, and an inadequate supply of farm equipment and spare parts will remain, on the national and on the local level. Despite limited financial reserves local authorities in the area should play a role in improving the technical infrastructure, by supporting private initiatives of artisans in the area (that do not require large government investment).

6) Credit supply of peasant and emergent farmers

Given limited funds of the credit institutions, seasonal loans for seeds and fertilizer have priority. Credit institutions are reluctant to disburse medium term loans, even on farm equipment (as e.g. for investment in procuring a span of oxen, about K 3000, and an ox-cart, about K 5000, 1987). Therefore the number of loans approved for domestic technologies as handpump/deep well (initial investment K 4370) or handpump/borehole, K 14,600) will be low, especially because these investments do not yield cash profit.

Even if credit for a energy(-related) technology is disbursed, two more aspects are important in financial viability:
1) learning period
Optimal results are achieved immediately after introduction of the new technology. In practice their will always be a learning process, in which results are not optimal.
2) repayment capacity
The repayment capacity of farm households is a very critical factor in introducing (energy-related) technologies. Repayment capacities can be limited by:
   a) loan conditions of the loan agency. These often demand security, which cannot be given by the small farmer in the case of big investment. If before introducing a technology a farm household lives below or just above the poverty line, receiving more money means a chance to raise above the minimum, and this will come before meeting repayment obligations. Loan agencies know this.
   b) high interest rates.
   c) repayment period. Often this period is shorter than the (economical or technical) lifetime of the investment. For example: assume a 10 m³ biogasplant costs K 19000. At a period of 10 years annual cost in the beginning period are K 3786 as compared with K 3339 in a 20 years period.

Furthermore, repayments usually start immediately, just in the "learning period", where the farmer is not yet getting optimal benefits. In the beginning period additional benefits from introduction of technology as irrigation may be insufficient to meet obligations of the loan agency. To meet these obligations other sources of income are required, such as saving deposits of the (extended) family. Alternative loan conditions or subsidies can (partly) solve this problem.
In the repayment period developments in levels of inputs and outputs take place over a number of years. In that period price levels (inflation and additional) change also.

6.1.3 Evaluation of impacts of introduction of energy technologies in charcoal production and consumption

Although this report primarily deals with farming households, rural woodfuel problems cannot be separated from urban ones. Charcoal is the main fuel of urban households. With expanding urban population demand for charcoal will increase, deforestation will become more widespread, resulting in rising charcoal prices and shortages (urban households) and a growing firewood shortage (rural households). Therefore options for urban households are included as well.

Most cost effective, complementary, options for urban household energy supply are:

Option A: electricity.
From a household's point-of-view connection to the grid at present charges or economic costs is cheapest. If supplied at the present charge annual fuel expenditure on cooking is K 318, supplied at the actual economic cost of the grid K 740 (assuming an annual energy expenditure on cooking of 2890 kWh, average household size: 8.5).

Where there is no grid connection yet the grid has to be extended. The cost competitiveness then depends whether costs of extension are borne (partially) by the consumer. Urban electrification is one of the government's aims. Given the constraints in government expenditure, this will only be a long-term option. Where no government-funded extension is possible, ZESCO will only consider extension if costs are borne by consumers themselves. Cost competitiveness then depends on the load utilization, and on the extent to which additional charges depend on load utilization. Earlier experiences with urban electrification have shown that, even if costs of extension are fully borne by ZESCO, only few households will be prepared or able to meet the initial capital outlay (for internal wiring, about K 8500, and for cookers/stoves and other implements).

If costs of extension are included annual costs of electric cooking of a household are estimated at K 1200-1700 (100% load utilization) and K 9650-10100 (10% load utilization).

Option B: Plantation woodfuel: firewood, charcoal production
Compared with present charcoal prices, wood and/or charcoal produced from plantations is not competitive on the urban markets. Range (depending efficiency end-use device, open fire or improved woodstove): wood, K 1000-3670, charcoal K 2130-4900 (also depending on method of production). Plantations require large initial government funding. Also, planted trees take several years to be mature, so plantation wood is at least a medium term option. Whether plantation wood or charcoal becomes competitive vis-a-vis charcoal produced from 'free' wood will depend on the future price development of charcoal, which will increase as
deforestation grows.

Option C: Improvement of charcoal production techniques and introduction of improved charcoal stoves.

For the urban consumer two options are affordable:
1) introduction of fuel-saving improved stoves, which gives even lower annual expenditures (on fuel and cooking device) than mbaulas.
2) charcoal produced by improved charcoal production techniques (e.g. oil drum kilns) is affordable in combination with fuel-saving stoves. These technologies (simple stove designs, oil drum kilns) do not require a large-scale infrastructure, as they can be manufactured by urban or rural workshops. Government investment is needed however to co-ordinate research and development, to implement extension activities and to promote dissemination.

If produced from 'free' wood annual fuel costs of cooking are K 880-1100, depending on ways of production and consumption.

Options A and C should not exclude each other, but be mutually supportive. Option C is a short and medium term option, easing the pressure on wood resources. Option B is a long term option, substituting electricity for charcoal.

6.2 Recommendations: an attempt to formulate an energy scenario for Magoye area

Looking at technologies, these can be divided in five groups:

1) Technologies that:
   - are or can be manufactured in Zambia;
   - fit in the existing infrastructure for maintenance and marketing;
   - the technology can be made from indigenously available raw materials, e.g. wood, brick. Steel has to be imported, and thus foreign exchange is needed. Using scrap metal is less costly than newly imported steel. In energy technologies using of local materials is possible in manufacturing of pumps, biogas plants (brick and concrete instead of steel domes), windmills (wood instead of metal).

2) Technologies that:
   - are or can be manufactured in Zambia;
   - fit in the existing infrastructure for maintenance and marketing;
   - cannot be made from indigenously available materials,
   - require little repair and maintenance.

3) Technologies that:
   - cannot be manufactured in Zambia;
   - fit in the existing infrastructure for maintenance and marketing;
   - require little repair and maintenance.

4) Technologies that:
- can be manufactured in Zambia, but do not fit in the existing infrastucture. Costs of developing a (new) supporting technical and organizational infrastructure, and of promotion of extension activities are low. Large-scale government funding of such activities will in most cases not be possible, even in the case of high growth of the economy in the coming two decades (i.e. such a growth that GDP (gross domestic product) per capita will at least remain static).

5) Other technologies.

In rural areas in Zambia handpumps, diesel and electric pumps are already in use (and be categorized in groups 2 and 3). These technologies are familiar, and there is a, though not optimally functioning, network for marketing and spare parts. Disadvantage of diesel pump sets, as compared with electric pumping, is that they require more maintenance and repair. In Zambia simple technologies that require little maintenance are to be preferred in view of the tremendous shortages of spare parts.

New potential technologies comprise:
- improved stoves and simple improved charcoal production methods (e.g. oil drum kiln). These can be made artisanally.
- solar power, windmill or biogas technology. Of these technologies production has not started or just started (solar power), and a marketing network has to be established yet.

In the energy scenario we will distinguish between 3 options in introduction of new alternative technologies:

SHORT TERM options (< 6 years). These comprise:
\[ a) \] introduction of existing prototypes of 'group 1' technologies (e.g. existing prototypes of improved charcoal stoves),
\[ b) \] research and development in new prototypes of technologies from groups 1 and 2 (e.g. wood stove, improved charcoal kiln, biogas plant),
\[ c) \] strengthening local repair and maintenance capacity.

MEDIUM TERM options (6-15 years). Beyond the short term there is a period during which a number of strategies is possible, based on initial 5 years of research and development, but within the longer term, in which major agricultural, industrial and forestry developments have hardly begun to produce significant results. Options comprise:
\[ a) \] widespread dissemination of proven prototypes of technologies from group 1 (e.g. improved charcoal stove),
\[ b) \] introduction of prototypes of technologies from group 1 and 2 (wood stove, improved charcoal kiln, biogas plant),
\[ c) \] introduction and/or dissemination of proven imported technologies of group 3 (if national economic performance permits so, e.g. the conventional diesel or electric pump),
\[ d) \] research and development in technologies from group 4 (e.g. dual-fuel engine, wood gasifiers).

LONG TERM options (> 15 years). These comprise:
\[ a) \] widespread dissemination of technologies from group 1 and (if the foreign exchange situation permits so) from group 2,
\[ b) \] introduction of low-cost imported technologies (group 3, if the economic situation permits so) or new local technologies (group 4).
In the following options for Magoye farming households and urban households are discussed. Options for urban households are mentioned as well, as woodfuel shortage is an interlinked problem of both rural and urban households. The options are compiled, based on the above-mentioned characteristics of technologies, in view of the findings sketched in paragraph 6.1. In improving energy infrastructure in Magoye area priority should be given to peasant and emergent farming households. Commercial farming households do not face major problems in energy supply (they are connected to the electricity grid), and comprise only 0.7% of Magoye farming households.

Short term

WOODFUELS:
- further enhancement of village forestry activities in peasant and emergent farming households by Lusume Services; integration with agricultural extension activities.
- introduction of already developed types of improved charcoal stoves in near-by urban areas.
- encouragement of private and small-scale reforestation projects, e.g. for charcoal production.

HUMAN POWER AND ANIMAL POWER:
- improving water supply (peasant, emergent farming households) in the area by simple methods:
  - simple open, but cased, wells using buckets and chain on private wells, and/or
  - installing handpumps on cased wells or boreholes (communal), drilling of boreholes. R&D in construction of low-cost handpumps and piping, made from local materials. Assistance of local governments is needed to construct improved wells or boreholes.
- to maintain or increase agricultural production availability of animal power must be ensured. The Veterinary Department should increase campaigning against diseases, stimulate proper cattle use and cattle management (adequate dipping) by peasant and emergent farmers.

NEW AND RENEWABLE ENERGIES:
- as part of R&D program a pilot project could be started, in the most promising technologies. Prime candidates are a biogas plant (in an emergent farming household), or a simple improved charcoal kiln (e.g. oil drum kilns).

INFRASTRUCTURE:
- development of rural workshops, by training of craftsmen and supply of critical inputs. Establishing a local technical capability is as a necessary basis for introduction of energy(-related) technologies and repair and maintenance of existing ones (e.g. ox-drawn equipment).
- credits are necessary to purchase seasonal inputs and technologies. Especially medium-term credit for peasant farmers is important, as savings capacity of these farmers is too small to purchase implements from their own financial means.
- inputs (consumer goods, seasonal inputs) are made available by the Multipurpose Societies and SPCMU. To increase availability and reliability in supply, this marketing and supporting infrastructure formed by the Societies and SPCMU must be strengthened. The Government should stimulate this. On the village level, primary societies play an important intermediate role between SPCMU and the village level. Increasing responsibilities of such Societies is suggested.
**Medium term**

**WOODFUELS:**
- development of village forestry in combined agriculture and forestry schemes that can meet food, cash and energy needs of the people, and further encouragement of private reforestation.
- dissemination of improved charcoal stoves in near-by urban areas.

**HUMAN AND ANIMAL POWER:**
- expansion of the activities, mentioned as short term options.
- Extension officials should encourage integration of cattle husbandry in the above-mentioned agriculture and forestry schemes.

**NEW AND RENEWABLE ENERGIES:**
- introduction of technologies, after the 5-year's period of testing in pilot projects, i.e. if proven viable (improved wood stoves in wood-using households, improved charcoal production methods and training of charcoal producers, biogas technology in emergent farms).

**INFRASTRUCTURE:**
- further development of local repair and maintenance capacity of farm implements and engines of improved rural workshops. Such workshops could supply spare parts (of implements, ox-carts, bicycles). Welding should be included in the activities of the workshop. 'Large' workshops could e.g. be set up in each camp headquarter and, if feasible, connected to the electricity grid.
- improvements in domestic activities will depend largely on women's emancipation. In the area already Woman's Clubs are operating. Such a Club is a small organization of women, that provide information (e.g. on nutrition). They generate income by selling items women produce (pottery, clothes). The money raised is usually partly distributed among women and partly put at a bank (outside the reach of the women's husbands), for later investment in e.g. a co-operatively owned technology. Such a technology could be oil extraction or maize grinding. Further development of such Clubs will contribute to women's emancipation and thus contribute to raising standards of living. Such development should be encouraged.

**Long term**

Long term strategies have to consider macro-level developments that will have manifested themselves significantly after 1-2 decades. Such developments include the performance of the economic sectors (agriculture, industry, mining, forestry, export), development in rural-urban relations, training and education possibilities, improved transport system, cultural developments.

The viability of technological options will depend on such macro-level development trends. On the district level (w.u. Magoye area) a strategy is the organization of a general rural development plan (including energy supply) aimed a.o. at raising productivity in agriculture, creating employment in rural industries, increasing standards of living, and improving women's emancipation. Implementation of such a plan will depend on basic provisions as social services, infrastructure (technical, agriculture, transport, energy) and credit facilities.

Long term options include:
- electrification of nearby urban areas by connection to the grid,
- dissemination of improved wood stoves, improved charcoal production methods and biogas technology,
- institutionalization of charcoal production and marketing,
- a beginning rural electrification (by means of grid extension from the
11 kV line, and/or produced by dual-fuel generators, on biogas or even woodgas and/or photovoltaics). Much would depend on external factors (i.e. outside the area or even Zambia), as international price development of technologies (such as photovoltaics), oil price development, Zambia's economic performance.

Substitution for petroleum products
As the agriculture and economy of Magoye area develop, consumption of kerosene and diesel will grow proportionally, as long as there are no alternatives for these fuels.

Kerosene consumption for lighting will remain the only alternative until biogas lanterns and/or solar-powered lighting become cost competitive.

For generating stationary and motive shaft power, diesel and gasoline engines will remain the only alternative on the short and medium term, until dual-fuel engines are adapted on a wide scale.
PART III

THE NATIONAL LEVEL REVISITED
Chapter 7

IMPLICATIONS OF THE MAGOYE CASE STUDY FOR THE NATIONAL LEVEL

7.1 Introduction

A regional energy policy is embedded in the national policy on energy. It is therefore interesting to confront the energy scenario for Magoye area with the national energy policy. Chapter 2 was ended with a short review of the national energy policy. In this chapter elements of the Magoye case study are linked with the national energy strategy, as laid down in the draft report "Zambia: Energy Sector Strategy" (ZAM 88), prepared by the Department of Energy (DoE). Where appropriate, differences between energy options of Magoye area and of the national level are identified, and then confronted with the vision of the DoE.

A rural energy strategy is part of a general rural development plan. Rural development stands or falls with adequate support from 'above': governmental policies, policies of donor organizations, situation on world markets, etcetera.

Even in high-potential areas (of which Magoye area is an example) resources can hardly be fully exploited without supportive measures induced by the Government. Yet, recent experience has shown that development of small-scale agriculture (and agriculture in general) was not considered by the Zambian government as a prime tool to achieve development. The role of agriculture was rather seen as supportive to other sectors, esp. the mining sector and city dwellers (see AKK 89, part B for more details on rural development in Zambia).

Conclusively, priorities in rural development are to raise agricultural production (to meet the food demand of the growing population and to diversify export) and incomes of the poor. This can only be ensured by (besides an adequate energy supply):

a) timely and adequate supply of agricultural inputs,
b) adequate marketing facilities and efficient collection and storage of produce;
c) timely and adequate supply of credits,
d) remunerative prices of produce,
e) agricultural research and extension,
f) micro-capital for small-scale farmers, which form the majority of the farming households (improved tools, high-yielding variety seeds, fertilizer, chemicals, water and energy supply equipment).
7.2 Woodfuel and household energy

Urban households depend largely on charcoal. This is already causing located deforestation in the line-of-rail, which will become more widespread in future. Future and urban and rural energy supply is endangered by this phenomena, as woodfuel will remain the most important fuel in the near future; fuel substitution is only a long-term option, essentially an option for urban households.

The DoE recommends in ZAM 88 the following options in household energy supply:
- community and private sector reforestation efforts, that do not require Government funding,
- more efficient versions of traditional charcoal production techniques, coupled with effective producer training,
- efficient charcoal stoves, that can be made by artisans (in the informal sector).
- fuel substitution in urban households by increasing the rate connection to the electricity grid.
- research and development on coal briquettes.

Urban household fuel options

More efficient woodfuel production and consumption methods

In the view of the high cost of plantation forestry programs and the limited government resources available, the emphasis should not be on large-scale government-funded measures, according to the DoE. Private sector reforestation should be encouraged (short, medium term). For example, leasing of woodland plots to individuals (for charcoal production) on condition that tree replacement is carried out. Further, a program aimed at introduction of improved charcoal kiln techniques and improved charcoal stoves should have a high priority in an energy policy. The analysis of this report confirms these views of the Department of Energy (DoE).

The DoE estimates the economic cost of charcoal production from plantation wood at K 27/GJ, but comments that this is a highly conservative estimate. This figure does correspond with my estimate given in table E.5, about K 29/GJ, in case of charcoal produced from village forestry wood (by the traditional or oil drum production method). The reader should note that the estimations given in table E.5 are based on international data, and are not Magoye-specific, but must be seen as rough general estimates. Charcoal from large-scale plantation, is estimated at about K 71/GJ (table E.5), much higher as the DoE estimate of K 27/GJ. It has to be stressed that my estimate can only be indicative, due to uncertainty in estimates of price of plantation wood (range: K 0.059-0.30/kg, table E.5). Yet, a general picture is (see e.g. also LEA 87, p.95-103) that wood from small-scale forestry (village forestry, private woodlots) is cheaper than from large-scale plantation. At the moment charcoal produced from free wood is cheaper (about K 15.5/GJ, table E.5), but with the expected growing deforestation, prices of charcoal are expected to rise, and will become
more in line with the costs of charcoal production from private woodlots.

The DoE has the view that costly (fixed or portable) charcoal kilns are not viable. The key is introducing more efficient versions of traditional techniques, and the outcome of this report confirms this view. In this report the oil drum kiln is studied, as an example of one of the simplest, but nevertheless effective designs (about a factor two increase in charcoal yield, and thus a factor two reduction in wood use per kg charcoal produced!!). Such kilns are e.g. used on the Tonga Islands. Costs of charcoal produced from an oil drum kiln, depend on the source of wood. Using 'free' wood, costs are K 21/GJ (estimate, table E.5), as compared with K 15.50/GJ (1987 market price of charcoal). Using village forestry wood, costs are K 28.60/GJ (oil drum) and K 28.80/GJ (earthen kiln).

In countries as Kenia improved charcoal stoves have been successfully introduced in urban life (BHA 85). In ZAM 88 the DoE makes a strong case for introducing more efficient charcoal stoves. The results of the analysis in this report support this view. For example, the simple improved prototype, developed by UNZA, would cost about K 40 (mid 1987 price), as compared with K 15 (mid 1987) a mbaula costs. Due to the increased efficiency of the stove, charcoal savings of 50% could be achieved, thus contributing to saving woodstock, and to reduce household expenditures on charcoal (see figures given in table 5.7).

Another specific measure lies in bringing wood prices more in line with wood "costs" by raising stumpage fees. The 1987 fee was K 0.12/m³. For charcoal, produced from 'stumpage fee' wood, the fee should at least be about K 18/m³ to become comparable with the price of charcoal produced from small-scale forestry wood (see analysis in appendix E.2.2, E.2.3). As 95% of charcoal production is "illegal", it is clear to my opinion that an effective collection of stumpage fees cannot be met. Consideration could be given to a more effective enforcement of stumpage fees, but also the DoE does not consider this as a real possibility.

Another alternative is to use plantation wood, directly, as cooking fuel, instead of charcoal. Because of large Government funding necessary, such large plantation are not considered a viable option at present by the DoE. The cost comparison of cooking fuels made in table 5.7 supports this view from a consumer's point-of-view. To the urban consumer, annual fuel expenditure on (plantation) wood, burnt in an open fire, would be higher than in case of charcoal (produced from plantation wood), burnt in an improved stove. However, in case wood is burnt in an improved wood stove (25% efficiency) annual expenditures of a household would be about the same as the present expenditures of a household on charcoal. It has to be stressed that, besides costs, there are other factors influencing the choice of charcoal vis-a-vis wood (such as ease of transport, convenience, smokeless burning).

Fuel substitution

Rapid increases in market prices of charcoal in the major urban areas, coupled with low actual charges and economic cost of electricity, have stimulated interest in fuel substitution for charcoal. The DoE comes to the following conclusions in ZAM 88:
- on an annual basis cost of electric cooking (inclusive installation of a single hot plate) is very similar to cooking with a traditional charcoal stove.
- an improved mbaula is less costly than electric cooking (at economic...
- paraffine is not financially competitive against charcoal or electricity. Paraffine, fossil fuels in general, do not offer much potential as cooking fuel, both from a consumer's (annual fuel expenditure) and national point-of-view (foreign exchange cost).

The fuel expenditure estimates given in table 5.7 confirm these conclusions. In analyzing table 5.7 the reader should note that the data presented, are not Magoye-specific (except in the case of 'photovoltaics' and 'rural grid extension'): costs of fuels and equipment are primarily based on national data.

Conclusion is therefore, that the pace of connection of households should be increased, to the extent that it is financially viable.

Large-scale fuel substitution for charcoal by urban electrification is a long term option, given the present small rate of electrification (due to limited financial resources of the Government). Necessary steps are:
- to reduce the financial burden of households of electricity connection and internal wiring, and electric household equipment, by using less expensive equipment or spreading annual financing cost (repayment) over a longer period.
- increase the rate of electricity connections.
- a structure of electricity charges, that will facilitate household energy use, but also cover the financial and economic costs of supply.

A third fuel substitution alternative are coal briquettes (besides electricity or paraffine). The viability of this alternative should be assessed (short term). In this report coal briquettes were not studied.

Rural household fuel options

In Zambian rural locations woodfuel, human and animal power supply the bulk of energy needs. Utilization of energy should be aimed at improvement of the basic living environment, using simple devices, (e.g. installation of handpumps), then followed by provision of energy to improve agricultural productivity and for small-scale industrial activities.

It is my opinion that, to secure future rural firewood supply, village forestry should be encouraged (short term) and integrated with existing agricultural extension activities (medium term). However, the DoE stresses limitation of the 'village forestry' concept. According to the DoE village forestry is a low-cost solution. Such schemes require that tree nurseries be established and effectively managed, and that extension services be strengthened to teach sound tree care. Such initiatives require additional public funds, which will not be forthcoming on large scale in the coming decade.

At present the Department of Energy does not see the need for introduction of wood stoves for rural households. This is a different opinion than the one promoted in this report. Introduction of simple design of wood stoves can lower current energy needs for cooking two- or three-fold. But the fuelwood crisis has only manifested locally, and the rural population may not yet percept the importance of wood stoves. As firewood shortage will become more widespread in the coming decades, R&D and extension activities should not be ignored, to my opinion, but promoted on the short term.

There is no scope for substitution for firewood in rural household
energy supply (with under certain conditions biogas in emergent farming households, see further, 'new and renewable energies'). This view corresponds with that of the DoE.

7.3 Animal draught power (ADP)

Oxen provide power and consequently play an important role in agriculture, as input of power determines the hectareage cultivated, which in turn determines the financial position of a farming household. To my opinion, a wider spread of the use of oxen in agriculture in all parts of Zambia is paramount. This asks for:

- promotion of livestock husbandry (private ownership) in "traditionally no cattle-keeping areas". About 95% of the work animals are located in Central, Southern and Eastern Provinces. About 75% of the crop output in Zambia is still produced by manual methods. In raising the volume of output of crops extension/introduction of the practice of ox-cultivation is a key-factor in the western, northern, and northwestern parts of the country.

- promotion of commercialization of the cattle sector in "traditionally cattle-keeping societies" and integration with agriculture.

Promotion of cattle husbandry goes with:

- special credit facilities for the procurement of oxen and equipment.

- establishment of private rural workshops for cost effective repair and maintenance of ox-drawn equipment and manufacture of (small) tools. Training courses, focussing on carpentry, blacksmithing, welding, ox-cart and bicycle repair should be started, with newly trained craftsmen being supplied with credit and an initial stock of spare parts.

- training of farmers that are not familiar with care and use of oxen.

The above-sketched views roughly correspond with the recent policy goals of the Ministry of Agriculture and Water Development (MAWD), which is involved in ADP, as recently published in ANI 85 ("Animal Draught Power"). Of course materialization of these objectives will depend on the availability of Government resources. In the past the Government promoted some different views, which are now reviewed.

In the seventies the Government still promoted 'tractor power' for middle-scale (emergent farmers). 'Tractor hire schemes' for these group of farmers (who could not afford a tractor on their own) were established and heavily subsidizid. The Magoye case study of this report confirms a general picture that tractor power is not viable for middle-scale farmers, even if facilities are shared. In the eighties the huge foreign exchange constraint (all tractors and 90% of the farm equipment are imported) have led to big problems in maintenance and repair of tractors, and more than 50% of the tractor fleet is inoperable. The Government therefore has shifted its view to promotion of ox power instead of tractor power.
Also, the Government acknowledges now the fact that the lack of industrial policy has militated against the small producer in favour of a monopolistic manufacturing structure. Small producers are quite capable of efficiently producing spare parts for implements, as well as complete implements, for the ox farmer. In the recent animal draught power programme of the MAWD improvement of the conditions of small producers have gained more importance. The scarcity and high price of steel will also be problem a to small producers, however.

In the past hiring of oxen from a central authority, or communal use, was encouraged. A number of ADP projects were heavily subsidized. Most of these efforts have proven to be unsuccessful. In ANI 85 the view is promoted (ANI 85, p.10) that oxen must be owned privately by farmers and ox-hire must be confined to the private sector.

7.4 New and renewable energies

Accumulated experience with new and renewable energy technologies (NRETs) is small, and limited to particular setting (missions, private farms). Being an oil-importing country, Zambia is a prime candidate for application of NRETs.

The DoE considers the following options as most promising:
- biogas technology,
- wind-powered water pumping,
- solar collector technology: solar water heaters, solar fish driers.

Biogas

At the moment technology of biogas plants and auxiliary equipment (lantern, stove, dual-fuel engine) is in the early R&D stage, and experience is limited to isolated pilot plants. Technology designs are already well-known in other parts of the Third World (China, India). Biogas is attractive, because of its multi-purpose use, as fuel directly used in cooking or lighting devices, or easily converted into motive power and electricity.

According to the cost analysis sketched in this report biogas power is competitive against diesel power. Also biogas is, of the new and renewable energies, the only fuel which could contribute to fuelwood substitution.

Therefore, testing activities and adaption of prototypes to Zambian circumstances should be expanded and application possibilities identified (short term), followed by a first introduction in pilot areas (medium term). Biogas technology is only viable in cattle-keeping areas.

Although the DoE acknowledges the fact that biogas is one of the promising technologies, it comes to different conclusions. According to ZAM 88, biogas is not competitive against diesel. The findings of this
Implications of the Magoye case study for the national level

The report are contradictory: the costs of biogas per energy value are similar to costs of diesel per energy value. The DoE estimates costs of a 10 m³ plant, installed by the NCSR in Southern Province, at K 18,700, which roughly corresponds with the estimation given in table E.10, K 19,000, based on prices of plants in India. In ZAM 88 costs of biogas per m³ are incorrectly derived: it is assumed there that the 10 m³ plant can only produce 1 m³ gas per day. However, generally, one can say that the volume of biogas produced daily is roughly equal to the volume of the digester (for a temperature of about 25-30°C, see e.g. DUN 86, p.282).

As a consequence costs of biogas per m³ are estimated too high in ZAM 88: K 9.00/m³ or K 0.36/MJ.

The findings of this report are (10 m³ plant): K 1.09/m³ or K 0.048/MJ, as compared with the financial price of diesel: K 0.062/MJ or the retail price: K 0.048/MJ!!

It is my conclusion therefore that biogas is competitive against diesel. Also, one can tentatively conclude that a 5-10 m³ plant is affordable for an (above-average) emergent farming household. Other factors play a role, however:
- availability and price of auxiliary equipment (biogas lantern, biogas stove, biogas-adapted engine).
- cost reduction possibilities in biogas plants. In the Zambian context a cost reduction could be achieved by using brick in the construction of the dome, instead of steel (10 m³ plant: a steel dome costs K 11,000, about 60% of the total costs of the plant!). Work on biogas plants should firstly be concentrated on finding an appropriate design with good sources of raw material.

Windmill technology and water supply

According to the cost analysis presented in this report introduction of imported windmills in the area is far from being feasible. This does not implicate that this technology should be ignored. Annual average windspeeds in Magoye area are quite low, but other parts of the country have higher annual average windspeeds. Much will depend on research and development of an appropriate technology windmill, constructed from indigenously available materials.

The Department of Energy also has the opinion that wind energy is (currently) not economic. Cost estimates given in this report are more negative than the ones presented in ZAM 88.

According to ZAM 88, providing water to a village (100 persons, 50 cattle) would by a borehole/windpump would cost K 6.65/m³ of water as compared to K 2.25/m³ for a borehole/ handpump.

The cost (estimated in this report) of handpump/borehole combination (at 30 m head), namely K 2.60/m³ (table 5.10), corresponds with the estimate given in ZAM 88. For wind pumping the following figures are found: K 6.80-8.80/m³ (depending on elevation height, 16 or 36 m), unit cost of capacity, but K 40.60-52.10/m³, unit cost of consumption (for an imported windmill, see appendix E.2.7). The great difference between unit cost of consumption and capacity is caused by the variance between monthly average wind speeds.

According to ZAM 88 wind pumping is competitive against diesel power in agricultural applications (irrigation). Again, this report
promotes another view: for Magoye area windpumping for irrigation would be the most expensive alternative, more expensive than biogas, diesel, or solar power.

It has to be stressed however, that wind characteristics of other areas than Magoye in Zambia are better. This is important as power delivered is proportionate to the wind velocity cubed. The area with the highest average wind speeds (Lusaka and environment) has an annual average of 3.5 m/s (compared with 2.4 m/s Magoye area). Furthermore a locally manufactured windmill could cost only half of the price of an imported one. Conclusively, a locally manufactured windmill, placed in the Lusaka wind regime, has a unit cost per kWh of about 7 times lower than an imported one in Magoye area! If such a mill is used for water supply, unit cost of consumption can roughly be estimated at K 6-7.5/m³, more in line with the estimate of the DoE.

The technology should not be totally discarded therefore. Further research is recommended on a windmill design suitable for Zambian conditions, constructed from indigenously available materials.

Solar power

Of solar energy technologies, solar fish driers have a considerable potential for application, according to the DoE. Solar driers are superior to sun drying or wood smoking. Proven designs of driers exist worldwide. Fishing takes place all year round, making investment attractive. In this report solar fish driers were not studied, as fishing is not a main source of income of Magoye farming households. So no comparison of views is possible.

Also solar water heating (for urban households and institutions) is viable, according to the DoE, compared to the cost of water heating by geysers. This technology is not elaborated in this report, as importance for rural households is small.

At current prices electricity of photovoltaics is restricted to low-power, remote, applications (telecommunications, signalling). Here, the views sketched in ZAM 88, and in this report coincide.

7.5 Recommendations for further research by TDAU

Introduction

TDAU has extensive and sophisticated workshop facilities for fabrication of prototypes and testing of raw materials, although it experiences management problems and personnel shortages. The Unit has expanded extension and assessment activities, as it has had little success in the promotion of local manufacture of intermediate technology items in the past.

As an applied research group, close to manufacturing companies,
TDAU can play a role in identification and testing of prototypes of NRETs and ADP equipment. TDAU could be responsible for:
- selection and adaption of designs to Zambian conditions, using locally available materials,
- testing of prototypes,
- determination of project costs and economics,
- transfer of design and know-how to industry,
- assisting craftsmen and rural workshops.

Simple technologies that are reliable, require little maintenance and can be repaired locally have the biggest chance of penetration.

**Short evaluation of this study**

The 'aims-tools-impacts' cycle (see chapter 1) was applied as basic methodological instrument in the case study. Practical application, given a limited time period of research, made a restrictions necessary in the scope of 'aims', as well as 'tools', as well as 'impacts'. We restricted here to study the aims of the target group of this research only: farming households. As tools only energy-related technological tools we considered. We mainly focussed on financial and capacity impacts. This study did not need to have more, as it is intended as a pilot study, aimed at fact-finding. A suggestion for further research is therefore to study a wider scope of aims (e.g. other target groups), tools, impacts, and combinations thereof. The advantage is that a fuller picture is obtained of the complex of relations between aims, tools and impacts. Another way to broaden the scope is to make case studies of energy supply in other geographical locations.

A second way is not to broaden the field of study, but in-depth research. As suggestions I can give here:
- aims: holding a small survey (instead of only informing key-informants) contributes to the representativeness of results.
- impacts: sensitivity analysis. In making the cost calculation of chapter 6 and income estimations of chapter 5, many variables were given an assumed value. Variation in values sheds light on the influence of a variable on annual expenditures and benefits. Thus a more profound view of the feasibility of a technology is obtained.
- tools: to penetrate more in the pros and cons of a technological option in a combination of comparing various existing and new designs, technical development of designs, fieldtesting and impact evaluation of introduction of a design.

**Implications of the case study of Magoye area for project work done at TDAU**

TDAU's involvement with renewable energy technologies (REts) has been:
- the design and implementation of a micro-hydro installation (water turbine/waterram system for water supply completed and installed at Kawambwa Mission).
- preparation of a preliminary design of a small windmill for waterpumping (no current activities).

Other projects of TDAU are (source: TDA 88):
- research and development of (ox-drawn) farm equipment (manufacture of
ox-cart with wooden bearings and non-pneumatic tyres).
- pumps (manufacture of a hand pump and an irrigation pump).
- oil expelling press/oil expeller (testing prototypes, manufacture),
- jab planter (testing),
- rural workshops support programme (in conjunction with SIDO).

In the past activities of TDAU (need assessment surveys, fieldtesting) were conducted in places too far away from Lusaka, making regular follow-ups difficult (TDA 88, p.7). Therefore TDAU has restricted further activities to a 'laboratory area', formed by the area lying between the radii of 80 km and 150 km from Lusaka. In this area 10 places (w.u. Magoye area) have been chosen as 'pilot area' on which activities (need assessment surveys, fieldtesting and extension) are focussed. Target groups of TDAU are subsistence, small and emergent farmers, artisans and small-scale industries. A preliminary survey in the pilot areas showed that planting, weeding, transport, water supply and livestock management are the major areas of need (TDA 88, p.8).

The research as laid down in this report, showed that for Magoye area the major areas of needs are roughly similar to the ones identified in the preliminary survey:

A) There are general needs related to technological hardware (ploughs, planters, ox-carts) resulting from a) bad quality of the hardware and scarcity of spare parts, b) lack of repair and maintenance facilities. Partly these technological problems are caused on the national level by the present deplorable economic situation, and the resulting depletion of foreign exchange reserves. Partly these problems can be traced back to the centralized structure of Zambian manufacturing industry, and insufficient maintenance facilities in Magoye area.

TDAU can play a role in:
- improving maintenance facilities in Magoye area and other pilot areas, by means of its rural workshops programme,
- continuing its work on research and development and extension of ox-drawn equipment. E.g. an ox-cart is an important cost entry on the farming household budget. Low availability of scrap axles and tyres is constraining manufacturing of ox-carts in Zambia in general, and this also makes them expensive. A project of TDAU is construction of a cart with other axle types (wood, with wooden sand-resistant bearings with low rolling resistance) and non-pneumatic tyres. A next step in the project could be construction of such a cart on an experimental base in a wood workshop (as part of the rural workshop programme) in e.g. Magoye area. One of the functions of such a shop, training of local craftsmen, could induce spin-off effects with respect to local production of low-cost ox-carts.

B) Water supply: as most surface water sources dry up and hand-dug wells dry out, there is a shortage of water for human and cattle consumption in Magoye area in the dry season. One of the current activities by TDAU is manufacturing of a low-cost handpump. Thus, this activity could be well fitted in the context of Magoye area and in other pilot areas that face problems in water supply. An outcome of this report is that a) an improved deep well (in combination with bucket & rope or a with a handpump installed) are financially feasible options. Installation of handpumps should go in collaboration with local authorities involved in
water management, responsible for digging and casing of deeper wells.

Another outcome of this study is that irrigation of large plots by means of human and animal power is not feasible. Two remarks have to be made to this general conclusion. Firstly, an application of a hand-powered irrigation pump, could be irrigation of a vegetable garden (about 0.1 ha). For low elevation of water (10 m) animal powered irrigation of a plot of 3 hectare (peasant farmer) could be technically possible. Much would depend on:
- the actual depth of the water table (in the dry season),
- finding a low-cost design pump.

C) In the preliminary survey of TDAU fuelwood was not identified as main area of needs. Deforestation, however is expected to increase rapidly in the decades to come, especially in the 'laboratory area', chosen by TDAU, comprising parts of the line-of-rail area of Southern, Lusaka and Central Province. It is suggested therefore that TDAU expands its scope of actions in the field of:
- Improved charcoal kilns. Already the Forest Project Research Division of the Forest Department at Kitwe has experimented with brick kilns and oil drum kiln. TDAU could participate in research of such simple improved kilns and promote dissemination in its pilot areas chosen. The oil drum kiln, was taken as an example in this report. Such a kiln operates in the same manner as the traditional earthen kiln. The wood is partially burnt by the admission of air through a slot, cut along the cylindrical side of the drum. The kiln is placed with the opening facing the direction of the wind. A small quantity of the wood is placed in the kiln and then ignited. A factor or two in charcoal yield seems possible (GOW 85, DUN 87, p.268).
- Improved charcoal stoves. Work on stoves in Zambia is currently restricted to stoves for urban households. Urban households as such are not one of the target groups on which TDAU focusses its activities. In view of the deforestation a case can be made, however, for research on small-scale urban household energy technology, to be included in TDAU’s activities.

At UNZA, Mechanical Engineering is involved in development of improved charcoal stove designs; the NCSR in briquette stoves. In collaboration with these institutions TDAU could play a role in testing of charcoal and briquette stoves, and promotion of small-scale production by artisans and small-scale urban workshops.
- Wood stoves. Currently no research is on-going in the field of wood stoves. With the growing deforestation, rural fuelwood shortage will occur in parts of the line-of-rail area. TDAU could play a role as initiator of research and development in wood stove technology:
  - identification of fuel shortages in its pilot areas,
  - selection and testing of prototypes of wood stoves (which already exist worldwide) in the identified areas, and villages therein, where firewood supply poses problems.

D) Other energy technologies. It is my opinion that technologies (mentioned under A, B and C) should have priority in the field of energy research. Two other projects of interest for TDAU are solar driers and biogas technology.
- Solar collector technology. According to the DoE solar drying of fish and of tobacco, can be feasible alternatives for the present use of (scarcer) wood in fish smoking and tobacco curing. Prototypes of solar
fish dryers already exist worldwide. TDAU could play a role in identification of such a drier, and manufacture and testing of a prototype in areas where fishing is important. Such work should be in cooperation with the Fisheries Department and Fisheries Development officers in the pilot area.

- **Biogas technology** The NCSR is presently involved in research in biogas technology. According to this report such technology can be affordable by (above-average) emergent farming households. It is suggested that TDAU should collaborate with the NCSR in development of biogas technology. With its well-equipped metal workshop TDAU could especially play a role in the manufacture of (prototypes of) auxiliary equipment as dual-fuel engines, lanterns or stoves.

The energy scenario developed for Magoye area can be helpful as a timetable for TDAU activities in the projects suggested above.
REFERENCES


BAS 81 Basic needs in an economy under pressure, ILO, Addis Abeba, 1981.

BEU 81 J.Beurskens, Wind Energy for Water Pumping in Cape Verde, Steering Committee on Wind Energy Development in Developing Countries, Amersfoort, Netherlands, 1981.


BLI 86 Blijvende Energiebronnen, collegepaper of the course 'Renewable energy sources' at Eindhoven University of Technology, 1986.


BRO 78 J.Brown, Charcoal and the Control of Illegal Felling of Trees for Firewood and Charcoal Production, Forestry Department, Ndola, 1978.


DUN 86 P.D.Dunn, Renewable energies: sources, conversion and
References


ENE 85a *Energy and Development in Southern Africa, SADCC Country Studies*, part 1

b ibid., part 2


FOO 83 NUT ibid., *Nutrition*.


References


OXD 83  Ox Draught, Department of Agriculture, MAWD, Lusaka, 1983.

PAA 81  J.P. van Paassen, Prospects for the Local Manufacture of Windmills for Waterpumping, TDAU, University of Zambia, 1981.


TEM 86  A.W.K. Tembo, Wind energy for waterpumping applications in Zambia, Department of Technical Physics, University of Technology Eindhoven, 1986.

TDA 87  TDAU Newsletter, Vol.1, No.1, TDAU, University of Zambia, 1988


VIN 86  J. Vingerhoets, The Zambian Economy: Implications for Project Appraisal, Co-operation Centre, Tilburg/Eindhoven Universities, 1986


APPENDICES
Cost calculations

Money has a time value associated with its use, because it can earn interest if saved or reinvested. Interest rates are the private market's value on time: the cost of money is expected to grow in future years at a rate i, the interest rate.

Gradual repayment or writing off the original investment is called amortization. In estimating annual financing cost, given the investment cost \( P \) of an asset, the capital recovery factor is used in this report:

\[
A = P \frac{i(1+i)^n}{(1+i)^n - 1}
\]

\( A \): equal payment
\( n \): economic (or productive) life
\( P \): principal
\( i \): discounting rate

This factor includes the money growth as well as the amortization component. The discounting factor used here is the real interest rate, the rate of return on capital (without inflation). In this report the prevailing bank rate of 1987 (after May) 15%, is chosen as the interest rate. Bank rates have risen however to 20% in 1988. In November 1988 the bank rate was set at 25% by the Government (together with the devaluation of the Kwacha).

Exchange rates and real value of currency

Throughout this report the value of the Kwacha is expressed in its

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<td>30</td>
</tr>
<tr>
<td>1989 (official, Nov.)</td>
<td>10</td>
</tr>
<tr>
<td>1989 (May)</td>
<td>35</td>
</tr>
<tr>
<td>1989 (October)</td>
<td>50</td>
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</tbody>
</table>

TABLE A.1 The exchange rate of the Kwacha (end of period rates).
Source: VIM 86; GAL 87; own observations.
In May 1987 the Government abandoned the system of weekly auctions of foreign exchange (since October 1985) and fixed the rate K 8 to 1 US$. This official rate was set in November 1986 at K 10 to 1 US$. At the black market much higher rates are prevailing however (November 1988: K 35 = 1 US$; March 1989: K 50 = 1 US$)
Year | Inflation | Value of dollar | (expressed in 1987 dollars)
--- | --- | --- | ---
1970 | 5.5 | 3.290 | 1979 | 9 | 1.697
1971 | 5.0 | 3.118 | 1980 | 12.5 | 1.556
1972 | 4.5 | 2.970 | 1981 | 10 | 1.384
1973 | 7 | 2.841 | 1982 | 7 | 1.258
1974 | 13 | 2.656 | 1983 | 4.5 | 1.175
1975 | 11 | 2.350 | 1984 | 4.5 | 1.125
1976 | 8 | 2.117 | 1985 | 4 | 1.076
1977 | 8 | 1.961 | 1986 | 3.5 | 1.035
1978 | 7 | 1.815

**TABLE A.2** Inflation in the industrial world in relation with real values of the dollar. Inflation rates are based on WOK 87, Fig. 1.1.

<table>
<thead>
<tr>
<th>End-use:</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
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<tbody>
<tr>
<td>Weight</td>
<td>1000</td>
<td>198</td>
<td>105</td>
<td>263</td>
<td>133</td>
<td>139</td>
<td>535</td>
<td>465</td>
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</table>

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Weight</td>
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<td>198.6</td>
<td>181.8</td>
<td>191.9</td>
<td>190.8</td>
<td>180.4</td>
<td>186.6</td>
<td>99.2</td>
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<tr>
<td>1976</td>
<td>175.7</td>
<td>219.7</td>
<td>200.1</td>
<td>211.9</td>
<td>253.4</td>
<td>209.9</td>
<td>221.6</td>
<td>122.9</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1977</td>
<td>211.6</td>
<td>264.8</td>
<td>251.3</td>
<td>251.8</td>
<td>320.6</td>
<td>279.9</td>
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<tr>
<td>1978</td>
<td>264.4</td>
<td>309.4</td>
<td>244.9</td>
<td>285.6</td>
<td>413.6</td>
<td>336.5</td>
<td>330.2</td>
<td>149.9</td>
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<td></td>
<td></td>
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<tr>
<td>1979</td>
<td>306.2</td>
<td>340.6</td>
<td>263.1</td>
<td>309.7</td>
<td>487.3</td>
<td>417.7</td>
<td>381.9</td>
<td>219.2</td>
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<td></td>
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<tr>
<td>1980</td>
<td>334.3</td>
<td>411.8</td>
<td>272.2</td>
<td>356.1</td>
<td>544.8</td>
<td>437.7</td>
<td>424.2</td>
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<td>1981</td>
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<td>458.4</td>
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<td>393.1</td>
<td>599.5</td>
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<td>1982</td>
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<td>545.6</td>
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<td>455.7</td>
<td>688.1</td>
<td>568.6</td>
<td>542.8</td>
<td>183.0</td>
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<tr>
<td>1983</td>
<td>456.8</td>
<td>645.7</td>
<td>405.9</td>
<td>551.7</td>
<td>851.9</td>
<td>695.7</td>
<td>663.7</td>
<td>233.2</td>
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</tr>
<tr>
<td>1984</td>
<td>878.2</td>
<td>743.5</td>
<td>475.3</td>
<td>636.4</td>
<td>1222.6</td>
<td>817.8</td>
<td>829.2</td>
<td>328.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>878.2</td>
<td>743.5</td>
<td>475.3</td>
<td>636.4</td>
<td>1222.6</td>
<td>817.8</td>
<td>829.2</td>
<td>328.0</td>
<td></td>
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</tr>
<tr>
<td>1986</td>
<td>1894.9</td>
<td>1573.1</td>
<td>1021.5</td>
<td>1352.9</td>
<td>4932.3</td>
<td>1800.5</td>
<td>2364.3</td>
<td>1355.0</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>1987</td>
<td>3494.4</td>
<td>2117.0</td>
<td>1325.1</td>
<td>2719.1</td>
<td>10510.3</td>
<td>4543.9</td>
<td>3535.2</td>
<td>1456.5</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**TABLE A.3** Index number of wholesale prices, 1966 = 100 (by end-use).

Source: Monthly Digest of Statistics, CSO, Lusaka: June/July 1985, April/December 1987. End-use groups: I all goods (VII+VIII), II non-durable consumption goods, III durable consumption goods, IV consumption goods (II+III), V goods for fixed capital formation, VI goods for further processing, VII domestically used goods (IV+V+VI), VIII export goods.
mid 1987 value, unless stated otherwise. In making the economic estimates presented in this report was often necessary to express prices (say 1980 ones given in 1980 Kwacha or dollars) in their real 1987 value. Conversion is done by:

a) using the price-index tables A.3 and A.4, for conversion of Kwacha in its real 1987 value,

b) using the inflation rates in the industrialized world (table A.2), for conversion of dollars in their 1987 value. The shadow rate of 1 US$ = K 12 is then used to get the value in mid 1987 Kwacha.

A more elaborate way for conversion of dollars in their present real value would be:

1) using the so-called MUV-index (Manufacturing Unit Value), which is widely used as an indicator of inflation (to be found annually in "Commodity trade and price trends", World Bank, Washington). The index gives the development in dollar terms of manufacturing exports in France, the FRG, Japan, the UK and the USA.

2) The index is expressed in dollar term, and has therefore to be corrected for changes in the US$ vis-a-vis other currencies. This can be done by expressing the MUV in terms in so-called SDR (Special Drawing Rights), thus comprising changes in the SDR/dollar rate (to be found annually in "International Financial Statistics", Yearbook, IMF, Washington.).

Conversion of, a given, 1988 values of currency into its 1987 value posed more difficulties, as at the moment of writing this report inflation rates 1987-1988 were not known yet. Based on the rapid depreciation of the Kwacha on the black market and inflation trends in the last decade, the following inflation rates were assumed:

- inflation of goods for fixed capital formation, mid/end 1987 - 1988: 110%. This value is used when converting end 1988 prices of solar equipment in 1987 values.
- prices of diesel products (given in early 1988 prices): 60%.
- prices of electromotors and pumping equipment (mid 1988 prices): 75%.

<table>
<thead>
<tr>
<th>Year</th>
<th>Low-income group</th>
<th>High income group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>116.8</td>
<td>116.1</td>
</tr>
<tr>
<td>1977</td>
<td>142.3</td>
<td>141.9</td>
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<tr>
<td>1978</td>
<td>165.6</td>
<td>152.6</td>
</tr>
<tr>
<td>1979</td>
<td>181.6</td>
<td>169.8</td>
</tr>
<tr>
<td>1980</td>
<td>202.9</td>
<td>189.4</td>
</tr>
<tr>
<td>1981</td>
<td>221.3</td>
<td>209.1</td>
</tr>
<tr>
<td>1982</td>
<td>260.2</td>
<td>236.6</td>
</tr>
<tr>
<td>1983</td>
<td>311.2</td>
<td>278.6</td>
</tr>
<tr>
<td>1984</td>
<td>375.5</td>
<td>336.4</td>
</tr>
<tr>
<td>1985</td>
<td>513.3</td>
<td>446.6</td>
</tr>
<tr>
<td>1986</td>
<td>778.4</td>
<td>707.2</td>
</tr>
<tr>
<td>1987 (August)</td>
<td>1143.8</td>
<td>1130.8</td>
</tr>
</tbody>
</table>

**TABLE A.4** Index number of consumer prices (1975 = 100).
Heating values and combustion

The energy potential of a fuel is defined as the energy potentially available from a fuel before the fuel goes into a combustion technology. For biomass fuels the moisture content of a fuel is the critical factor affecting the input energy value. Moisture affects the energy potential, because it must be evaporated before the fuel's organic material provides usable heat. Losses occur due to:
- warming of water molecules in the biomass to evaporation point,
- vaporization if this water,
- formation of water molecules from H and O atoms during combustion.

The figure depicts mass and energy conventions, in which E: oven-dry (od) weight and G: wet weight.

The following definitions are frequently used in literature:
1) HHV (high heating value) = D/E (in J/kg),
   also called oven-dry HV, calorific HV or gross HV.
2) NHV (net heating value) = C/G (in J/kg),
   also called low HV.
3) Moisture content, wet basis (mcwb) = (G-E)/G (x 100%) 

The difference between HHV and LHV for a fuel is the inclusion, respectively exclusion of the energy needed to evaporate water. Unless a biomass is reported in od weight, it has some moisture, expressed by its moisture content. This moisture content may vary and according to this variation other energy terms are derived:
- air-dried (ad), referring to the atmospheric equilibrium moisture content of a fuel, when it is left outside over time;
- green weight, referring to the moisture content of wood, directly after it has been cut, before moisture has evaporated to ad or od weight.

The amount of energy, delivered by a technology for use is affected by heat loss characteristics. According to the First Law of Thermodynamics, a balance of energy always exists, so that energy inputs equal total dissipated and delivered energy outputs. In other words: energy is always conserved, although its form may change. According to the Second Law of Thermodynamics no conversion of a fuel into heat or work is totally efficient. There are always conversion losses.

The following table gives heating values (energy contents) of fossil and biomass fuels (Source: LEA 87, Annex 1). In this report the following specific gravities are used for wood and charcoal:
- wood, 725 kg/m³
- charcoal 89.97 kg/m³.

For biomass fuels these data should be used only as rough approximations
FIGURE A.1 Definition of weight and energy content of biomass

TYPICAL ENERGY CONTENT OF FOSSIL AND BIOMASS FUELS (continued)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Net Heating Value (MJ/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuels</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>34.8</td>
</tr>
<tr>
<td>Refinery Gas</td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>46.1</td>
</tr>
<tr>
<td>Ethane</td>
<td>33.5</td>
</tr>
<tr>
<td>Propane (LPG)</td>
<td>59.5</td>
</tr>
<tr>
<td>Butane (LPG)</td>
<td>85.8</td>
</tr>
<tr>
<td>Pentane</td>
<td>111.8</td>
</tr>
<tr>
<td>Coke oven gas</td>
<td>134.0</td>
</tr>
<tr>
<td>Town gas</td>
<td>17.6</td>
</tr>
<tr>
<td>Biomass-Derived</td>
<td></td>
</tr>
<tr>
<td>Producer gas</td>
<td>5.9</td>
</tr>
<tr>
<td>Digester or Biogas</td>
<td>22.5</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.6 MJ/kWh</td>
</tr>
</tbody>
</table>

Note: For biomass fuels, these data should be used only as rough approximations.
## Typical Energy Content of Fossil and Biomass Fuels (continued)

<table>
<thead>
<tr>
<th>Liquid Fuels</th>
<th>Specific Gravity</th>
<th>Net Heating Values (MJ/kg)</th>
<th>Net Heating Values (MJ/litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fossil Fuels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude oil</td>
<td>0.86</td>
<td>41.9</td>
<td>36.7</td>
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<tr>
<td>LPG</td>
<td>0.54</td>
<td>45.6</td>
<td>24.6</td>
</tr>
<tr>
<td>Propane</td>
<td>0.51</td>
<td>45.7</td>
<td>23.3</td>
</tr>
<tr>
<td>Butane</td>
<td>0.58</td>
<td>45.3</td>
<td>26.3</td>
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<tr>
<td>Gasoline</td>
<td>0.74</td>
<td>43.9</td>
<td>32.6</td>
</tr>
<tr>
<td>Avgas</td>
<td>0.71</td>
<td>44.3</td>
<td>31.5</td>
</tr>
<tr>
<td>Motor gasoline</td>
<td>0.74</td>
<td>44.0</td>
<td>32.6</td>
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<tr>
<td>Wide-cut</td>
<td>0.76</td>
<td>43.7</td>
<td>33.3</td>
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<td><strong>White spirit</strong></td>
<td>0.78</td>
<td>43.5</td>
<td>34.0</td>
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<td><strong>Kerosene</strong></td>
<td>0.81</td>
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<td><strong>Aviation turbine fuel</strong></td>
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<td><strong>Distillate fuel oil</strong></td>
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<tr>
<td>Heating oil</td>
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<tr>
<td>Autodiesel</td>
<td>0.84</td>
<td>42.8</td>
<td>36.0</td>
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<td>Heavy diesel</td>
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<td><strong>Residual fuel oil</strong></td>
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<tr>
<td>Light</td>
<td>0.94</td>
<td>41.5</td>
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<tr>
<td>Heavy</td>
<td>0.96</td>
<td>41.4</td>
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<td><strong>Lubricating oils</strong></td>
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<tr>
<td>Asphalt</td>
<td>1.05</td>
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<tr>
<td>Tar</td>
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<td>Liquified natural gas</td>
<td>0.42</td>
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<td><strong>Biomass-Derived liquids</strong></td>
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<tr>
<td>Ethanol</td>
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<td>Methanol</td>
<td>0.80</td>
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<table>
<thead>
<tr>
<th>Solid Fuels</th>
<th>Moisture Content</th>
<th>Net Heating Values a/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biomass Fuels</strong></td>
<td>Wet Basis (MJ/kg)</td>
<td>Net Heating Values (MJ/kg)</td>
</tr>
<tr>
<td>Wood (wet, fresh cut)</td>
<td>40</td>
<td>10.9</td>
</tr>
<tr>
<td>Wood (air-dry, humid zone)</td>
<td>20</td>
<td>15.5</td>
</tr>
<tr>
<td>Wood (air-dry, dry zone)</td>
<td>15</td>
<td>16.6</td>
</tr>
<tr>
<td>Wood (oven-dry)</td>
<td>0</td>
<td>20.0</td>
</tr>
<tr>
<td>Charcoal</td>
<td>5</td>
<td>29.0</td>
</tr>
<tr>
<td>Bagasse (wet)</td>
<td>50</td>
<td>8.2</td>
</tr>
<tr>
<td>Bagasse (air-dry)</td>
<td>13</td>
<td>16.2</td>
</tr>
<tr>
<td>Coffee husks</td>
<td>12</td>
<td>16.0</td>
</tr>
<tr>
<td>Rice hulls (air-dry)</td>
<td>9</td>
<td>14.4</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>12</td>
<td>15.2</td>
</tr>
<tr>
<td>Maize (stalk)</td>
<td>12</td>
<td>14.7</td>
</tr>
<tr>
<td>Maize (cobs)</td>
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<td>15.4</td>
</tr>
<tr>
<td>Cotton gin trash</td>
<td>24</td>
<td>11.9</td>
</tr>
<tr>
<td>Cotton stalk</td>
<td>12</td>
<td>16.4</td>
</tr>
<tr>
<td>Coconut husks</td>
<td>40</td>
<td>9.8</td>
</tr>
<tr>
<td>Coconut shells</td>
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<td>17.9</td>
</tr>
<tr>
<td>Dung Cakes (dried)</td>
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<td><strong>Fossil Fuels</strong></td>
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<tr>
<td>Anthracite</td>
<td>5</td>
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<tr>
<td>Sub-bituminous coal</td>
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<td>11.3</td>
</tr>
<tr>
<td>Peat</td>
<td>-</td>
<td>14.6</td>
</tr>
<tr>
<td>Lignite briquettes</td>
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</tr>
<tr>
<td>Coke briquettes</td>
<td>-</td>
<td>23.9</td>
</tr>
<tr>
<td>Peat briquettes</td>
<td>-</td>
<td>21.8</td>
</tr>
<tr>
<td>Coke</td>
<td>-</td>
<td>28.5</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>-</td>
<td>35.2</td>
</tr>
</tbody>
</table>
### UNITS AND PREFIXES FOR THE INTERNATIONAL SYSTEM OF UNITS (SI)

**SI**
- kilo (k)
- hecto (h)
- deka (da)
- deci (d)
- centi (c)
- milli (m)

**British**
- meg (M)
- giga (G)
- tera (T)
- peta (P)

### ABBREVIATIONS

#### SI
- m = meter
- cm = centimeter
- km = kilometer
- m² = square meter
- ha = hectare
- m³ = cubic meter
- l = liter
- s = second
- W = watt
- J = joule
- kg = kilogram
- Btu = British thermal unit
- Wh = watt hour
- kWh = kilowatt hour
- eV = electron volt

#### British
- m = inch
- ft = foot
- mi = mile
- ft² = square foot
- ac = acre
- m² = square mile
- ft³ = cubic foot
- B gal = Imperial gallon
- US gal = US gallon
- US bbl = US barrel
- SCF = standard cubic foot
- ft³/sec = cubic feet per second
- mph = miles per hour
- ft³/min = cubic feet per minute
- Mgd = million gallons per day
- lb = pound
- t = ton
- lbm = pound mass
- BTU/hr = BTU per hour

- Billion
- Trillion
- Million
- Thousand
**Power**

\[
W = \text{Watt} \\
J/\text{sec} = \text{joules per second} \\
Ly = \text{Langley}
\]

**CONVERSION FACTORS**

<table>
<thead>
<tr>
<th>Length (meters)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m = 3.281 ft</td>
<td>1 ft = 0.3048 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km = 0.6214 mi</td>
<td>1 mi = 1.609 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 cm = 2.540 in</td>
<td>1 in = 0.0937 cm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area (square meters)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m(^2) = 10.76 ft(^2)</td>
<td>1 ft(^2) = 0.09290 m(^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ha = 10 m(^2)</td>
<td>1 ac = 0.4047 ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ha = 2.471 ac</td>
<td>1 m(^2) = 640 ac</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume (cubic meters)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m(^3) = 6.102 X 10(^4) in(^3)</td>
<td>1 in(^3) = 1.639 X 10(^{-3}) m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 10(^3) liters</td>
<td>1 US gal = 3.785 X 10(^{-3}) m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 264.2 US gal</td>
<td>1 B gal = 4.546 X 10(^{-3}) m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 10(^3) ft(^3)</td>
<td>1 ft(^3) = 0.02832 m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 35.31 ft(^3)</td>
<td>1 US bbl = 0.1590 m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 6.290 US bbl</td>
<td>1 US bbl (oil) = 42 US gal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 0.2759 cord</td>
<td>1 cord = 3.625 m(^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 cord (wood) = 128 ft(^3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Velocity (meters per second)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m/sec = 3.600 km/hr</td>
<td>1 km/hr = 0.2778 m/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 3.281 ft/sec</td>
<td>1 ft/sec = 0.3048 m/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 2.237 mph</td>
<td>1 mph = 0.4470 m/sec</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow rate (cubic meters per second)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m(^3)/sec = 2.119 ft(^3)/min</td>
<td>1 ft(^3)/min = 4.719 X 10(^{-4}) m(^3)/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 22.82 Mgd</td>
<td>1 Mgd = 0.0436 m(^3)/sec</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass (kilograms)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg = 10(^{-3}) MT</td>
<td>1 MT = 10(^3) kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 2.205 lbm</td>
<td>1 lbm = 0.4536 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 1.102 X 10(^{-3}) t</td>
<td>1 t = 907.2 kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density (kilograms per cubic meters)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg/m(^3) = 0.06243 lbm/ft(^3)</td>
<td>1 lbm/ft(^3) = 16.02 kg/m(^3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy (joules)(^a)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 J = 10(^{-2}) KJ</td>
<td>1 J = 0.23990 cal</td>
<td>1 cal = 4.184 J</td>
<td></td>
</tr>
<tr>
<td>= 10(^{-8}) MJ</td>
<td>= 9.485 X 10(^{-4}) BTU</td>
<td>1 BTU = 1,054.4 J</td>
<td></td>
</tr>
<tr>
<td>= 10(^{-9}) GJ</td>
<td>= 1 BTU = 252 cal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Energy (watt hours)\(^b\)**

\[
1 \text{Wh} = 3,600 J = 3.6 MJ \\
1 \text{kWh} = 3,412 BTU \\
1 \text{kWh} = 85.99 Ly
\]

**Power (watts)\(^a\)**

\[
1 W = 1 J/\text{sec} \\
= 3.414 BTU/\text{hr} \\
= 0.03156 GJ/\text{yr} \\
= 1.340 \times 10^{-3} \text{HP}
\]

**Power (Langleys, BTUs)\(^c\)**

\[
1 \text{Ly/hr} = 11.6277 \text{W/m}^2 \\
1 \text{Ly/min} = 697.4 \text{W/m}^2 \\
1 \text{Ly/min} = 1 \text{cal/cm}^2 \cdot \text{min} \\
1 \text{BTU/ft}^2 = 3.154 \text{Wh/m}^2 \\
1 \text{BTU/ft}^2 = 0.2713 \text{Ly} \\
1 \text{MJ/ft}^2 = 88.1 \text{BTU/ft}^2
\]

**Solar constant (energy flux)\(^a\)**

\[
1.353 \text{ kW/m}^2 \\
1.94 \text{ Ly/min} \\
116.4 \text{ Ly/hr} \\
428 \text{ BTU/hr} \cdot \text{ft}^2
\]

**Energy Unit Matrix\(^b\)**

\begin{align*}
\text{1 joule} & = 2.39 \times 10^{-4} \text{ kcal} & = 9.48 \times 10^{-4} \text{ BTU} & = 2.78 \times 10^{-7} \text{ kWh} & = 6.25 \times 10^{18} \text{ eV} \\
\text{1 kilocalorie} & = 4186 \text{ joules} & = 1 \text{ kcal} & = 3.97 \text{ BTU} & = 1.16 \times 10^{-3} \text{ kWh} & = 2.62 \times 10^{22} \text{ eV} \\
\text{1 British thermal unit} & = 1055 \text{ joules} & = 0.252 \text{ kcal} & = 1 \text{ BTU} & = 2.93 \times 10^{-4} \text{ kWh} & = 6.59 \times 10^{21} \text{ eV} \\
\text{1 kilowatt-hour} & = 3.6 \times 10^6 \text{ joules} & = 860 \text{ kcal} & = 3413 \text{ BTU} & = 1 \text{ kWh} & = 2.25 \times 10^{25} \text{ eV} \\
\text{1 electron-volt} & = 1.60 \times 10^{-19} \text{ joules} & = 3.82 \times 10^{-23} \text{ kcal} & = 1.52 \times 10^{-22} \text{ BTU} & = 4.45 \times 10^{-26} \text{ kWh} & = 1 \text{ eV}
\end{align*}

Sources:

\(^a\)Socolow (1978, Appendix D, pp. 311–14).
\(^b\)Thorndike (1976, Appendix E).
Appendix C  STATISTICAL ANNEX: THE ENERGY SECTOR IN ZAMBIA

<table>
<thead>
<tr>
<th>Province</th>
<th>Population (% of total)</th>
<th>Wooded area (% of total)</th>
<th>Wooded area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copperbelt</td>
<td>23</td>
<td>4</td>
<td>26,030</td>
</tr>
<tr>
<td>Lusaka</td>
<td>14</td>
<td>4</td>
<td>20,650</td>
</tr>
<tr>
<td>Southern</td>
<td>12</td>
<td>10</td>
<td>66,030</td>
</tr>
<tr>
<td>Northern</td>
<td>11</td>
<td>20</td>
<td>122,050</td>
</tr>
<tr>
<td>Eastern</td>
<td>11</td>
<td>11</td>
<td>66,170</td>
</tr>
<tr>
<td>Central</td>
<td>9</td>
<td>13</td>
<td>78,290</td>
</tr>
<tr>
<td>Western</td>
<td>8</td>
<td>16</td>
<td>95,390</td>
</tr>
<tr>
<td>Luapula</td>
<td>7</td>
<td>6</td>
<td>35,230</td>
</tr>
<tr>
<td>Northwestern</td>
<td>5</td>
<td>17</td>
<td>102,200</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>100</td>
<td>612,040*</td>
</tr>
</tbody>
</table>

TABLE C.3 Distribution of population and forests by province.
Source: Dpt. of Energy; WOO 86 ELIM. p.4.
Remark: I think the above estimation is too high. Estimations for 1985 vary between 41,250,000 ha ("lowest possible" extent and 46,140,000 ha (Zambia Forest Department report (1985) to the African Forestry Commission), with corresponding standing volumes of 3,046,852 and 3,501,821 million m³; source: WOO 86 TEA. p.36.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>charcoal</td>
<td>87</td>
<td>24</td>
</tr>
<tr>
<td>fuelwood</td>
<td>42</td>
<td>100</td>
</tr>
<tr>
<td>electricity</td>
<td>48</td>
<td>-</td>
</tr>
<tr>
<td>kerosene</td>
<td>57</td>
<td>-</td>
</tr>
<tr>
<td>candlewax</td>
<td>47</td>
<td>-</td>
</tr>
</tbody>
</table>

TABLE C.1 Percentage uses of various energy sources by Zambian households.
Source: EWE 85b, table 4.3; CHI 79, p.7.

---

TABLE C.3 Estimates of annual firewood consumption for household use and fueling.
Table 7: LAM 88.

<table>
<thead>
<tr>
<th>Per cubic consumption</th>
<th>Per consumer per year</th>
<th>Percentage of annual consumption - Urban pop. (in 1000 tonnes)</th>
<th>Million cubic metres</th>
<th>Total Cubic Litre of woodfuel per year (square km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>194.6 kg</td>
<td>74.9 kg</td>
<td>65</td>
<td>95.9</td>
</tr>
<tr>
<td>Rural</td>
<td>124.6 kg</td>
<td>87.4 kg</td>
<td>65</td>
<td>95.9</td>
</tr>
<tr>
<td>Total</td>
<td>319.2 kg</td>
<td>162.3 kg</td>
<td>130</td>
<td>191.8</td>
</tr>
</tbody>
</table>

---

TABLE C.4 Woodfuel required per year to meet this consumption.
Source: WOO 86 ELIM.
### Table 3.4

Final energy consumption forecast by source of energy.

<table>
<thead>
<tr>
<th>Source</th>
<th>1986</th>
<th>1996</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Base</td>
<td>High</td>
</tr>
<tr>
<td>(1000 toe')</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Electricity</td>
<td>539</td>
<td>13</td>
<td>601</td>
</tr>
<tr>
<td>Coal</td>
<td>366</td>
<td>9</td>
<td>322</td>
</tr>
<tr>
<td>White Petrol.</td>
<td>419</td>
<td>10</td>
<td>407</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>88</td>
<td>2</td>
<td>71</td>
</tr>
<tr>
<td>Bitumen LPG</td>
<td>14</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td><strong>SUTOTAL</strong></td>
<td>1427</td>
<td>34</td>
<td>1453</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>2263</td>
<td>54</td>
<td>2714</td>
</tr>
<tr>
<td>Charcoal</td>
<td>533</td>
<td>13</td>
<td>934</td>
</tr>
<tr>
<td><strong>SUTOTAL</strong></td>
<td>2795</td>
<td>66</td>
<td>3657</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>5425</td>
<td>100</td>
<td>5073</td>
</tr>
</tbody>
</table>

### Table 3.5

Final energy consumption forecast per sector.

<table>
<thead>
<tr>
<th>Sector</th>
<th>1986</th>
<th>1996</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Base</td>
<td>High</td>
</tr>
<tr>
<td>(1000 toe')</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Households</td>
<td>2445</td>
<td>52</td>
<td>3326</td>
</tr>
<tr>
<td>Agriculture</td>
<td>237</td>
<td>5</td>
<td>222</td>
</tr>
<tr>
<td>ZCCM</td>
<td>757</td>
<td>17</td>
<td>659</td>
</tr>
<tr>
<td>Industry</td>
<td>466</td>
<td>12</td>
<td>531</td>
</tr>
<tr>
<td>Govt/Service</td>
<td>50</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Transport</td>
<td>276</td>
<td>7</td>
<td>274</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>4216</td>
<td>100</td>
<td>5073</td>
</tr>
</tbody>
</table>

Source: Department of Energy.
<table>
<thead>
<tr>
<th>Category</th>
<th>Maximum</th>
<th>Fixed charge (K/month)</th>
<th>Max. demand charge (K/kVA/month)</th>
<th>Unit charge (K/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D3 Industrial C</td>
<td>&gt; 2001</td>
<td>17.225</td>
<td>13.81</td>
<td>0.0405</td>
</tr>
<tr>
<td>D2 Industr./Large comm.</td>
<td>300-2000</td>
<td>1.722.5</td>
<td>11.81</td>
<td>0.0533</td>
</tr>
<tr>
<td>D3 Industrial: A (ZCCK)</td>
<td>306</td>
<td>-</td>
<td>345</td>
<td>0.0114</td>
</tr>
<tr>
<td>E4 Commercial</td>
<td>15</td>
<td>71.5</td>
<td>*</td>
<td>0.1011</td>
</tr>
<tr>
<td>E3 Residential</td>
<td>15</td>
<td>15</td>
<td>*</td>
<td>0.07</td>
</tr>
<tr>
<td>E2 Small domestic</td>
<td>3.6</td>
<td>5</td>
<td>*</td>
<td>0.07</td>
</tr>
<tr>
<td>E3 Very small domestic</td>
<td>1.2</td>
<td>2.5</td>
<td>*</td>
<td>0.07</td>
</tr>
</tbody>
</table>

TABLE C.6  
Electricity tariffs for selected consumer groups. March 1988.  
Source: Department of Energy. ZAM 83. Additional surcharges are levied on consumers supplied by small hydro (consumers under E3-D3 tariff 20%) or diesel thermal stations (all tariff groups 15%). A 15% sales tax is paid by all consumers. Besides these internal tariffs there is also an export tariff * charge varies per 1 amp. and 15 amp. load limitation.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low scenario</td>
<td>High scenario</td>
</tr>
<tr>
<td>Bulk (ZCCK)</td>
<td>less than 1</td>
<td>less than 1</td>
</tr>
<tr>
<td>Large commercial</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Household</td>
<td>18</td>
<td>26</td>
</tr>
</tbody>
</table>

TABLE C.7  
Estimated economic costs of power (in ngwee/kWh), expressed in end 1987 prices (Source: Dpt. of Energy).

<table>
<thead>
<tr>
<th>Costs/price per m³</th>
<th>Kerosene</th>
<th>Gas oil/diesel</th>
<th>Gasoline</th>
<th>Fuel oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic costs</td>
<td>X 1.951</td>
<td>X 1.810</td>
<td>X 1.723</td>
<td>X 1.315</td>
</tr>
<tr>
<td>Financial costs</td>
<td>X 2.247</td>
<td>X 2.126</td>
<td>X 1.983</td>
<td>X 1.645</td>
</tr>
<tr>
<td>Wholesale price</td>
<td>X 1.190</td>
<td>X 1.350</td>
<td>X 2.120 (premium)</td>
<td>X 950</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X 1.930 (regular)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE C.8  
See text for definition of economic and financial costs; including CIF cost, pipeline transport and refinery costs. Wholesale price ex-Mosco (National Oil Supply Company). (prices in 1987 kwacha).

<table>
<thead>
<tr>
<th>Kerosene</th>
<th>Gas oil/diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-tax retail price</td>
<td>1,379</td>
</tr>
<tr>
<td>Tax</td>
<td>92</td>
</tr>
<tr>
<td>Total retail price</td>
<td>1,471</td>
</tr>
</tbody>
</table>
Retail prices of charcoal 1983-1986 per large bag (usually 40 kg).

<table>
<thead>
<tr>
<th>Year</th>
<th>Lusaka</th>
<th>Kitwe</th>
<th>Ndola</th>
<th>Livingstone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>4.00-4.50</td>
<td>n.a.</td>
<td>6.00-7.00</td>
<td>n.a.</td>
</tr>
<tr>
<td>1984</td>
<td>5.30-7.00</td>
<td>5.00</td>
<td>8.10-8.55</td>
<td>5.50-5.50</td>
</tr>
<tr>
<td>1985</td>
<td>7.70-8.00</td>
<td>7.80-8.00</td>
<td>10.50</td>
<td>n.a.</td>
</tr>
<tr>
<td>1986</td>
<td>12.00</td>
<td>15.00</td>
<td>18.00</td>
<td>10.00-13.00</td>
</tr>
</tbody>
</table>

TABLE C.10

Charcoal prices for various quantities in Lusaka, January 1986.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Price per kg</th>
<th>Price per GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bag (40 kg)</td>
<td>10.40</td>
<td>0.26</td>
</tr>
<tr>
<td>Buckets (5 kg)</td>
<td>4.05</td>
<td>0.81</td>
</tr>
<tr>
<td>Tins (2 kg)</td>
<td>2.20</td>
<td>1.10</td>
</tr>
<tr>
<td>Heaps (1 kg)</td>
<td>1.73</td>
<td>1.73</td>
</tr>
</tbody>
</table>

TABLE C.11

Charcoal prices for various quantities in Lusaka, September 1986.

<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price paid to charcoal producers on site</td>
<td>5.0</td>
</tr>
<tr>
<td>Transport charges (truck hire round-trip)</td>
<td>4.0</td>
</tr>
<tr>
<td>Average wholesale and retail margin</td>
<td>3.0</td>
</tr>
<tr>
<td>Retail price, Lusaka market</td>
<td>12.0</td>
</tr>
</tbody>
</table>

TABLE C.12
### Appendix D

**STATISTICAL ANNEX: RENEWABLE ENERGY TECHNOLOGIES**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Residue</th>
<th>Residue Production (tonnes per tonne of crop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>straw</td>
<td>1.1 - 2.9</td>
</tr>
<tr>
<td>Deep water rice</td>
<td>straw</td>
<td>14.3</td>
</tr>
<tr>
<td>Wheat</td>
<td>straw</td>
<td>1.0 - 1.8</td>
</tr>
<tr>
<td>Maize</td>
<td>stalk + cob</td>
<td>1.2 - 2.5</td>
</tr>
<tr>
<td>Grain sorghum</td>
<td>stalk</td>
<td>0.9 - 4.9</td>
</tr>
<tr>
<td>Millet</td>
<td>stalk</td>
<td>2.0</td>
</tr>
<tr>
<td>Barley</td>
<td>straw</td>
<td>1.5 - 1.8</td>
</tr>
<tr>
<td>Rye</td>
<td>straw</td>
<td>1.8 - 2.0</td>
</tr>
<tr>
<td>Oats</td>
<td>straw</td>
<td>1.8</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>shell</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>straw</td>
<td>2.3</td>
</tr>
<tr>
<td>Pigeon Pea</td>
<td>stalk</td>
<td>5.0</td>
</tr>
<tr>
<td>Cotton</td>
<td>stalk</td>
<td>3.5 - 5.0</td>
</tr>
<tr>
<td>Jute</td>
<td>sticks</td>
<td>2.0</td>
</tr>
<tr>
<td>coconut (copra)</td>
<td>shell</td>
<td>0.7 - 1.1</td>
</tr>
<tr>
<td></td>
<td>husk</td>
<td>1.6 - 4.5</td>
</tr>
</tbody>
</table>

**TABLE D.1** Residue-to-crop ratios for certain crops. Source: LEA 87, p.112

<table>
<thead>
<tr>
<th>Type of livestock</th>
<th>Liveweight (kg)</th>
<th>Biogas (m3/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cow</td>
<td>800</td>
<td>1.95</td>
</tr>
<tr>
<td>Dairy heifer</td>
<td>500</td>
<td>1.05</td>
</tr>
<tr>
<td>Beef heifer</td>
<td>500</td>
<td>0.82</td>
</tr>
<tr>
<td>Beef stocker</td>
<td>250</td>
<td>0.57</td>
</tr>
<tr>
<td>Hog</td>
<td>250</td>
<td>0.23</td>
</tr>
<tr>
<td>Hog</td>
<td>100</td>
<td>0.14</td>
</tr>
<tr>
<td>Hog</td>
<td>50</td>
<td>0.070</td>
</tr>
<tr>
<td>Piglet</td>
<td>7</td>
<td>0.010</td>
</tr>
<tr>
<td>Hen (broiler)</td>
<td>2</td>
<td>0.0071</td>
</tr>
<tr>
<td>Hen (laying)</td>
<td>0.2</td>
<td>0.0056</td>
</tr>
<tr>
<td>Human (including urine)</td>
<td>0.75</td>
<td>0.035</td>
</tr>
</tbody>
</table>

**TABLE D.4** Average biogas production. Based on GOV 85, table 4.8, p.80.
Oven-dry weight of wood (tonnes) to produce 1 tonne of charcoal (approximate data):

<table>
<thead>
<tr>
<th>Moisture-%: dry basis</th>
<th>15</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>wet basis</td>
<td>13</td>
<td>16.7</td>
<td>28.6</td>
<td>37.5</td>
<td>44.4</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kiln type:</th>
<th>6.2</th>
<th>8.1</th>
<th>9.9</th>
<th>13.0</th>
<th>14.9</th>
<th>16.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth kiln</td>
<td>3.7</td>
<td>4.4</td>
<td>5.6</td>
<td>8.1</td>
<td>9.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Portable steel kiln</td>
<td>3.7</td>
<td>3.9</td>
<td>4.4</td>
<td>6.2</td>
<td>6.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Brick kiln</td>
<td>2.8</td>
<td>2.9</td>
<td>3.1</td>
<td>4.4</td>
<td>5.0</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Energy conversion efficiency

<table>
<thead>
<tr>
<th>Kiln type:</th>
<th>25</th>
<th>19</th>
<th>16</th>
<th>12</th>
<th>10</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth kiln</td>
<td>43</td>
<td>36</td>
<td>28</td>
<td>19</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Portable steel kiln</td>
<td>43</td>
<td>40</td>
<td>36</td>
<td>25</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Brick kiln</td>
<td>56</td>
<td>54</td>
<td>51</td>
<td>36</td>
<td>32</td>
<td>28</td>
</tr>
</tbody>
</table>

TABLE D.2 Yield and conversion factors for charcoal produced from wood.


The energy conversion efficiencies are computed by:

\[
\frac{(\text{heating value})_{\text{charcoal}}}{(\text{heating value})_{\text{wood}}}
\]

where \( m_{\text{wood}} \) is the oven dry weight of wood (tonnes) needed to produce 1 tonne of charcoal.

Assumed heating values: wood 20 MJ/kg (oven-dry), charcoal 31.5 MJ/kg (5% moisture, wet basis).

<table>
<thead>
<tr>
<th>Use</th>
<th>Specification</th>
<th>Quantity of gas consumed (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td>2&quot; burner</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>4&quot; burner</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>6&quot; burner</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>per person per day</td>
<td>0.24 m³/day</td>
</tr>
<tr>
<td>Gas lighting</td>
<td>100 Candle power</td>
<td>0.15</td>
</tr>
<tr>
<td>(mantle lamp)</td>
<td>(60 W equiv.)</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>1 kW</td>
<td>0.75</td>
</tr>
<tr>
<td>Dual fuel engine</td>
<td>1 kW</td>
<td>0.68</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>depending on outside temperature</td>
<td>0.30-0.75</td>
</tr>
</tbody>
</table>

TABLE D.5 Biogas consumption for different applications.

Source: KHA 86, table 4.4, p.14; SAS 84, figure 38, p.55.
### Fuel/device average efficiencies range

<table>
<thead>
<tr>
<th></th>
<th>Cooking Efficiency</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wood</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>open fire (clay-pot)</td>
<td>7% (5-10%)</td>
<td></td>
</tr>
<tr>
<td>open fire (aluminium pot)</td>
<td>15% (13-15%)</td>
<td></td>
</tr>
<tr>
<td>mud/clay oven</td>
<td>10% (8-14%)</td>
<td></td>
</tr>
<tr>
<td>brick oven</td>
<td>15% (13-16%)</td>
<td></td>
</tr>
<tr>
<td>portable metal stove</td>
<td>25% (20-30%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Charcoal</strong></th>
<th>Energy Conversion Efficiency</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>earth kiln</td>
<td>16% (9-25%)</td>
<td></td>
</tr>
<tr>
<td>portable steel kiln</td>
<td>28% (16-43%)</td>
<td></td>
</tr>
<tr>
<td>brick kiln</td>
<td>36% (21-43%)</td>
<td></td>
</tr>
<tr>
<td>retort</td>
<td>51% (28-56%)</td>
<td></td>
</tr>
<tr>
<td><strong>clay/mud/mbaula</strong></td>
<td>15% (13-25%)</td>
<td></td>
</tr>
<tr>
<td>improved metal stove</td>
<td>25% (20-35%)</td>
<td></td>
</tr>
</tbody>
</table>

### Wood-use efficiency

<table>
<thead>
<tr>
<th></th>
<th>Earth Kiln</th>
<th>Portable Steel Kiln</th>
<th>Brick Kiln</th>
<th>Retort</th>
</tr>
</thead>
<tbody>
<tr>
<td>mbaula/clay/mud</td>
<td>2.4%</td>
<td>4.2%</td>
<td>5.4%</td>
<td>7.7%</td>
</tr>
<tr>
<td><strong>range</strong></td>
<td>1.3%-6.3%</td>
<td>2.4%-10.8%</td>
<td>3.2%-10.8%</td>
<td>4.2%-14%</td>
</tr>
<tr>
<td>improved metal stove</td>
<td>4.0%</td>
<td>7.0%</td>
<td>9.0%</td>
<td>12.8%</td>
</tr>
<tr>
<td><strong>range</strong></td>
<td>1.8%-6.8%</td>
<td>3.2%-15.1%</td>
<td>4.2%-15.1%</td>
<td>5.6%-19.6%</td>
</tr>
</tbody>
</table>

**TABLE D.3**

A) **Average cooking efficiency for wood and charcoal stoves: energy conversion efficiencies of charcoal production methods.**

The conversion efficiencies hold for wood with 28.6% moisture content (dry basis) and charcoal with 5% moisture content (wet basis).

Source: tables 3.5 and 4.10, LEA 87.

B) **Wood-use efficiency of various charcoal stoves, combined with different charcoal production methods.** The averages are calculated by taking the "average cooking efficiency of the stove" involved and the "average energy conversion of the production method" involved, both given in part A). The ranges are calculated as follows:

- **Lower range:** lowest cooking efficiency value of the stove, as given in part A) (mbaula: 15%, improved stove: 20%), times the lowest energy conversion efficiency of the production method (depending on moisture content of wood used) as given in part A).

- **Higher range:** highest cooking efficiency value of the stove, as given in part A) (mbaula: 25%, improved stove: 35%), times the highest energy conversion efficiency of the production method as given in part A).
<table>
<thead>
<tr>
<th>Station</th>
<th>Altitude (m above sea level)</th>
<th>Global radiation (kWh/year)</th>
<th>Annual rainfall (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lusaka Int. Airport</td>
<td>1154</td>
<td>1921</td>
<td>850</td>
</tr>
<tr>
<td>Kasama</td>
<td>1364</td>
<td>2020</td>
<td>1250</td>
</tr>
<tr>
<td>Mansa</td>
<td>1258</td>
<td>1980</td>
<td>1150</td>
</tr>
<tr>
<td>Muwe</td>
<td>570</td>
<td>2335</td>
<td>1050</td>
</tr>
<tr>
<td>Ndola</td>
<td>1270</td>
<td>1905</td>
<td>1250</td>
</tr>
<tr>
<td>Mongu</td>
<td>1055</td>
<td>2300</td>
<td>950</td>
</tr>
<tr>
<td>Livingstone</td>
<td>951</td>
<td>2147</td>
<td>750</td>
</tr>
</tbody>
</table>

**TABLE D.7 Global radiation and rainfall values. Source: Dept. of Energy.**

<table>
<thead>
<tr>
<th>Device</th>
<th>Specification</th>
<th>Price (1988 Kwacha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar lantern</td>
<td>providing 4 hours' reading or working light; equivalent to 40 W bulb.</td>
<td>4,076.04</td>
</tr>
<tr>
<td>Battery charger</td>
<td>Type 20WSP: 10 W, charging 12 and 24 V</td>
<td>4,310.00</td>
</tr>
<tr>
<td></td>
<td>Type 33WSP: 45 W, charging 12 and 24 V</td>
<td>6,387.00</td>
</tr>
<tr>
<td>Vaccine refrigerator</td>
<td>4 modules, producing 1 kg ice for storage of 45 litres vaccine. Complete with batteries, wiring array structure. Producing 2 kg ice</td>
<td>62,500.00*</td>
</tr>
<tr>
<td>Teelite lighting kit</td>
<td>for lighting, portable TV, radio. 1 solar panel, 5 fluorescent 15 W tubes and fitting, 1 battery box, 50 m flex cable installation manual.</td>
<td>67,500.00*</td>
</tr>
<tr>
<td>Plug-in lighting kit</td>
<td>1 solar panel, 3 fluorescent tubes and fitting, installation manual. For lighting, portable TV and radio.</td>
<td>8,542.00*</td>
</tr>
<tr>
<td>Domestic power system</td>
<td>250 W (available 250, 500, 750, 800, 1500, 2500 W). water supply from boreholes of 5-120 m head to give a flow of 10-220 m³/day. The flow depends on sunlight levels, head and solar panel size. Systems including wiring, solar modules, support structure, pump and manual.</td>
<td>60,000.00</td>
</tr>
<tr>
<td></td>
<td>1500 W</td>
<td>250,000.00</td>
</tr>
<tr>
<td>Borehole waterpumps</td>
<td>water supply from boreholes of 5-120 m head to give a flow of 10-220 m³/day. The flow depends on sunlight levels, head and solar panel size. Systems including wiring, solar modules, support structure, pump and manual.</td>
<td>55,000-200,000</td>
</tr>
<tr>
<td>Surface waterpumps</td>
<td>Type Loewe BPPDI: 4000 litres/day at 40 m head, complete system.</td>
<td>55,000.00</td>
</tr>
<tr>
<td></td>
<td>Type KSB floating pump: 100,000 litres/day at 10 metres head, complete system.</td>
<td>122,250.00</td>
</tr>
<tr>
<td></td>
<td>Positive displacement pump: for household supply and drip irrigation. Maximum head 40 m, flow 8 m³/day. Systems include solar module, pump, wiring, manual and support structure.</td>
<td>30,000-55,000*</td>
</tr>
</tbody>
</table>

**TABLE D.8 Typical costs of solar systems sold by BP Zambia Ltd.**


* converted from British pounds at rate 1 pound = K 25 (April 1988).
Size of plant  Floating gas holder type  Fixed dome  Ganesh model
(m³)  (retention period in days)

30  40  55  55  40

2
3
4
6
8
10

5.910  6.660  7.220  5.680  5.310
7.220  8.070  8.980  7.130  6.440
8.010  9.190 10.800  7.830  7.250
11.560 13.270 15.930 11.480 10.530
13.890 15.770 19.100 13.500 12.700


7.1 m³: 9.870  8.4 m³: 42.300

Source: PAA 81, p.17. Prices are without pump and piping and converted from 1980 Kwacha into 1987 Kwacha, using an conversion factor 19.3, based on the "index of goods for fixed capital formation". Monthly Digest of Statistics, April/December 1987, CSO, Lusaka.
The "Climax" is South African make, and was available from Water Engineering Ltd., Kitwe and Water Wells Ltd, Lusaka. The "Southern Cross" is Australian make, and was available from Robert Hudson Ltd., Lusaka/Mdola.

Dempster 6 ft

1.8 m: 41,000

3.0 m: 63,500

4.3 m: 119,500

5.5 m: 201,600

TABLE D.6  Estimated costs of different models and sizes of plants in India.

TABLE D.11  Prices of windmills.

The "Climax" is South African make, and was available from Water Engineering Ltd., Kitwe and Water Wells Ltd, Lusaka. The "Southern Cross" is Australian make, and was available from Robert Hudson Ltd., Lusaka/Mdola.

**Table D.10** Evaluation of solar cookers, obtained from a test concerning 16 solar cookers.

<table>
<thead>
<tr>
<th>Solar Cooker Type</th>
<th>Reflector</th>
<th>Absorber</th>
<th>Steam Cooker</th>
<th>Abs - refl.</th>
<th>Oven refl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation aperture (m)</td>
<td>1.2 (0.4-2.0)</td>
<td>0.1</td>
<td>1.9 (0.8-3.6)</td>
<td>0.6 (0.4-1.7)</td>
<td>1.3 (0.8-1.7)</td>
</tr>
<tr>
<td>Portability</td>
<td>Good (vb-ex)</td>
<td>Good</td>
<td>-</td>
<td>Good</td>
<td>vb-ex</td>
</tr>
<tr>
<td>Effective cooking power (W)</td>
<td>300 (185-350)</td>
<td>160</td>
<td>247 (120-470)</td>
<td>209 (160-510)</td>
<td>310 (250-470)</td>
</tr>
<tr>
<td>Degree of efficiency</td>
<td>34 (22-50)</td>
<td>50</td>
<td>14 (9-20)</td>
<td>43 (35-50)</td>
<td>34 (26-40)</td>
</tr>
<tr>
<td>Cooking capacity (kg)</td>
<td>3 (2.5-5)</td>
<td>4</td>
<td>4 (3.5-6)</td>
<td>4 (3-6)</td>
<td>4 (2-6)</td>
</tr>
<tr>
<td>Possible cooking hour (o'clock)</td>
<td>8-16</td>
<td>11-15</td>
<td>10-17</td>
<td>10-16</td>
<td>9-15</td>
</tr>
<tr>
<td>CBR</td>
<td>CR</td>
<td>C</td>
<td>C</td>
<td>CBR</td>
<td></td>
</tr>
<tr>
<td>Repositioning</td>
<td>15 min (10-20)</td>
<td>-</td>
<td>-</td>
<td>32 (10-60)</td>
<td>13 (10-15)</td>
</tr>
<tr>
<td>Local materials</td>
<td>Mostly</td>
<td>exclusively</td>
<td>exclusively</td>
<td>exclusively</td>
<td>exclusively</td>
</tr>
<tr>
<td>Life-time (years)</td>
<td>7 (5-10)</td>
<td>5</td>
<td>9 (7-10)</td>
<td>6 (5-7)</td>
<td>7 (5-10)</td>
</tr>
<tr>
<td>Costs (1987 US$)</td>
<td>89 (10-180)</td>
<td>75</td>
<td>160 (106-265)</td>
<td>80 (44-160)</td>
<td>300 (89-530)</td>
</tr>
<tr>
<td>Costs/power (US$/W)</td>
<td>0.30 (0.044-0.92)</td>
<td>0.76</td>
<td>0.39 (0.57-0.89)</td>
<td>0.39 (0.27-0.48)</td>
<td>0.97 (0.35-1.47)</td>
</tr>
<tr>
<td>Starry light</td>
<td>Inconvenient</td>
<td>None</td>
<td>None</td>
<td>-</td>
<td>Slight</td>
</tr>
<tr>
<td>Max temperature</td>
<td>190 (140-300)</td>
<td>90</td>
<td>100</td>
<td>165 (130-250)</td>
<td>135 (130-135)</td>
</tr>
</tbody>
</table>

**Table D.9** Monthly mean of hourly wind speeds in Zambia. Windspeeds in metres/second.

<table>
<thead>
<tr>
<th>Month</th>
<th>Chipata</th>
<th>Kabwe</th>
<th>Kasama</th>
<th>Livingstone</th>
<th>Lusaka</th>
<th>Mansa</th>
<th>Mongu</th>
<th>Ndola</th>
<th>Solwezi</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1.50</td>
<td>1.85</td>
<td>2.20</td>
<td>1.65</td>
<td>2.00</td>
<td>1.30</td>
<td>2.20</td>
<td>1.65</td>
<td>0.80</td>
</tr>
<tr>
<td>February</td>
<td>1.55</td>
<td>1.85</td>
<td>2.15</td>
<td>1.40</td>
<td>2.35</td>
<td>1.35</td>
<td>2.20</td>
<td>1.65</td>
<td>0.80</td>
</tr>
<tr>
<td>March</td>
<td>1.85</td>
<td>2.25</td>
<td>1.95</td>
<td>1.75</td>
<td>2.65</td>
<td>1.45</td>
<td>2.25</td>
<td>1.75</td>
<td>0.80</td>
</tr>
<tr>
<td>April</td>
<td>2.10</td>
<td>2.80</td>
<td>2.40</td>
<td>1.55</td>
<td>3.10</td>
<td>1.75</td>
<td>2.50</td>
<td>2.05</td>
<td>0.90</td>
</tr>
<tr>
<td>May</td>
<td>2.20</td>
<td>2.70</td>
<td>2.55</td>
<td>1.60</td>
<td>3.35</td>
<td>1.90</td>
<td>3.05</td>
<td>2.05</td>
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<tr>
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<td>2.80</td>
<td>3.00</td>
<td>1.65</td>
<td>2.85</td>
<td>1.90</td>
<td>3.00</td>
<td>2.20</td>
<td>--</td>
</tr>
<tr>
<td>July</td>
<td>2.50</td>
<td>3.15</td>
<td>3.20</td>
<td>1.80</td>
<td>3.60</td>
<td>2.15</td>
<td>3.35</td>
<td>2.70</td>
<td>1.05</td>
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<tr>
<td>August</td>
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<td>3.40</td>
<td>3.60</td>
<td>1.80</td>
<td>4.05</td>
<td>3.45</td>
<td>3.50</td>
<td>3.20</td>
<td>1.15</td>
</tr>
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<td>3.15</td>
<td>3.55</td>
<td>3.45</td>
<td>2.10</td>
<td>4.20</td>
<td>2.40</td>
<td>3.90</td>
<td>3.45</td>
<td>1.00</td>
</tr>
<tr>
<td>October</td>
<td>3.30</td>
<td>3.65</td>
<td>3.25</td>
<td>2.15</td>
<td>4.05</td>
<td>1.95</td>
<td>2.80</td>
<td>2.80</td>
<td>0.55</td>
</tr>
<tr>
<td>November</td>
<td>2.50</td>
<td>2.30</td>
<td>2.50</td>
<td>1.90</td>
<td>3.25</td>
<td>1.75</td>
<td>1.80</td>
<td>2.35</td>
<td>0.90</td>
</tr>
<tr>
<td>December</td>
<td>1.75</td>
<td>2.00</td>
<td>2.30</td>
<td>2.50</td>
<td>2.30</td>
<td>1.15</td>
<td>1.45</td>
<td>1.85</td>
<td>0.90</td>
</tr>
</tbody>
</table>

**ANNUAL**

|       | 2.3 | 2.7 | 2.5 | 1.6 | 3.5 | 1.9 | 3.2 | 2.3 | 1.7 |

*Source: PAA 81, appendix I; HUT 74; TEM 86, p.9.*
Appendix E gives the calculations, on which the data presented in the paragraph 5.6 are based.

### E.1 Estimates of energy consumption of a farming household

#### E.1.1 Energy consumption in domestic tasks

In a traditional household main fuel use is for cooking and lighting. In a modern household various appliances are in use, besides for cooking or lighting (such as a refrigerator, iron, fan, radio). Whether such appliances are in use depends (often) on the availability of electricity.

**Cooking and water heating**

We assume that a household needs energy for the following tasks: cooking, water heating, lighting, provision of drinking water, refrigeration.

In assessing daily energy requirements for cooking and water heating we make the following assumptions (see appendix B for a list of symbols and units used):
- the daily food consumption per person is 0.7 kg, thus 6 kg per household, assuming a household size of 8.5 (average Magoye area). According to FOO 81 NUT (various tables) average daily intake of nshima and relish in Zambia is about 0.615 kg.
- to cook 1 kg of food 2 kg of water is needed, of which 40% evaporates;
- mean specific heat of food is (because of the high water content) taken the same as that of water: \( c = 4.18 \text{ kJ/kg/°C} \);
- temperature rise \( \Delta T \) above ambient during cooking: 75 °C.

The energy \( E \) required to cook 6 kg of food is:

\[
E = (c \cdot m_f + c \cdot m_w)\Delta T + 0.4 \cdot m_w \cdot r_w
\]

\[
= (6+12) \cdot 4.18 \cdot 75 + 0.4 \cdot 12 \cdot 2260 \text{ kJ}
\]

\[
= 16.49 \text{ MJ (= 4.58 kWh)}
\]

(With: \( m_f, m_w \): masses of food, resp. water
\( r_w \): evaporation heat of water (\( = 2260 \text{ kJ/kg} \)).

Further it is assumed that 8 litre of water per person is heated every day for various purposes. The required energy for water heating per household per day follows from (assuming \( T = 45 \text{ K} \)):
So total energy requirements of a household for cooking and water heating are 28.52 MJ/day (≈ 7.92 kWh/day).

It has to be stressed that efficiency of cooking devices is not taking into account yet in this figure. If we would use wood in an open fire for cooking this implies (at a consumption of 28.52 MJ/day, an efficiency of 7% and a heating value of wood of 16.0 MJ/kg) a wood consumption of 25.5 kg (≈ 25.5/(0.07·16.0)). Chidumayo (p.c.) for instance has estimated a wood consumption of 21 kg for a 6-person household (in the rural areas around Chipata; for cooking and heating). So the estimate of 28.52 MJ seems reasonable to me.

Lighting

As energy for lighting the following sources will be considered:
- electricity (electric bulbs),
- biogas (lantern),
- paraffine (various lamps).

It is assumed that a household uses 4 bulbs (60 W incandescent) for 4 hours (each bulb giving a light intensity of 430 lumen/m² at 30 cm). So, daily energy consumption by a household is 0.96 kWh.

If biogas is used directly, a lantern equivalent to a 60 W bulb consumes 0.15 m³/hr of biogas (see table D.5). So 4 bulbs kept on for 4 hours will consume 2.40 m³.

In the case of lighting by means of paraffine lamps the following types can be used:
- can & wick (illuminance 5.4 lm/m², fuel use 10.0 ml/hr),
- hurricane (illuminance 32 lm/m², fuel use 12.0 ml/hr),
- pressure lamp (illuminance 340 lm/m², fuel use 48 ml/hr)

To give the same illuminance as 4 bulbs, 5 pressure lamps are required, 42 hurricanes and 329 can & wicks!

Refrigeration

Assumptions:
- 0.2 m³ refrigerator, in which 20 kg of food is stored.
- cold storage temperature is 0°C, at ambient temperature of 25°C;
- surface area of the insulated box $A = 2.20 \text{ m}^2 (1 \times 0.45 \times 0.44 \text{ m})$;
- thermal conductivity of the walls $k = 4/10^4 \text{ kJ/(cm}\cdot\text{K}\cdot\text{s})$;
- wall thickness $d = 10 \text{ cm}$;
- storage time $t = 24 \text{ hours}$.

Heat requirements for cooling are:

\[
Q_c = M \cdot c \cdot \Delta T
\]

\[
= 20 \cdot 4.2 \cdot 25
\]

\[
= 4160 \text{ kJ}
\]

(with $M$: mass of food,
$c$: mean specific heat,
$\Delta T$: temperature difference).
Losses occur through conduction of heat through the walls:

\[ Q_1 = \kappa \cdot A \cdot \Delta T \cdot t / d \]

\[ = 4 \cdot 2.2 \cdot 25 \cdot 24 \cdot 3600 / (10^5) \]

\[ = 190 \text{ kJ} \]

The total heat requirement for refrigeration is \( Q = Q_c + Q_1 = 2.27 \text{ MJ/day} \)

(\( = 0.631 \text{ kWh/day} \)). The following energy sources are studied:

a) electricity (assuming overall efficiency of 30\%): 2.10 kWh/day.

b) biogas is used for flame-operated refrigeration. Taking a consumption of 0.50 m\(^3\) biogas per hour per m\(^3\) (see table D.5) this implies a biogas consumption of 2.4 m\(^3\) per day (implicating an efficiency of the system of 9\%, and a heating value of biogas of 22.5 MJ/m\(^3\)).

### E.1.2 Energy consumption in water pumping

**Domestic water requirements**

It is assumed that total water requirement for drinking, washing, bathing by the members of a household is 300 litres. To meet the daily needs of 1 cow, 40 litres are required; 1 pig needs 6 litres. We will consider two cases:

- **Case A**: a peasant farm household with 15 cattle and 4 pigs. Total daily water needs are 620 litres;
- **Case B**: an emergent farm household with 25 cattle and 8 pigs. Total daily water requirement: 1050 litres.

Livestock size is chosen with present averages (see table F.7).

Thirdly we assume that the household needs an additional 700 litres of water per day for e.g. watering of the vegetable garden during the dry season (which is estimated according to the method described in table E.2).

So total water requirements are, in case A 1.620 m\(^3\) and in case B 2.050 m\(^3\). We will assume that water storage is used (tank at a height of 6 metres). Table E.1 gives the energy requirements \( E_{water} \) for lifting water from a borehole with a depth of 10 and 30 metres. These figures are calculated by using:

<table>
<thead>
<tr>
<th>Required water volume (m(^3))</th>
<th>E(_{water}) (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 m</td>
</tr>
<tr>
<td>Case A</td>
<td>1.62</td>
</tr>
<tr>
<td>Case B</td>
<td>2.05</td>
</tr>
<tr>
<td>Average area</td>
<td>1.68</td>
</tr>
</tbody>
</table>

**TABLE E.1** Daily energy requirement \( E_{water} \) (in kWh) for lifting water from a borehole for drinking water provision and garden watering. Two elevation heights: 16 and 36 m. The average for the area is calculated by using the weights 87/100 (peasant farmer, case A) and 13/100 (emergent farmer), depending on the number of families in each categories estimated for Nagoye area.
Actual energy requirements of the pump system can be estimated by:

\[ E_{\text{system}} = E_{\text{water}} / \eta \]

\[ \eta: \text{efficiency of pump system (pump, engine, losses)} \]

**Water and energy requirements in irrigation**

Power requirements for pumping water for irrigation are at least one factor higher than for domestic purposes. In this study we will take as an example a plot of 25 hectares, irrigated by furrow irrigation. On the plot 4 kind of crops are grown (maize, cotton, oil crops and wheat) are grown in a 3-year rotation system. The cropping pattern is visualized in figure E.1. It is assumed (in accordance with present practices of Magoye commercial farmers) that maize covers 33% of the area, cotton 25%, wheat 25%, sunflower 5%, soyabean 8%, groundnuts 13%.

In designing the cropping pattern the following climate and other aspects were taken into account (based on AGR 81, practices Magoye area):

- the continuous growing of cereals (wheat, maize) should be avoided (AGR 81).
- maize: cannot withstand frost, moisture stress at flowering is very important, maturation and harvesting should take place in dry weather, optimum temperature for growth: 20-25°C.
- wheat: the crop is drought tolerant.
- cotton: sufficient soil moisture is essential during flowering, rainfall during boll-opening and harvest reduces the quality of seed and fibre. The optimum average daily temperature is 30°C. For an adequate germination average daily temperature should be over 15°C. Cotton is

**FIGURE E.1** Cropping pattern: crop rotation with 6 crops in 3 years.

Maize, cotton, wheat, oil/protein crops (sunflower, soyabean, groundnuts).

Data based on present crop practices, and AGR 81, VLI 81. It is assumed that wheat is cultivated as new drought-resistant crop in the dry months.

![Diagram of cropping pattern](image-url)
susceptible to frost. During flowering abundant sunshine is required.
- sunflower: sunflower can grow under marginal conditions (rainfall, soil). A good but not excessive supply of moisture (esp. during flowering) is important for a good yield. Optimum mean daily temperature: 25°C. Maturation requires dry, warm weather.
- soyabean: general climate requirements resemble that of maize. Soyabean is slightly frost-tolerant. Dry weather is needed during maturing.
- groundnuts: dry weather needed during maturing. Absolute minimum temperature is 14°C.
It is assumed that wheat is grown as new cash crop in the dry months.

Furrow irrigation is best suited to deep, moderately permeable soils with uniform flat slopes, not steeper than 3% (STE 79, p.43) for crops that cannot tolerate standing in water. If the slopes are too steep the velocity of the water will cause erosion, resulting in formation of gullies and loss of soil. The amount of water needed depends not only on climatic conditions but also on crop characteristics. In furrow irrigation about 1/5-1/2 of the ground surface is wetted; this reduces evaporation. Furrows are usually V-shaped, about 25-30 cm wide and 15-20 cm deep. Many crops are cultivated in rows 0.75-1 m apart, with one row on each ridge. Vegetables are often planted with two rows 40 cm apart. The more permeable the soil, the more closer together should be the furrows (STE 79, chapter 9). For annual crops as maize, grains and vegetables furrows are constructed as part of the ploughing operations each year.

In calculating irrigation requirements and supply the following factors are important:
- evapotranspiration, the process by which water in the form of vapour enters the air from open water surfaces, lakes, rivers and wet land surfaces (evaporation) or from plant leaves (transpiration);
- precipitation, in the Zambian case, rainfall. The effectiveness of rain for plants depends on rain intensity, soil type and depth, cropping patterns, etc. Part of the rain is lost by surface run-off, percolation beyond the plant’s roots and evaporation;
- irrigation efficiency. Losses occur in surface irrigation due to deep percolation in free draining soils, from overspill and wastage of water and from evaporation. For furrow irrigation efficiency is about 50%.

In table E.2 the calculation of the monthly water needs per hectare are presented, for our example of a plot of 25 hectare (with 6 crops). The method used is based on STE 79, chapter 9, and will be described shortly:

Rd is the annual rainfall per month (in mm). E is the evaporation per month (in mm). The figures used here are derived from appendix 5.1 (for Kafue Flats area). ETo is the reference crop evaporation, defined as "the rate of evapotranspiration from an extensive surface of 8-15 cm for a tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (STE 79, p.70). ETo can be calculated by multiplying E by a factor Kp. This factor Kp is the pan coefficient. Evaporation is measured by an evaporation pan, which is basically a container with a means of measuring the water lost daily in evaporation. Because water in the pan tends to be warmer than open water, the measured pan evaporation has to be reduced by a pan factor, depending on the relative humidity and windspeeds of the location.
<table>
<thead>
<tr>
<th>Month</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>W</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
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<tbody>
<tr>
<td>E (mm/month)</td>
<td>150</td>
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<td>164</td>
<td>179</td>
<td>166</td>
<td>139</td>
<td>164</td>
<td>187</td>
<td>225</td>
<td>169</td>
<td>190</td>
</tr>
<tr>
<td>Rd (mm/month)</td>
<td>197</td>
<td>149</td>
<td>55</td>
<td>18</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>Rel hum (%)</td>
<td>81</td>
<td>81</td>
<td>76</td>
<td>67</td>
<td>62</td>
<td>60</td>
<td>54</td>
<td>47</td>
<td>43</td>
<td>41</td>
<td>59</td>
</tr>
<tr>
<td>Rp</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.75</td>
</tr>
<tr>
<td>ETo (mm/month)</td>
<td>128</td>
<td>109</td>
<td>139</td>
<td>134</td>
<td>125</td>
<td>104</td>
<td>123</td>
<td>131</td>
<td>152</td>
<td>118</td>
<td>143</td>
</tr>
</tbody>
</table>

### MAIZE
- Kc | 1.1 | 1.0 | 0.7 | 0.4 | 0.4 | 0.4 |
- ETo (mm/month) | 141 | 109 | 84 | 20 | 104 | 113 |
- In (mm/month) | - | - | - | - | - | - |
- Factor 33% | 26 | 34 |

### COTTON
- Kc | 1.1 | 0.9 | 0.8 | 0.7 | 0.4 | 0.4 | 0.7 |
- ETo (mm/month) | 141 | 98 | 112 | 152 | 88 | 104 | 88 |
- In (mm/month) | - | - | - | - | - | - | - |
- Factor 33% | 26 | 22 |

### SUNFLOWER
- Kc | 0.3 | 0.7 | 1.1 | 0.7 | 0.4 | 0.4 |
- ETo (mm/month) | 42 | 94 | 73 | 49 | 49 |
- In (mm/month) | - | 152 | 146 | 98 | 98 |
- Factor 33% | 8 | 7 | 5 |

### SOYABEAN
- Kc | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 |
- ETo (mm/month) | 44 | 111 | 134 | 63 | 63 |
- In (mm/month) | - | 112 | 146 | 146 | 146 |
- Factor 8% | 9 | 10 | 9 |

### GROUNDNUTS
- Kc | 0.4 | 0.7 | 0.9 | 0.8 | 0.5 | 0.5 |
- ETo (mm/month) | 56 | 94 | 83 | 62 | 62 | 62 |
- In (mm/month) | - | 152 | 146 | 132 | 132 |
- Factor 13% | 9 | 15 | 16 | 17 |

### WHEAT
- Kc | 0.3 | 0.7 | 1.0 | 0.7 | 0.2 |
- ETo (mm/month) | 31 | 86 | 131 | 111 | 24 |
- In (mm/month) | 62 | 172 | 262 | 218 | 18 |
- Factor 25% | 16 | 43 | 66 | 55 | 5 |

### TOTAL water requirements per hectare
- mm/month | 65 | 82 | 77 | 45 | 64 | 83 | 55 | 5 | 60 |
- m3/day | 22 | 23 | 26 | 15 | 21 | 27 | 18 | 2 | 20 |
- E, water (kWh) | 1.79 | 2.20 | 2.13 | 1.22 | 2.71 | 1.67 | 0.16 | 0.63 |

Total annual water requirement per hectare: 5370 m³

Total water energy required (see formula E.5): 423.8 kWh. Assumed elevation head: 30 m.

**TABLE E.2**

Calculation of the field irrigation requirements of a plot of 1 hectare, with
the following cropping pattern: crop rotation of 6 crops in 3 years. An
explanation of the symbols is given in the text. Data on E, Rd and relative
humidity were derived from Appendix F.5 (Kafue Flats); data on Rp based on STE
79, table 13; data on Kc from STE 79, chapter 9 and VLI 81, p.21.

According to the convention 1 mm/month is equal to 10 m³/hectare.

In calculating In for the crops maize and cotton an additional 80 mm/month is
included as pre-irrigation after a dry period (see also figure E.1).
Higher windspeeds mean higher evaporation. High precipitation and humidity mean low evapotranspiration.

Under the same climatic conditions different crops require different amounts of water and the quantities of water used by a particular crop vary by its stage of growth. With most crops water consumption increases during the vegetative period, reaching a maximum at the approach of flowering and then declining towards maturity. This is taken into account by introducing crop coefficients $K_c$ for various crops. Factors that influence the value of $K_c$ are the plant physiology (waxy or hairy leaves, closure of stomata), crop height and roughness, growing phase and ground cover. The crop evapotranspiration $ET_c$ is related to $ETo$ by: $ET_c = ETo \cdot K_c$.

Finally the net irrigation requirement $In$ is:

$$In = \frac{(Rd - ET_c)}{0.5}$$

the difference between $Rd$ and $ET_c$, with 0.5 the furrow irrigation efficiency. From table E.2 it follows that the water requirements are largest in August ($28 \text{ m}^3/\text{day/hectare}$).

Table E.2 also gives the required energy per day to lift the irrigation water from a borehole. These are calculated by using formula (E.5), assuming a borehole depth of 30 m.

**Irrigation practice**

Continuous irrigation requires continuous attention. Without this, irrigation efficiency will be reduced further. Constant attention for a small flow is very inefficient and expensive. Irrigation at night and as well as during hot midday hours is unattractive. In this report a maximum working period of 8 hours is assumed per day.

The irrigation interval $i$ (in days) is defined as, as the period between two successive irrigations, and can be calculated by:

$$i = \frac{Am \cdot D}{ET_c}$$

$Am$: available moisture in the soil (in mm/m)

$D$: rooting depth of the crop (in m)

$ET_c$: evapotranspiration (in mm/day)

The amount of available moisture in the soil depends strongly on the soil type. The rooting depths differ for types of plants, depending also on their age.

The required capacity $Q$ (in $\text{m}^3$/hour) of the system can then be calculated using:

$$Q = \frac{\text{application (mm/month)} \cdot 10}{i \cdot (\text{working hours per day})}$$

The following figures are used (see STE 79, chapter 9): $Am = 150 \text{ mm/m}$ (for clay loam, as in Magoye area), $D = 1 \text{ m}$ (maize and cotton). We then find irrigation intervals in the order of months. Therefore $i$ is taken equal to the number of days of the month concerned in the calculations of this chapter.
E.2 Capacity and cost estimates of energy (conversion) technologies

E.2.1 Electricity from the grid

To provide a useful context for comparing the costs of supplying electricity, extension from the existing grid must be studied as well. Such grid extension is not implemented on a household level, but rather on a village or camp level. Magoye Town is connected to a 33 kV line. It is assumed that further power distribution in the area is done by means of a 11 kV line, which is connected by means of a 33-11 kV transformer to the 33 kV line. Various substations along the 11 kV line transform the electricity into 220 V and is then transported to the various households.

We examine the following cases:
a) an area of 60 km², inhabited by 600 families (roughly the size of an agricultural camp in Magoye area), which centre is located at 50 km from the grid (see map Magoye, figure 4.1),
b) a similar area, now located near the 11 kV line (e.g. Ngwezi or Magoye Camps,
c) urban electrification of an area of 10 km², 600 families.
We study this case, as we consider urban household energy options, as indirect means to tackle deforestation.

A summary of the analysis is given in table E.3. Remark that the calculations does not take into account maintenance costs of the extended grid and that it is assumed that ZESCO would be willing to sell electricity for its cost of generation.

The total available annual capacity for the area is 8,760,000 kWh. To give an idea of this capacity we calculate what the annual consumption (by the 600 households) in the area would be for a particular purpose, assuming that all households would use electricity for that purpose.

Cooking and water heating: Daily consumption per household, assuming a cooking efficiency of 70%: 11.31 kwh. Total annual consumption: 2,477,000 kWh (is 28% of available capacity).
Lighting: Total annual consumption: 210,200 kWh (2.4% of available capacity).
Refrigeration: Daily consumption per household: 0.97 kWh. Total annual consumption: 212,000 kWh (2.4% of available capacity).
Irrigation: pumpset efficiency 0.32, assumed total hectarage irrigated 3000 ha. Annual consumption: 4,104,000 kWh (47% of available capacity).

A grid system, like the one described, is in practice poorly matched to the village needs. It is most likely that for many years after construction of the system people would only use electricity for lighting, some household appliances. Actually only a few farming households would use electricity for, say cooking or irrigation. As a consequence the load factor will be low and thus the unit cost of consumption correspondingly high. To my opinion a load factor of 10% is a very reasonable estimate. This tallies with reported load utilization factors from other developing countries, about 1-14% (INT 85, p.4).
The cost analysis of grid extension as presented in Table E.3 is based on a simple mathematical model, developed for this purpose. It is assumed that an area of $A$ km$^2$ (with its centre at a distance $d$ from an existing 33 kV line) will be connected to the national grid. At the connection point the 33 kV is transformed into 11 kV and then transported to the area and distributed within the area. A certain number of substations are used to transform the 11 kV in 220 V, which is then distributed among the individual consumers. The total costs $K$ of the extension project are a summation of 4 terms:

<table>
<thead>
<tr>
<th>Basic data</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from grid to centre village</td>
<td>0 km</td>
<td>50 km</td>
<td>0 km</td>
</tr>
<tr>
<td>Number of stations assumed *)</td>
<td>120</td>
<td>120</td>
<td>60 km</td>
</tr>
<tr>
<td>Length of the 11 kV distribution line in the area</td>
<td>78.2 km</td>
<td>78.2 km</td>
<td>28 km</td>
</tr>
<tr>
<td>Average hook-up distance given the number of substations, the number of families and the area</td>
<td>217 m</td>
<td>217 m</td>
<td>153 m</td>
</tr>
</tbody>
</table>

**Fixed costs**

<table>
<thead>
<tr>
<th>High voltage step-down transformer</th>
<th>( K \ 360,000 )</th>
<th>( K \ 360,000 )</th>
<th>( K \ 360,000 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission line (11 kV at ( K \ 55,000/km ))</td>
<td>( K \ 4.300,000 )</td>
<td>( K \ 7.050,000 )</td>
<td>( K \ 1.540,000 )</td>
</tr>
<tr>
<td>Substation transformers</td>
<td>( K \ 5.280,000 )</td>
<td>( K \ 5.280,000 )</td>
<td>( K \ 2.640,000 )</td>
</tr>
<tr>
<td>Transmission line (220 V at ( K \ 90/metre ))</td>
<td>( K \ 8.640,000 )</td>
<td>( K \ 8.640,000 )</td>
<td>( K \ 1.458,000 )</td>
</tr>
<tr>
<td>TOTAL</td>
<td>( K \ 11.700,000 )</td>
<td>( K \ 11.700,000 )</td>
<td>( K \ 8.280,000 )</td>
</tr>
</tbody>
</table>

**Financing cost (at $i=15\%$, $n=20$) \#**

<table>
<thead>
<tr>
<th></th>
<th>( K \ 3.457,000 )</th>
<th>( K \ 3.897,000 )</th>
<th>( K \ 1.991,000 )</th>
</tr>
</thead>
</table>

**Cost of electricity**

<table>
<thead>
<tr>
<th>Annual financing cost per household</th>
<th>( K \ 5761 )</th>
<th>( K \ 6495 )</th>
<th>( K \ 3516 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total annual capacity: 1000 kW 8760 hour/year</td>
<td>( K \ 0.395/kWh )</td>
<td>( K \ 0.445/kWh )</td>
<td>( K \ 0.227/kWh )</td>
</tr>
<tr>
<td>Unit cost of capacity (load utilization 100%)</td>
<td>( K \ 3.95/kWh )</td>
<td>( K \ 4.45/kWh )</td>
<td>( K \ 2.27/kWh )</td>
</tr>
<tr>
<td>Unit cost of capacity (load utilization 10%)</td>
<td>( K \ 0.465/kWh )</td>
<td>( K \ 0.515/kWh )</td>
<td>( K \ 0.297/kWh )</td>
</tr>
<tr>
<td>Total unit cost of electricity: unit cost of capacity + charge/ economic cost of electricity to the point where the 11 kV line starts. Present charge grid is ( K \ 0.07/kWh, 100% ) load</td>
<td>( K \ 4.02/kWh )</td>
<td>( K \ 4.52/kWh )</td>
<td>( K \ 2.34/kWh )</td>
</tr>
<tr>
<td></td>
<td>( K \ 0.575/kWh )</td>
<td>( K \ 0.625/kWh )</td>
<td>( K \ 0.407/kWh )</td>
</tr>
<tr>
<td>Economic costs grid is ( K \ 0.18/kWh, 100% ) load</td>
<td>( K \ 4.13/kWh )</td>
<td>( K \ 4.63/kWh )</td>
<td>( K \ 2.45/kWh )</td>
</tr>
</tbody>
</table>

**TABLE E.3** Cost of supplying electricity from existing and extended grid.

Case 1: rural area, 600 families, 60 km2.
Case 2: rural area, 600 families, 60 km2, located at 50 km from a 33 kV line.
Case 3: urban area, 600 families, 10 km2.

*) Local distribution is expensive, so it is cost effective to underutilize the substations by using many of them to reduce local hook-up distance.
Calculations are made, based on ZESCO estimates of costs and EWE 80, p.306.

\# based on amortization of loan in annual equal instalments.
Appendix E

(1) $k_{tr} \cdot n_{tr}$: cost of a transformer (33 kV to 11 kV),
n_{tr}: number of transformers used.

(2) $k_{1} \cdot d$
$k_{1}$: cost of a 11 kV distribution line per unit length,
d: distance area - 33 kV line.

(3) $k_{n} \cdot n$
$k_{n}$: cost of a substation (11kV-220 V transformer),
n: number of substations used.

(3) $k_{1} \cdot n \cdot D(n)$
$D(n)$: average connection distance of the 11 kV line
between two substations.

(4) $600 \cdot k_{h} \cdot h(n)$
$k_{h}$: cost of a 220 V distribution line per unit length,
h(n): average hook-up distance per household
600: number of families in the area.

The variable D follows from the equation:

$$D = \frac{1}{2} \cdot \frac{2 \cdot A_s}{\pi}.$$ 

in which $A_s = A/n$, the area covered per substation, and A the total area (60 or 10
km², whether it is a rural or urban area).

The average hook-up distance h is calculated from:

$$h = \frac{\int_{0}^{D/2} r \cdot 2r \cdot dr}{A_s}.$$

If the number of substations is known in this model one can calculate
$K = K(n) = (1)+(2)+(3)+(4)+(5)$. In principle the number of substations
is chosen such that the total power capacity of the n substations is
equal to the power of the $n_{tr}$ transformers. Often, as also happens in
our case, it is cost effective to underutilize the capacity of the
substations, by using more of them, as otherwise total costs of the 220
V lines would be prohibitive. The optimal number of substations is that
value of n for which the cost function $K(n)$ is minimal. This optimal n
can be calculated from:

$$\frac{\partial K(n)}{\partial n} = 0.$$

E.2.2 Forestry schemes

Let us elaborate an example of the financial consequences of a
fuelwood production scheme (data based on AKK 89, part D.1.1). The
following assumptions are made:

- establishing costs: plantation K 5200/ha
  village forestry project K 1300/ha
- rotation period of 10 years
- productivity (using fast-growing species) 20 m³/hectare/year
- interest rate 15%
- heating value (air-dry) wood of 11.6 GJ/m³ (1 m³ of wood is assumed
to have a mass of 725 kg, see appendix B)
The production costs (10 years after establishment, but expressed in present value) will be:

- plantation wood: \( K \ 105/m^3 \) \(- 5200 \ (1.15)^{10}/(20\cdot10)\)
  or \( K 0.145/kg \) or \( K 9.07/GJ \)

- village forestry: \( K 26.3/m^3 \) or \( K 0.0363/kg \) or \( K 2.27/GJ \).

We assume that the market for plantation wood is the near-by urban areas and that the transport and retail margin per kg is about the same as charcoal, \( K 0.25/kg \). This brings the retail price of plantation wood at \( K 0.395/kg \) or \( K 24.69/GJ \). The range in plantation investment costs of \( K 2100 - K 10,700/hectare \), mentioned in AKK 89 (part D.1.1) corresponds with a range in plantation wood prices of \( K 10.00 - K 50.80/GJ \). We assume that village forestry wood is consumed at the spot by rural households themselves. Thus village forestry wood costs \( K 2.27/GJ \)

If sold at the present stumpage fee of \( K 12.50/m^3 \) (with a transport and retail margin of \( K 0.25/kg \)) then price of wood would be \( K 16.70/GJ \).

### E.2.3 Charcoal production

In this paragraph cost calculations are made for charcoal produced from free wood, stumpage fee wood, village forestry and plantation wood. We will calculate retail prices for charcoal produced from such wood, by using traditional production methods and improved methods. The Department of Energy has conservatively estimated that charcoal produced from plantation wood would cost about \( K 35/GJ \). The 1987 charcoal retail price in urban areas is about \( K 22.00/40 \) kg bag \((K 0.55/kg \) or \( K 16/GJ \)). The 1987 price paid to the producer is about \( K 7 \) per 40 kg bag (source data: own observations, tables C.10, C.11, C.12).

#### Traditional production methods

The following assumptions are made here:

Energy conversion efficiency of 16\%; heating value of air-dry wood 16.0 MJ/kg. This implicates that for the production of 1 GJ of charcoal, 391 kg of wood is necessary.

**Case a**

Plantation wood is used; costs \( K 0.145/kg \) (see above).

Costs wood: \( K 56.70/GJ \) charcoal produced = \( K 65.80/40 \) kg bag of charcoal

Producer margin: \( K 6.70/bag \)

Transport and retail margin: \( K 10.20/bag \)

TOTAL costs: \( K 82.70/bag \) (or \( K 71.30/GJ \))

**Case b**

Village forestry wood is used; costs \( K 0.0363/kg \) (see above)

Costs wood: \( K 14.20/GJ \) charcoal produced = \( K 16.50/40 \) kg bag of charcoal

Producer margin: \( K 6.70/bag \)

Transport & retail margin: \( K 10.20/bag \)

TOTAL costs: \( K 33.40/bag \) (or \( K 28.80/GJ \)).
Case c
A stumpage fee of K 12.50/m³ wood has to be paid, as proposed by a World Bank mission (see paragraph 4.3.1).
Costs wood: K 9.42/GJ charcoal produced = K 10.95/40 kg bag of charcoal.
Producer, transport and retail margin: K 16.90/bag.
TOTAL costs: K 27.85/bag (or K 24.00/GJ).

Oil drum kilns

As an example of a improved process, production of charcoal by one labourer, using oil drum kilns is elaborated. In table E.4 cost

<table>
<thead>
<tr>
<th></th>
<th>Free wood</th>
<th>Stumpage fee</th>
<th>Village forestry</th>
<th>Plantation wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs (annually):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 16 kilns</td>
<td>K 3900</td>
<td>K 3900</td>
<td>K 3900</td>
<td>K 3900</td>
</tr>
<tr>
<td>- tools</td>
<td>K 1170</td>
<td>K 1170</td>
<td>K 1170</td>
<td>K 1170</td>
</tr>
<tr>
<td>- total annual capital cost</td>
<td>K 5070</td>
<td>K 5070</td>
<td>K 5070</td>
<td>K 5070</td>
</tr>
<tr>
<td>- Operation/maintenance costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- tools (snips, chisels)</td>
<td>K 580</td>
<td>K 580</td>
<td>K 580</td>
<td>K 580</td>
</tr>
<tr>
<td>- cost wood</td>
<td>--</td>
<td>K 4369</td>
<td>K 6574</td>
<td>K 26245</td>
</tr>
<tr>
<td>- total op/maint costs</td>
<td>K 580</td>
<td>K 4949</td>
<td>K 7154</td>
<td>K 26825</td>
</tr>
<tr>
<td>Production costs/year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- production costs/40 kg sack</td>
<td>K 7.53</td>
<td>K 13.36</td>
<td>K 16.30</td>
<td>K 42.53</td>
</tr>
<tr>
<td>- producer margin/40 kg sack</td>
<td>K 6.70</td>
<td>K 6.70</td>
<td>K 6.70</td>
<td>K 6.70</td>
</tr>
<tr>
<td>- transport+retail costs/40 kg sack</td>
<td>K 10.20</td>
<td>K 10.20</td>
<td>K 10.20</td>
<td>K 10.20</td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>per year</td>
<td>K 24.40</td>
<td>K 30.26</td>
<td>K 34.20</td>
<td>K 59.43</td>
</tr>
<tr>
<td>per 40 kg sack</td>
<td>K 18300</td>
<td>K 22700</td>
<td>K 24900</td>
<td>K 44570</td>
</tr>
<tr>
<td>per 6J</td>
<td>K 21.03</td>
<td>K 26.09</td>
<td>K 26.62</td>
<td>K 51.23</td>
</tr>
</tbody>
</table>

TABLE E.4 Average annual production costs calculation for oil drum charcoal kilns. Capital and operational costs are adapted from GOW 85, table 5.3. Transport costs and retail margin are based on data provided by Dept. of Energy.

Basic assumptions:
- 10 drums of 200 litres are used, with a life-time of 6 months
- one labourer can manage 10 drums
- cycle-time is 1 week (5 days), annual production in 50 weeks
- charcoal production is 12 kg per day per drum
- energy conversion efficiency is 30%
- energy content of charcoal: 29.0 GJ/tonne (5% moisture)
Above assumptions implicate that (at the annual charcoal production of 30 tonnes) the annual wood requirements are 181 tonnes.

Base data:
- stumpage fee wood K 17.50/cubic metre
- cost village forestry wood K 0.0363/kg
- cost plantation wood K 0.145/kg
calculations of this charcoal production method are given. We see in table E.4 that production costs range from K 7.53 to K 42.53 per 40 kg bag, depending on the costs of wood used. Compared with the 1987 production price (which is K 7.0/40 kg bag) this means that this relatively simple technology is competitive economically (if 'free' wood is used as raw material) vis-a-vis present charcoal producer prices. The advantage, as compared with the traditional method using free wood, from an environmental point-of-view is the higher efficiency of the oil drum method. Using wood from projects will become viable only if present charcoal prices rise.

Charcoal retort

Assumptions (based on the proposed project of the Forest Department of 2 steel retort, see AKK 89, part D.1.1):
- Investment costs: K 76,000,000.
- Annual production: 30,000 tonnes of charcoal.
- Lifetime of the project: 15 years.
- Operation/maintenance costs: 10% of initial investment costs.
- As raw material plantation wood is used. It is assumed that 1000 kg of wood yields 347 kg of charcoal (ENE 76, p.41, fig.2.33). So, annual wood consumption is 85,455 tonnes. Production price plantation wood is K 0.145/kg.

Annual capital cost (yearly equal instalments, n=15, i=15%):
- K 12,142,000
- Operation/maintenance: K 7,600,000
- Costs wood: K 12,536,000
- TOTAL costs: K 32,098,000

Gross cost per unit production of charcoal would be K 1.07/kg. Assuming again a retail margin of K 0.42/kg, this would mean a price of K 1.49/kg (or K 51.38/GJ). The annual profits of selling by-products as woodgas, tar and acids have to be subtracted from the total costs, however, leading to a lower price of the charcoal. The viability of a charcoal retort would clearly depend on the market for by-products!

---

**FIGURE E.2 Flow-chart of carbonization products.** Source: ENE 76, p.41, fig.2.33.
Appendix E

---

### Production costs wood

<table>
<thead>
<tr>
<th></th>
<th>Price per unit of weight (K/kg)</th>
<th>Price per unit of energy (K/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantation wood</td>
<td>0.145 (0.0586-0.298)</td>
<td>9.06 (1.78-18.63)</td>
</tr>
<tr>
<td>Village forestry</td>
<td>0.0363 (0.197-0.213)</td>
<td>2.27 (1.23-15.51)</td>
</tr>
</tbody>
</table>

### Retail prices on the urban market

| Plantation wood     | 0.395 (0.309-0.550)            | 24.69 (19.31-34.38)            |

---

### Charcoal retail costs on the urban market (in K/GJ)

<table>
<thead>
<tr>
<th>Method</th>
<th>Price (K/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional methods</td>
<td>15.50</td>
</tr>
<tr>
<td>Oil-drum method</td>
<td>21.03</td>
</tr>
<tr>
<td>Retort</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table E.5

Summary of results of woodfuel cost calculations, presented in this chapter.

**ABOVE:** production costs and retail prices of forestry schemes wood.

**BELOW:** casts of charcoal on the urban market, produced by various methods, from forest wood ("free" or with stumpage fee wood) or forestry schemes wood (village forestry or large-scale plantations). The higher the share of wood costs in the total costs, the more feasible become improved charcoal production techniques.

In table E.5 a summary is presented of the calculations in this chapter: cost prices of woodfuels per unit energy. For a proper comparison one also has to take the end-use efficiency into account of the device used (e.g. a wood or charcoal stove), i.e. one has to compare the costs per unit of useful energy. Such comparisons are presented in table 5.7.

---

### E.2.4 Gasification of biomass

This section deals with estimating costs of shaft-power application of gasifier technology, based on data given in FOL 83. The applications considered here are 1) electricity generation, 2) waterpumping.

We will consider two cases in the cost calculations presented here:

- **Case 1:** indigenous repair and maintenance is available;
- **Case 2:** all spare parts and know-how has to be imported, which makes the technology more expensive than in the first case.

In both cases it is assumed that all gasifiers are imported. On the longer term manufacture of low-cost gasifiers in Zambia itself could be possible by a well-established light engineering industry. Examples are Brazil and the Philippines were systems are available commercially of about US$ 60-120/kW (about K 720-1440/kW).

Fuel supply should be guaranteed, but without placing a burden on available wood resources. It is assumed therefore that only wood produced in village forestry schemes (at the cost rate given in table E.5) is used as fuel for the shaft-power gasifier.
### Basis for cost comparison

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>K 101,520</td>
<td>K 25,380</td>
</tr>
<tr>
<td>Gasifier</td>
<td>K 42,250</td>
<td>K 41,250</td>
</tr>
<tr>
<td>Generator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhaul generator (10% of inv. cost)</td>
<td>K 6,500</td>
<td>K 6,500</td>
</tr>
<tr>
<td>Annual financing cost (i=15%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasifier (n=6)</td>
<td>K 26,825</td>
<td>K 6,706</td>
</tr>
<tr>
<td>Generator</td>
<td>K 12,306</td>
<td>K 12,306</td>
</tr>
<tr>
<td>Overhaul (5000 hours, every 1.7 year)</td>
<td>K 6,028</td>
<td>K 6,028</td>
</tr>
<tr>
<td>Maintenance gasifier (10% of invest. cost)</td>
<td>K 10,152</td>
<td>K 2,538</td>
</tr>
<tr>
<td>Maintenance generator (5% of inv. cost)</td>
<td>K 2,113</td>
<td>K 2,113</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 57,424</td>
<td>K 29,691</td>
</tr>
<tr>
<td>Fuel cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual cost wood</td>
<td>K 1,039</td>
<td>K 1,039</td>
</tr>
<tr>
<td>Annual cost diesel</td>
<td>K 2,850</td>
<td>K 2,850</td>
</tr>
<tr>
<td>Annual cost lubricant (oil)</td>
<td>K 174</td>
<td>K 174</td>
</tr>
<tr>
<td>Cost of generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total annual cost</td>
<td>K 61,487</td>
<td>K 33,754</td>
</tr>
<tr>
<td>Unit cost of generation</td>
<td>K 3.03/kWh</td>
<td>K 1.65/kWh</td>
</tr>
</tbody>
</table>

TABLE E.6 Cost estimate of electricity generation by a dual-fuel generator, using woodgas as source of energy, for two cases. Case 1: indigenous repair and maintenance available. Case 2: all spare parts and know-how has to be imported. Prices are based on cases described in FOL 83.

Base data: capacity generator 7 kW. Efficiency of generator 77%. Cost of gasifier are K 11,280/kW (case 1, kW as delivered by generator), and K 2820/kW (case 2). Daily operating period: 8 hours/day.

Gasifier: wood consumption: 1.4 kg/kWh (corresponding with gasifier efficiency 55%. Price of wood: K 0.0363/kg (assuming village forestry, see table E.5)

Dual-fuel generator: diesel consumption of 0.08 litre/kWh (at K 1.743/litre). Oil consumption 0.0075% of diesel consumption (at K 14.16/litre). Consumption data based on the cases in FOL 83; diesel price: see table C.8/9; oil price: "Consumer Price Statistics", CSO, Lusaka, 1987. It is assumed that a dual-fuel generator costs are the same as of a comparable diesel generator (see table E.14).

Table E.6 gives a cost analysis of electricity generation by a 7 kW dual-fuel generator, using diesel and woodgas as fuels. Electricity generation capacity is 56 kWh/day, assuming a daily operating period of 8 hours/day, which means 20,440 kWh/year.

The case of a dual-fuel engine, run on woodgas and diesel is studied in section E.2.8.

### E.2.5 Biogas

A biogas digester energy assessment requires several estimates:
a) the capacity of the digestor needed to match end-use demand,
b) the available feedstock,
c) the digestor's conversion efficiency.
In our case feedstock supply is the critical factor. So, calculations are made from feedstock supply requirements to end-use demand.

In calculating available feedstock we assume that it consists of:
- excreta of livestock and humans,
- residues of maize and cotton.

When discussing energy demand for waterpumping we considered two cases. We will do the same here:

**Case A:** a farm household with 15 cattle, 4 pigs, cultivating 1.3 ha of maize (with an annual production of 17.5 90 kg bags per ha) and 0.6 ha of cotton (with a production of 470 kg/ha/year).

**Case B:** a farm household with 25 cattle, 8 pigs, cultivating 5.6 ha of maize (with an annual production of 27.5 90 kg bags per ha) and 2.3 ha of cotton (with a production of 700 kg/ha/year). These figures have been chosen in accordance with the characteristics of an average peasant and an emergent household in Magoye area.

For both cases production data for biogas digested from dung and human excreta are presented in table E.7. Table E.8 does the same for the potential biogas production from residues. I have assumed hereby that residues, collected after harvesting the crops, are, stored in bins, available throughout the year with collection and storage losses of 20%.

The volume of gas produced is found by multiplying the annual feedstock volumes by a gross efficiency factor (assumed to be 80%).

The daily usable gas production is then:

<table>
<thead>
<tr>
<th>Gas production (in m³/day)</th>
<th>Usable gas (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Dung</td>
</tr>
<tr>
<td>Case A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.21</td>
</tr>
<tr>
<td>Case B</td>
<td>15.39</td>
</tr>
</tbody>
</table>

After calculating feedstock supply we will estimate the demand for biogas and examine if supply and demand can be matched. We assume that biogas is used directly for cooking and lighting, for refrigeration and in a dual-fuel engine to drive a waterpump.

The **daily domestic biogas needs** of a household are:

a) **Cooking.** Assuming a heating value of biogas of 22.5 MJ/m³, an efficiency of the biogas stove of 55%, to fulfill the demand of 28.5 MJ would require 2.30 m³ of biogas.

b) **Lighting.** See paragraph E.1.1: required biogas volume: 2.40 m³/day.

c) **Refrigeration.** See paragraph E.1.1: required biogas volume: 2.4 m³/day.

The total biogas demand is 7.10 m³/day.

In table D.4 we gave biogas production figures for dung produced from various livestock. The biogas (3.64 m³) produced from the dung of 6 cows can supply the energy needed for cooking and water heating by a household, assuming a gas production of 0.65 m³ per cow per day. To supply the energy required for refrigeration and biogas mantle lighting 3.4 m³ gas is needed, which can be produced from the dung of 5 cows.
According to table D.5 to generate 1 kWh electricity with a biogas/diesel mixture requires 0.75 m$^3$ of biogas and 0.066 litre of diesel (with an efficiency of 23%). We see that lighting by electricity (960 Wh/day, equivalent to 0.67 m$^3$) is much more efficient than gas lighting (2.40 m$^3$ required). In the case of cooking on biogas-generated electricity the daily volume of biogas needed is 13.39 m$^3$ (assuming a cooking efficiency of 70%). To provide the domestic tasks cooking, lighting and refrigeration by biogas-generated electricity, 14.86 m$^3$ of biogas and 1.30 of diesel would be needed per day. An advantage of using

<table>
<thead>
<tr>
<th>Case A</th>
<th>Biogas potential (m$^3$/day)</th>
<th>Dung collectible</th>
<th>Available dung (kg/day)</th>
<th>Biogas production (m$^3$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 cattle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 cows</td>
<td>17.55</td>
<td>1/3</td>
<td>30</td>
<td>5.85</td>
</tr>
<tr>
<td>3 oxen</td>
<td>5.85</td>
<td>1/3</td>
<td>10</td>
<td>1.95</td>
</tr>
<tr>
<td>1 heifer</td>
<td>0.82</td>
<td>1/3</td>
<td>1.8</td>
<td>0.27</td>
</tr>
<tr>
<td>2 calves</td>
<td>1.14</td>
<td>1/3</td>
<td>2.1</td>
<td>0.36</td>
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<tr>
<td>4 pigs</td>
<td>0.56</td>
<td>0.9</td>
<td>14.4</td>
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<tr>
<td>8 humans</td>
<td>0.26</td>
<td>0.9</td>
<td>2.2</td>
<td>0.23</td>
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<td>TOTAL</td>
<td>60.5</td>
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<td>9.18</td>
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</table>

<table>
<thead>
<tr>
<th>Case B</th>
<th>Biogas potential (m$^3$/day)</th>
<th>Dung collectible</th>
<th>Available dung (kg/day)</th>
<th>Biogas production (m$^3$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 cattle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 cows</td>
<td>29.25</td>
<td>1/3</td>
<td>50</td>
<td>9.75</td>
</tr>
<tr>
<td>5 oxen</td>
<td>9.75</td>
<td>1/3</td>
<td>16.7</td>
<td>3.25</td>
</tr>
<tr>
<td>2 heifers</td>
<td>1.64</td>
<td>1/3</td>
<td>3.6</td>
<td>0.55</td>
</tr>
<tr>
<td>3 calves</td>
<td>1.71</td>
<td>1/3</td>
<td>3.1</td>
<td>0.57</td>
</tr>
<tr>
<td>8 pigs</td>
<td>1.12</td>
<td>0.9</td>
<td>28.8</td>
<td>1.01</td>
</tr>
<tr>
<td>8 humans</td>
<td>0.26</td>
<td>0.9</td>
<td>2.2</td>
<td>0.23</td>
</tr>
<tr>
<td>TOTAL</td>
<td>104.4</td>
<td></td>
<td></td>
<td>16.26</td>
</tr>
</tbody>
</table>

TABLE E.7 Biogas and dung production.
Data on biogas production are derived from table D.7; cow and ox 1.95 m$^3$/day, heifer 0.82 m$^3$/day, calf 0.57 m$^3$/day, pig 0.14 m$^3$/day, family members: assumed total 0.255 m$^3$/day.
Data on dung production derived from GOW 85, Appendix E: cow and oxen 10 kg dung/day, heifer 5.4 kg/day, calf 3.7 kg/day, pig 4 kg/day and human excreta (incl. urine, for adults) 0.40 kg/day. It is assumed that cattle are roaming freely during the day. Therefore only dung produced when cattle are kept in the kraals at night can be collected.

<table>
<thead>
<tr>
<th>Residue production (kg/kg crop)</th>
<th>Total residue production (kg/year)</th>
<th>Gas production per day (in m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>Case B</td>
<td>Case A</td>
</tr>
<tr>
<td>Maize</td>
<td>1.8</td>
<td>368</td>
</tr>
<tr>
<td>Cotton</td>
<td>4.2</td>
<td>1184</td>
</tr>
</tbody>
</table>

TABLE E.8 Daily gas production from residues, available in the cases A and B. It is assumed that a) 1 kg of residue yields 0.16 m$^3$ of biogas and b) of the total residue production there is 20% loss in collection and storage of residues. Residue production data are based on table D.1.
biogas-generated electricity is that such engines can also run on diesel alone in times of lacking biogas supply. Disadvantages are (except in the case of lighting) that the overall energy rendement is lower as compared with direct application is higher, and that investment costs are higher (wiring, dual-fuel generator).

The mechanical power of 1 kW delivered by a dual-fuel engine requires 0.68 m$^3$ of biogas per hour (which could be supplied from the dung of one cow, equivalent to 12.9 MJ/kWh(engine)) and 0.06 litre of diesel (equivalent to 2.1 MJ/kWh(engine)). Here it is implicitly supposed that the efficiency of the engine is 24%.

In table E.1 we gave the daily power required by a waterpump to lift water. We assume that a dual-fuel engine is used to drive the pump (which has a pump efficiency of 15%, national pump, used for drinking water; or 30%, large pump used for irrigation). The biogas and diesel volumes $V$ needed to fulfill the energy required by a waterpump follows from:

$$V = 2.27 \cdot E_{\text{water}} \text{ (biogas, in m}^3\text{)},$$

$$V = 0.2 \cdot E_{\text{water}} \text{ (diesel, in litre)}.$$

Table E.9 gives a review of the thus calculated biogas requirements. In estimating biogas needs for waterpumping I have also taken into account that the biogas plant needs water itself. The solid material must be mixed with at least the same volume of water to guarantee a free-flowing liquid or else blockages will occur. If diluted too much gas production will be reduced. Assuming mixing ratios of dung : water = 1 kg : 1 litre and green refuse : water = 2 : 1, we can thus calculate that total water demand is 77 litre (case A), resp. 276 litre (case B) a day, which has to be pumped up also. So total domestic water demand (drinking water, vegetable garden, digester) is:

Case A: 1.497 m$^3$,
Case B: 2.096 m$^3$.

Conclusively, we see that a 10 m$^3$ plant can match the supply (in case A, a peasant farm household) and energy demand for the purposes cooking, lighting, refrigeration, waterpumping for drinking water provision and garden watering. In case A the supply limit of about 9 m$^3$

<table>
<thead>
<tr>
<th>Domestic requirements per household:</th>
<th>cooking, lighting, refrigeration: 7.1 m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>- lighting, refrigeration:</td>
<td>4.8 m$^3$</td>
</tr>
</tbody>
</table>

Waterpumping for domestic purposes (drinking water, garden watering, digester, table E.19) per household:

<table>
<thead>
<tr>
<th>table E.19</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Required biogas volume (m$^3$/day)</th>
<th>0.34</th>
<th>0.48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required diesel volume (litre/day)</td>
<td>0.030</td>
<td>0.066</td>
</tr>
</tbody>
</table>

Waterpumping for irrigation purposes (elevation 30 m, 25 hectare, see table E.21)) for the critical month August:

<table>
<thead>
<tr>
<th>Required biogas volume (m$^3$/day)</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required diesel volume (litre/day)</td>
<td>13.8</td>
</tr>
</tbody>
</table>

| TABLE E.9 Waterpumping by using a dual-fuel engine: daily biogas and diesel requirements. Biogas and diesel consumption rates per kW per hour of a dual-fuel engine are given in the text. Assumed pump efficiency 30%. |
|-------------------------------|-------------------|
|                             |                  |
|                             |                  |
### Basis for cost comparison

<table>
<thead>
<tr>
<th>BIOGAS PLANT (10 m³)</th>
<th>BIOGAS PLANTS (65 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic energy supply</td>
<td>Irrigation plot of 25 ha</td>
</tr>
<tr>
<td>1 plant of 10 m³ required</td>
<td>2 plants of 60 m³ required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Domestic Plant</th>
<th>Irrigation Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost</td>
<td>€ 19,000</td>
<td>€ 142,800</td>
</tr>
<tr>
<td>Annual financing cost (n=20, i=15%)</td>
<td>€ 3,036</td>
<td>€ 22,820</td>
</tr>
<tr>
<td>Operation costs (5% of initial investm.)</td>
<td>€ 950</td>
<td>€ 7,140</td>
</tr>
<tr>
<td>TOTAL annual costs</td>
<td>€ 3,986</td>
<td>€ 29,980</td>
</tr>
</tbody>
</table>

| Annual capacity of biogas plant | 3650 m³ |
| Annual consumption of biogas   | plant is sized such that demand 'equals' supply 28,400 m³ (if biogas is only used for irrigation, 24800 m³, and domestic purposes 3600 m³) |

| Cost per unit capacity         | € 1.09/m³ |
| Cost per unit of consumption (irrigation, domestic) | € 0.631/m³ |

<table>
<thead>
<tr>
<th>BIOGAS PLANT (67 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 plants of 67 m³ used for generation of electricity (for driving an electric pump for irrigation of the plot of 25 ha). Generator: 11.2 kV, peak demand: 179 kWh/day (August);</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Domestic Plant</th>
<th>Irrigation Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost plant</td>
<td>€ 146,600</td>
<td>€ 189,000</td>
</tr>
<tr>
<td>Annual financing cost</td>
<td>€ 23,420</td>
<td>€ 32,100</td>
</tr>
<tr>
<td>Operation costs</td>
<td>€ 7,330</td>
<td>€ 9,240</td>
</tr>
<tr>
<td>TOTAL annual costs</td>
<td>€ 30,750</td>
<td>€ 41,590</td>
</tr>
</tbody>
</table>

| Unit cost of capacity (annual 48,910 m³) | € 0.629/m³ |
| Unit cost of consumption (annual 30,160 m³) | € 1.02/m³ |
| (it is assumed that the biogas is used for irrigation, annual 25550 m³; and for domestic purposes, estimated annual consumption of 3600 m³) |

| Investment cost dual-fuel generator | € 52,700 |
| overhauls                           | € 17,570 |
| Annual financing cost (i=15%):    |         |
| generator (n=5 years)              | € 12,760 |
| overhauls (every 1.7 yrs)          | € 12,460 |
| Maintenance costs (7% initial investm.) | € 3,690 |
| TOTAL                               | € 28,910 |

| Annual biogas costs                | € 30,750 |
| Annual diesel & lubricant cost     | € 3,710  |
| TOTAL COSTS                         | € 63,370 |

| Unit cost of generation (3054 hours) | € 1.69/kWh |

### TABLE E.10 Cost estimates of biogas plants

a) used for domestic biogas supply (10 m³).

b) two 65 m³ plants used for irrigation of the example of a plot of 25 ha with a pump driven by dual-fuel engine (see table E.21), and domestic biogas supply (direct use of gas, 10 m³/day).

c) two 67 m³ plants used for irrigation of the same plot by an electric pump driven by biogas-generated electricity (see table E.20) for pump specifications) and domestic energy supply.

Data (prices, fuel consumption) based on: table D.6, table E.15 (assuming that a dual-fuel generator can be sold at the same price as a comparable diesel generator).
of biogas excludes field irrigation. In case B (emergent farmer) the supply limit is about 22 m³ and of this about 16 m³ could be used for field irrigation. The farmer could thus partly irrigate the field, depending on area under cultivation and elevation of the water.

Table E.10 gives a review of cost estimates of:
- a 10 m³ plant, supplying gas for domestic purposes (cooking, lighting, refrigeration).
- two 65 m³ plants, supplying gas for irrigation of the plot of 25 ha. (pump driven by a dual-fuel engine).
- two 67 m³ plants, supplying gas to a generator, which provides electricity for irrigation of the plot of 25 ha and domestic purposes.

### E.2.6 Solar power

**Photovoltaics**

In this paragraph the economics of photovoltaics will be examined. Generally one can say that applications which require constant high energy levels are usually costly. The variation in radiation makes additional storage and control units necessary. Lowest cost applications are those that have intermittent loads, preferably during the day (such as drinking water/garden watering with electric pump, described in table E.10).

**Base data**

<table>
<thead>
<tr>
<th>Peak daily load</th>
<th>7.5 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of solar panels (75 W panel at 16820)</td>
<td>18.5</td>
</tr>
<tr>
<td>Total capacity panels</td>
<td>3164 kWh</td>
</tr>
<tr>
<td>Total electricity consumption for waterpumping</td>
<td>2737.5 kWh</td>
</tr>
</tbody>
</table>

**Costs**

| Equipment cost (in 1987 Kwacha) | 126,170 |
| Annual financing cost (in Kwacha; i=15%, n=20) | 20,160 |
| Unit cost of capacity (Kwacha/kWh) | 6.37 |
| Unit cost of consumption (Kwacha/kWh) | 7.36 |

---

**IRRIGATION (plots of 25 ha, 30 m elevation, pump: see table E.20)**

**Base data**

| Peak daily load (August) | 224 kWh |
| Number of solar panels (75 W panel at 16820) | 464 |
| Total capacity panels | 79344 kWh |
| Total electricity consumption for irrigation | 342000 kWh |

**Costs**

| Equipment cost (in 1987 Kwacha) | 3,164,480 |
| Annual financing cost (in Kwacha, i=15%, n=20) | 505,680 |
| Unit cost of capacity (Kwacha/kWh) | 6.37 |
| Unit cost of consumption (Kwacha/kWh only use irrigation) | 1.479 |

**TABLE E.11** Costs of solar panels in waterpumping applications. It is assumed that the solar system provides energy to the waterpumps, with the specifications as given in table E.18 and E.20. Prices of solar panels are determined using the following base data: 6 W panel: 1900, 20 W: 6290, 50 W: 5810, 75 W: 6820. Financing costs are derived, assuming annual equal instalments, with a period of 20 years and interest rate of 15%.
Basis for cost comparison

as pumping drinking water).

Photovoltaic systems consists of 3 basic elements:
- the collector: a (system of interconnected) panel(s), (each) consisting of, often 36, individual solar cells;
- the control unit, necessary to adjust the solar panel’s output to meet the load requirements. In AC applications an inverter is necessary.
- a storage unit. In the case of a waterpumping unit the storage may be water tank, in other cases may be a battery unit.

PV systems as irrigation pumps do not require a control unit or storage, but deliver the energy just as it is received from the sun. A battery storage system must be designed to handle the stress of continual cycling between charge and partial discharge without damage. Attempts to draw more power than capacity permits, results in battery damage, damage of the control unit and/or customer dissatisfaction. Deep-discharge batteries, specifically for PV-service, are available. Although costs are more than automobile batteries, their life is much longer.

Calculations are based on meteorological data presented in Appendix F.4. Table E.12 gives data on average daily insolation and number of sunshine hours per day for Kafue Flats area (near Magoye). Using these data the necessary size and storage needs of the system for the proposed applications can be assessed.

The number of modules $N$ follows from:

$\text{(E.6)} \quad N = \frac{L}{d \cdot W \cdot \frac{R_{P}}{R_{S}}} \quad \text{with:}

- L: daily load of the system (in Wh/day),
- d: daily hours of sunshine,
- $W_{P}$: standard module peak wattage (in Watt),
- $R$: daily solar insolation (in W/m²)
- $R_{S}$: standard radiance, as specified by manufacturer of the module (here: 1000 W/m²)

If the number of storage days (i.e. maximum number of days without bright sunshine) $D$ is known, the battery storage requirement $D$ can be determined by:

$\text{(E.7)} \quad D = \frac{L \cdot D}{\eta} \quad \text{with:}

- L: daily load of the system (Wh/day)
- $\eta$: efficiency battery.

In this paragraph the economics of the following applications will be studied:

a) **Lighting.**

Photovoltaic lighting units for houses have become relatively standard units, typically consisting of (GOW 85, p.158; BP Zambia Ltd.):
- a 40 W panel,
- a battery (capacity of 55-95 Ah).

BP Zambia Ltd. sells 40 W-lanterns (providing 4 hours light) for about K 1900 (converted from 1988 price of K 4000, by using an inflation rate mid 1987 - mid 88 for goods of fixed capital formation of 110%, see appendix A). To generate the 960 Wh/day that our household consumes, 6
of such units would be required. Assuming a lifetime of 10 years, and an interest rate of 15% the total annual financing cost are K 379. At an annual consumption rate of 350 kWh/year, costs per unit energy delivered are K 6.48/kWh.

Besides solar lanterns, other standard units are plug-in lighting kits, which also have plugs for operating small electrical appliances and a battery charger for "C" and "D" cells (used in portable lights). Such units (with 30-45 W fluorescent tubes) cost about K 3970-4470 (again 1987 prices converted from figures given in table D.8).

b) **Power generation for domestic tasks** (cooking, lighting, refrigeration).

Base data are (see paragraph E.1.1):
- Daily load of the system:
  - cooking (at 70% efficiency) 11.31 kWh
  - lighting 0.96 kWh
  - refrigeration 2.10 kWh
  TOTAL 14.37 kWh

The number of panels needed follows from equation (6.6). The system should be sized in such way that even in the critical month June (when radiation is lowest) enough electricity can be provided. It is assumed further that the storage system adds an additional 15% load on the system.

We can calculate that the number of panels required (at daily load: 16.53 kWh) is 61 (number of panels is 16,530/(9.1·50·595.6/1000), assuming 50 W panels are used), forming an array of 8 m² (at an area of 0.13 m²/50 W panel). Battery requirements are (assuming D = 2 days and a battery efficiency of 80%) 41.2 kWh. Assumed type of battery: type 2P110 sold by BP Zambia Ltd. (2.2 kWh). So, 19 batteries are needed.

**Equipment cost:**
- solar panels (50 W peak at K 5810 per panel) K 354,400
- battery system (K 3300 per battery, type 2P110) K 62,700
- control unit K 4,760

**Financing cost:**
- solar panels (at 15% for 20 years) K 56,630
- battery system (at 15% for 8 years) K 3,980
- control unit (at 15% for 20 years) K 760
- TOTAL K 71,370

**Unit cost:**
- Annual capacity of the system (annual capacity per panel P follows from: P = W · Σ(R · d · n m m)/R s, with
  - W = 50 W, R: radiation (in kWh/day) in month m,
  - n m: number of days in month m, d m: daily sunshine hours in month m and R s: standard radiance of solar panel. P = 114.1 kWh, for 50 W panels) 6930 kWh/yr
- Unit cost of capacity K 10.31/kWh
- Annual energy consumption 6030 kWh/yr
- Unit cost of consumption K 11.84/kWh
c) Waterpumping for provision of drinking water and irrigation.

The efficiency of a photovoltaic-powered waterpumping unit requires a special motor/pump combination. The PV unit provides DC, so usually a DC motor is used. AC can be provided by use of an inverter (at some efficiency loss).

Base data and cost analysis of solar-powered water supply (domestic and irrigation of the 25 hectare plot) are given in table E.11.

In calculating annual consumption and capacities the following relations are used:

- number of solar panels required (see formula E.6).
- domestic pumping, daily load \( L = 7.5 \text{ kWh/day} \) (see table E.18); critical month is June (\( d \cdot R = 5.42 \text{ kWh/m}^2/\text{day} \)).
- irrigation: daily load (peak water demand, August, see table E.20): \( L = 224 \text{ kWh/day} \); critical month solar energy, also August (\( d \cdot R = 6.34 \text{ kWh/m}^2/\text{day} \)). The critical month is determined by calculating, for each month, the number of panels required. The month that has the largest number is critical month.

- total annual capacity \( E_{\text{tot}} = N \cdot P \), with \( P = W_p \cdot \sum (d \cdot R_m) / R_s \), where the summation goes over \( m \): month, \( R_m \): radiation in month \( m \), \( d_m \): number of days in month \( m \), \( R_s \): standard radiation (see formula E.6). Annual capacity per panel \( P = 171 \text{ kWh} \) (for 75 W panels).

- total annual consumption: drinking water provision: see table E.18.
  irrigation: see table E.20

<table>
<thead>
<tr>
<th>Monthly mean windspeed (m/s)</th>
<th>January</th>
<th>Febr.</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Sept.</th>
<th>October</th>
<th>Nov.</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.39</td>
<td>1.29</td>
<td>1.59</td>
<td>1.95</td>
<td>2.47</td>
<td>2.52</td>
<td>2.74</td>
<td>2.85</td>
<td>3.39</td>
<td>3.14</td>
<td>1.06</td>
<td>2.93</td>
</tr>
</tbody>
</table>

**Table E.12** Meteorological base data: 1) monthly mean of hourly windspeeds (in metres/second). Data are adapted from Appendix E.1: PAA 81. appendix 1. p.18: tables in MET 74. \( T = 10.800 \text{ seconds (3 hours)} \); 2) average daily insolation: data based on appendix E.1.
In the case of power generation of domestic tasks differences between these two unit costs are not that big. This is due to a) careful matching of system capacity to the daily demand (which is constant throughout the year),
b) only small differences in solar radiation levels between months.
In the case of a solar pumpset for irrigation this difference is larger, due the fact that irrigation demand is only concentrated in a few months. In other months the capacity is not used (unless one would decide to use electricity for other purposes than irrigation). This is expressed by the unit cost of consumption in table E.11.

Solar thermodynamic pumping

As an example of cost calculation of a solar thermodynamic pump, the example is chosen of the Rankine pump SOFRETES, installed in Achada Sao Felipe at the Cape Verde Islands. The cost analysis is presented in table E.13.

Solar cookers

The following assumptions are made:
- daily cooking time is 4 hours, daily energy demand 4.58 kWh (exclusive water heating),
- cooker: effective power 570 W, costs K 6200, lifetime 10 years (data based on table D.10).
To meet the daily demand for cooking 2 solar cookers of the specified type are needed. total costs: K 12,400. Annual costs are then (i=15%, equal annual instalments): K 2470.

<table>
<thead>
<tr>
<th>Base data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector area:</td>
<td>65 m²</td>
</tr>
<tr>
<td>Efficiency pump set (including collectors, engine, pump):</td>
<td>0.5%</td>
</tr>
<tr>
<td>Energy deliverance in critical month June (insolation of 5.42 kWh/m²/day):</td>
<td>1.76 kWh/day</td>
</tr>
<tr>
<td>Annual energy capacity collectors:</td>
<td>742 kWh/year</td>
</tr>
<tr>
<td>Annual energy consumption pumping:</td>
<td>642 kWh/year</td>
</tr>
<tr>
<td>Daily water requirements per family:</td>
<td>1.68 m³/day</td>
</tr>
</tbody>
</table>
At 16 m elevation: 24 families served, annual water consumption: | 14720 m³ |
At 36 m elevation: 11 families served, annual water consumption: | 6745 m³ |

<table>
<thead>
<tr>
<th>Investment costs:</th>
<th>K 900,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual costs</td>
<td></td>
</tr>
<tr>
<td>Financing costs (n=15, i=15%)</td>
<td>K 153,920</td>
</tr>
<tr>
<td>Maintenance (3% of initial investment)</td>
<td>K 27,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 180,900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs/m³ delivered</td>
<td>K 12.30 (16 m)</td>
</tr>
<tr>
<td>Annual costs/family</td>
<td>K 7450</td>
</tr>
</tbody>
</table>

This section deals with the economics of the application of wind turbines for water pumping. Generation of electricity is not studied here, as generation systems require cut-in speeds of 2.5-3 m/s, too high for the Zambian wind regimes (see paragraph D.5).

A windmill should be sized in such way that the monthly available energy at least meets the monthly energy requirements. The windmill size (expressed by its rotor diameter D) can be calculated by formula (E.8) based on the daily wind distribution for each month:

\[ E = \frac{1}{2} \rho c_p \eta \frac{1}{4} \pi D^2 \cdot \sum (v^3 \Delta T) \]

with:
- \( \rho \): air density (1.29 kg/m³)
- \( c_p \): the efficiency with which the mill can extract power from the wind; here we assume a value of \( c_p = 0.22 \) (for water pumping; see section E.2.10 for technical details).
- \( \eta \): windmill transmission efficiency, \( \eta = 0.7 \) is assumed here.

The variable \( \sum (v^3 \Delta T) \) is the summation of the product of the cubed windspeed and the period \( \Delta T \) (3 hours), from the cut-in speed (1 m/s, assumed) to the rated speed (here assumed to be always higher than the maximum windspeed).

To meet monthly water requirements for irrigation at any time the windmill diameter should be set according to the windspeed distribution of the critical month, i.e. March. Which is the critical month is determined by a) energy potential of the wind distribution, b) energy requirements. March is critical: water requirements in April are higher, but windspeed distribution of March is more unfavourable.

To meet monthly drinking water requirements at any time the windmill should be sized according to the windspeed distribution of February, which is in this case the critical month, because it has the lowest windspeeds.

The above implicates the following values of \( \sum v^3 \Delta T \) are used in calculations in this chapter 0.38x10⁶ m³/s²

With this information it is easy to derive the following relations between the diameter \( D \) and the required daily energy \( E \) (with \( E \) expressed in kWh) from equation (E.8):

\[ D = \frac{15.58k}{E} \text{ (drinking water provision)} \]

In this paragraph we will estimate the unit costs of water delivered for domestic purposes by a water pumping unit. We assume an average daily water demand of 1.68 m³ per farm household (see table E.1). The water is lifted from a borehole (depth 10, 30 m respectively) and stored at 6 m height.
Appendix E

Elevation head,

| 16 m | 36 m |

**Base data:**

- Daily work of pump (table E.1) 0.1590 kWh
- Pump efficiency 50%
- Required diameter, see equation (E.9) 4.4 m

**Investment cost**

- windmill (estimated from table D.11) K 94,000
- pump (based on PAA 81) K 2,700
- accessoires (source: AW Tarry Ltd.) K 2,200
- borehole (based on PAA 81) K 11,060

**Annual financing cost** (i=15%)

- windmill (n=15) K 16,080
- pump + accessoires (n=7) K 1,180
- maintenance (5% inv.cost: mill, pump+acc.) K 4,950
- borehole (n=20) K 1,770
- storage (at K 236/m³ storage capacity, here tank of 3.7 m³ is assumed) K 880

**TOTAL** K 23,980

**Unit costs**

- annual capacity 3639 m³, 311 kWh
- annual consumption 613 m³, 58 kWh
- unit cost of capacity K 6.83/m³
- unit cost of energy capacity windmill K 51.7/kWh
- unit cost of consumption K 40.56/m³
- unit costs of energy consumption windmill K 277/kWh

The annual energy capacity of the windmill can be calculated from:

\[
(E.9) \quad E_{cp} = \frac{1}{8} \cdot 1.29 \cdot 0.22 \cdot 0.7 \cdot \pi \cdot D^2 \cdot \sum_{m} (\Sigma \nu \cdot \Delta T) \cdot d_m \quad \text{(in Joule)}
\]

compare with formula (6.8), here summation over each month \(m\), with \(d_m\): number of days in each month.

\[
\sum_{m} (\Sigma \nu \cdot \Delta T) \cdot d_m = 742.0 \times 10^6 \text{ m}^3/\text{s}
\]

\[
E_{cp} = 16.08 D^2 \quad \text{(in kWh, 1 kWh = 3.6x10^6 Joule)}
\]

Annual water deliverance capacity can then be calculated using equation (E.5), correcting for the pump efficiency of 50%.

The great differences between unit costs of capacity of the system and of consumption is due to the variance in windspeed between months.

**E.2.8 Diesel-generated electricity**

This section offers an economic assessment of diesel generators.

Table E.14 provides information on diesel engines and generators as sold by AFE Ltd., Lusaka, Zambia (some technical principles of diesel engines and generators are discussed in AKK 87, part D.7).

Table E.15 presents a cost analysis on electricity generations by 3 types of diesel plants. The TS1 generator could be used by a farm.
### Basis for cost comparison

<table>
<thead>
<tr>
<th>Type</th>
<th>Power (kW)</th>
<th>Fuel cons. (litre/hr)</th>
<th>1988 price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIESEL ENGINES</strong></td>
<td></td>
<td></td>
<td>K</td>
</tr>
<tr>
<td>TS1</td>
<td>4.5</td>
<td>1.3</td>
<td>26,000</td>
</tr>
<tr>
<td>TS2</td>
<td>9.0</td>
<td>2.5</td>
<td>40,000</td>
</tr>
<tr>
<td>TS3</td>
<td>13.5</td>
<td>3.8</td>
<td>60,000</td>
</tr>
<tr>
<td>HL3</td>
<td>26</td>
<td>7.5</td>
<td>85,000</td>
</tr>
<tr>
<td>HL4</td>
<td>33.5</td>
<td>9.5</td>
<td>115,000</td>
</tr>
<tr>
<td>HL6</td>
<td>51</td>
<td>14.1</td>
<td>130,000</td>
</tr>
<tr>
<td><strong>DIESEL GENERATORS</strong></td>
<td></td>
<td></td>
<td>K</td>
</tr>
<tr>
<td>TS1</td>
<td>3.5</td>
<td>1.3</td>
<td>45,000</td>
</tr>
<tr>
<td>TS2</td>
<td>7.0</td>
<td>2.5</td>
<td>66,000</td>
</tr>
<tr>
<td>TS3</td>
<td>12.5</td>
<td>3.8</td>
<td>90,000</td>
</tr>
<tr>
<td>HL3</td>
<td>25</td>
<td>7.5</td>
<td>140,000</td>
</tr>
<tr>
<td>HL4</td>
<td>30</td>
<td>9.5</td>
<td>166,000</td>
</tr>
<tr>
<td>HL6</td>
<td>50</td>
<td>14.1</td>
<td>205,000</td>
</tr>
</tbody>
</table>

**TABLE E.14** Techno-economic data on Lister-Petter diesel products

Source: AFE Ltd., Lusaka. Oil consumption is generally taken as 0.75% of fuel consumption.

<table>
<thead>
<tr>
<th>Capital cost</th>
<th>TS1</th>
<th>HL6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>K 28,130</td>
<td>K 128,200</td>
</tr>
<tr>
<td>Overhaul (at 10% investment cost)</td>
<td>K 5,630</td>
<td>K 25,640</td>
</tr>
</tbody>
</table>

Annual financing cost (1=15%):

| Generator (15,000 hrs. 5 years) | K 8,391 | K 54,350 |
| Overhaul (5000 hours, every 1.7 year) | K 4,465 | K 38,550 |
| Maintenance (at 5% of investment cost) | K 1,407 | K 6,410 |

**Fuel**

| Fuel consumption/year       | 3796 litres | 41,170 litres |
| Oil consumption/year        | 18.5 litres  | 309 litres   |
| Cost fuel (at K 1.743/litre, retail) | K 6,616 | K 71,760 |
| (at K 2.519/litre, econ.marg) | K 9,561 | K 103,708 |
| Cost oil (at K 14.16/litre)  | K 262      | K 4,375     |

**Cost of electricity**

| Total annual cost | K 31,140 | K 175,450 |
|                   | K 24,085 | K 207,398 |

**Total generated energy per year**

| 10,220 kWh | 146,000 kWh |

**Unit cost of generation (at retail prices)**

| 2.07/kWh | 1.20/kWh |
| 3.36/kWh | 1.42/kWh |

**Table E.15** Cost estimates of electricity generation by TS1 and HL6 diesel generators.

Engine cost are expressed in mid 1987 prices, converted from 1988 prices using an inflation rate of 60% (see appendix A). Financing cost are calculated using equal yearly instalments. Daily work period: 8 hours.

Source data: table E.14; diesel/oil price: same as table E.6.
family, say to provide electricity for cooking, lighting, refrigeration and drinking water provision/garden watering (at 4 hours/day: 20 kWh); or lighting, refrigeration and irrigation of a few hectares. The TS3 could be used to provide electricity for domestic appliances and irrigation of the example of a plot of 25 ha. The HL6 could be used to provide domestic energy to a village (say 20-30 families).

E.2.9 Cost and capacity calculations of waterpumping applications

Capacity calculations

The capacity of human and animal-powered pumping are estimated below. Background information on human and animal power deliverance is presented in appendix F.3.

I Human-powered pumping.
Useful power: 50 W, daily working period: 4 hours.
Efficiency handpump, 40%.
Daily water discharge (using formula E.5): 2.9 m³ (10 m head), or 0.96 m³ (30 m head).

II Animal-powered pumping (2 pairs of oxen).
Useful power: 1200 W, daily working period: 6 hours/day.
Efficiency pump and animal gear, 10%.
Daily water discharge: 26.5 m³ (10 m head), 8.8 m³ (30 m head).

<table>
<thead>
<tr>
<th>Base data</th>
<th>Elevation (m)</th>
<th>Deep well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily water demand per household: 1.68 m³</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Rate of discharge (cubic metres/hour)</td>
<td>2.92</td>
<td>0.972</td>
</tr>
<tr>
<td>Number of families provided</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Fixed costs (in 1987 Kwacha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump and accessoires</td>
<td>3517</td>
<td>3517</td>
</tr>
<tr>
<td>Borehole or casing of well</td>
<td>11060</td>
<td>24800</td>
</tr>
<tr>
<td>Annual financing costs (i=15%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump (lifetime n= 5 years)</td>
<td>1050</td>
<td>1050</td>
</tr>
<tr>
<td>Borehole (n=20)</td>
<td>1770</td>
<td>3960</td>
</tr>
<tr>
<td>Maintenance costs (7% of initial investment pump)</td>
<td>246</td>
<td>246</td>
</tr>
<tr>
<td>Unit cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total annual costs</td>
<td>3066</td>
<td>3256</td>
</tr>
<tr>
<td>Annual costs per household</td>
<td>341</td>
<td>1752</td>
</tr>
<tr>
<td>Costs per cubic meter water delivered</td>
<td>0.51</td>
<td>2.58</td>
</tr>
</tbody>
</table>

TABLE E.16 Cost analysis of water lifting using a handpump/borehole and a handpump/deep well combination. No storage of water is assumed. Data on handpumps provided by A.W.Tarry Ltd., converted from 1988 prices, using an inflation rate of 7%. Daily water demand per household: see table E.1.
Domestic water supply for a family (man-operated) or group of households (animal-powered) lies well within the above capacity ranges. In our example of irrigation of a plot of 25 ha, daily water demand in irrigation is estimated at 28 m³/hectare in the peak month August. Assuming a 10 m elevation, one person can irrigate about 0.1 hectare. Two pairs of oxen can irrigate about 1 hectare. Clearly, irrigation of large plots is only possible with engine-powered pumpsets.

**Cost estimates of water supply**

This section starts with estimating costs of alternative options in domestic waterpumping. The following options are studied:

Small-scale devices, providing water to a (few) household(s):
- a) handpump/cased deep well (see table E.16)
- b) handpump/borehole, (see table E.16)
- c) animal-powered pump (see table E.17)

Medium-scale devices, providing water to a village:
- d) electric pumpsets (see table E.18)
- e) dual-fuel and diesel pumpsets (see table E.19).

---

**Base data**

National pump D8 A.W. Tarry, powered by 2 pairs of oxen
(power deliverance oxen, 1200 W)
Assumed efficiency pumping and animal gear 10%
Daily water demand per family: 1.68 m³
Operating period: 6 hours per day
Rate of discharge per day: 16.6 m³ (16 m), 7.3 m³ (36 m)
Number of families provided: 10 (16 m), 4.3 (36 m)
Cattle are bought at K 6000, and sold after 6 years at K 4800.
Feeds: 2 kg supplementary feeds per animal for 365 days (at K 1.60 kg)
Dipping against diseases (K 32 per animal, see paragraph 5.3)

<table>
<thead>
<tr>
<th>Fixed costs</th>
<th>16 m</th>
<th>36 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump and accessories</td>
<td>K 7700</td>
<td>K 7700</td>
</tr>
<tr>
<td>Borehole</td>
<td>K 11060</td>
<td>K 24800</td>
</tr>
<tr>
<td>Two pairs of oxen</td>
<td>K 1200</td>
<td>K 1200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual costs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Financing costs pump (n=10, i=15%)</td>
<td>K 1534</td>
<td>K 1534</td>
</tr>
<tr>
<td>Financing costs borehole (n=10, i=15%)</td>
<td>K 1770</td>
<td>K 3960</td>
</tr>
<tr>
<td>Financing costs cattle</td>
<td>K 420</td>
<td>K 420</td>
</tr>
<tr>
<td>Maintenance costs (7% of initial investment)</td>
<td>K 539</td>
<td>K 539</td>
</tr>
<tr>
<td>Operating costs cattle (feeds, dipping)</td>
<td>K 4672</td>
<td>K 4672</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 8925</td>
<td>K 11125</td>
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</table>

<table>
<thead>
<tr>
<th>Annual costs per m³ delivered</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K 0.16</td>
<td>K 0.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual costs per family</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

---

**TABLE E.17** Cost estimates of animal-powered pumping for domestic water provision, for two elevation heads, 16 m and 36 m.
Cost analysis of pumping options in irrigation are presented next:
1) electric pumpsets (see table E.20)
2) dual-fuel and diesel pumpsets (see table E.21).

---

**Base data**

Submersible electric pump, 0.75 kW (Cora 1-21, 220 V)
Pump efficiency 40%, efficiency electromotor 80%
Operating period: 8 hours/day (electricity consumption of 7.5 kWh/day)
Lifetime pump set: about 20,000 hours (7 years)
Annual energy consumption: 2737.5 kWh
Rate of discharge: 16 m elevation, 6.90 m³/hour
36 m elevation, 3.07 m³/hour
Annual water deliverance: 16 m elevation, 20150 m³
36 m elevation, 8964 m³
Number of families served (assumed daily consumption of 1.68 m³ per family, table E.1):
16 m elevation, 33
36 m elevation, 15

<table>
<thead>
<tr>
<th>Fixed costs (1987 Kwacha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump (incl. electromotor)</td>
</tr>
<tr>
<td>Accessoires</td>
</tr>
<tr>
<td>Borehole</td>
</tr>
</tbody>
</table>

**Annual financing costs**

<table>
<thead>
<tr>
<th>Pump (incl. electromotor) and accessoires (n=7)</th>
<th>K 2945</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borehole (n=20)</td>
<td>K 1770 (10 m), K 3960 (30 m)</td>
</tr>
<tr>
<td>Maintenance pump set (7% of initial investment)</td>
<td>K 858</td>
</tr>
<tr>
<td>TOTAL</td>
<td>K 5573 (16 m), K 7763 (36 m)</td>
</tr>
</tbody>
</table>

**Annual energy costs**

<table>
<thead>
<tr>
<th>16 m</th>
<th>36 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct grid connection: charge</td>
<td>K 0.07/kWh</td>
</tr>
<tr>
<td>econ. cost</td>
<td>K 0.18/kWh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grid extension, 100% load: at</th>
<th>K 0.515/kWh</th>
<th>K 1409</th>
<th>K 6982</th>
<th>K 9177</th>
</tr>
</thead>
<tbody>
<tr>
<td>at</td>
<td>K 0.625/kWh</td>
<td>K 1710</td>
<td>K 7283</td>
<td>K 9473</td>
</tr>
<tr>
<td>10% load: at</td>
<td>K 4.52/kWh</td>
<td>K 12374</td>
<td>K 17947</td>
<td>K 20137</td>
</tr>
<tr>
<td>at</td>
<td>K 4.63/kWh</td>
<td>K 12675</td>
<td>K 18248</td>
<td>K 20438</td>
</tr>
</tbody>
</table>

**Diesel-generated: HL6 generator**

| K 1.20/kWh | K 3285 | K 8558 | K 11048 |

**TSI generator**

| K 2.07/kWh | K 5667 | K 11240 | K 14430 |

**Woodgas-generated: case 1**

| K 1.65/kWh | K 4517 | K 10090 | K 12280 |

**case 2**

| K 3.03/kWh | K 8295 | K 13668 | K 16058 |

**Solar power: unit cost of capacity**

| K 6.37/kWh | K 14437 | K 23010 | K 25200 |

**unit cost of consumpt.**

| K 7.36/kWh | K 20148 | K 25721 | K 27911 |

**TOTAL ANNUAL COSTS**

<table>
<thead>
<tr>
<th>16 m</th>
<th>36 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>192</td>
<td>5765</td>
</tr>
<tr>
<td>492</td>
<td>6065</td>
</tr>
<tr>
<td>1409</td>
<td>6982</td>
</tr>
<tr>
<td>1710</td>
<td>7283</td>
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<td>12374</td>
<td>17947</td>
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<td>12675</td>
<td>18248</td>
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<tr>
<td>3285</td>
<td>8558</td>
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<tr>
<td>5667</td>
<td>11240</td>
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<tr>
<td>4517</td>
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<tr>
<td>8295</td>
<td>13668</td>
</tr>
<tr>
<td>14437</td>
<td>23010</td>
</tr>
<tr>
<td>20148</td>
<td>25721</td>
</tr>
</tbody>
</table>

---

**TABLE E.18**

A cost analysis of domestic water provision, using electricity as source of energy. Pump data based on A.W.Tarry Ltd, costs of pump converted from 1988 prices, using an inflation rate of 75% (see appendix A.1).
Total annual costs = annual financing costs + annual energy costs.
Electricity rates based on tables E.3 (grid), E.15 (diesel), E.6 (woodgas) and E.11 (solar).
Base data
National pump: DE 2.2 kW pump; efficiency of 15%
Lister-Petter diesel engine: 2.2 kW
Operating period: 8 hours per day, lifetime pump: about 20,000 hours
Lifetime engine: about 15,000 hours (5 years); overhaul every 5000 hours (1.7 year)
Fuel consumption: 0.64 litre/hour (X 1.743/litre diesel, present retail price, table E.9)
(X 2.519/litre diesel), economic retail price, table E.8/9
Oil consumption: 4.77 ml/hour (X 14.16/litre oil, "Consumer Price Statistics", 1977, CSO)
Rate of discharge: 36 m³/hour, 7.59 m³/hr
Annul water deliverance: 36 m³ elevation, 9840 m³
6 m elevation, 22,160 m³
Number of families served: 36 m elevation, 16, 16 m elevation, 16, 16 m elevation, 36.
Biogas/diesel engine: biogas consumption of 0.68 m³/kW per hour (at X 1.09/m³ gas:
diesel consumption of 0.06 litre/kW per hour (see paragraph E.2.5)
Investment cost gasifier: case 1 (indigenous repair and servicing capacity): X 11280/kW
case 2 (spare parts and major servicing from abroad): X 2820/kW (1 kW
of the whole system, gasifier + engine).
Wood consumption: 1.4 kg per kW delivered (corresponding with a gasifier efficiency of 55%
by the whole system, gasifier + engine). Village forestry wood is used at
X 0.0343/kg (see table E.6 for reference of data).
Woodgas/diesel engine: diesel consumption of X 0.09 litre/kW.

Fixed costs (in 1987 Kwacha)
Pump: X 2660
Accessories: X 1630
Gasifier: X 24616 (case 1), X 6504 (case 2)
Diesel or dual-fuel engine: X 13300
Borehole: X 11060 (10 m), X 24800 (30 m)
Overhaul engine (total): 10% invest. cost, n=1.7) X 2660

Annual financing cost (i=15%)
Pump and accessories (n=7): X 1716
Gasifier (n=5): X 6556 (case 1), X 1639 (case 2)
Engine (n=5): X 3977
Overhaul engine (n=1.7): X 1866
Borehole (n=30): X 1770 (10 m), X 3960 (30 m)
Maintenance (7%, pump set and engine): X 1231
Maintenance (10%, gasifier): X 2462 (case 1), X 620 (case 2)

Annual fuel/lubricant cost
DIESEL ENGINES
Diesel: X 3257
Oil: X 4707
X 197
DUAL-FUEL
Biogas: X 4761
Diesel: X 672
Oil: X 197
WOODGAS
Wood: X 326
Diesel: X 896
Oil: X 197

TOTAL ANNUAL COST
Diesel engine: X 14034 (16 m), X 16234 (36 m)
Biogas dual-fuel: X 15484 (16 m), X 17674 (36 m)
Woodgas dual-fuel, case 1: X 16210 (16 m), X 18400 (36 m)
Woodgas dual-fuel, case 2: X 14258 (16 m), X 16448 (36 m)

TABLE E.19 A cost analysis of domestic water provision, using diesel, woodgas or biogas as
source of energy. Pump data: A.V.Terry Ltd. (prices converted from 1986 prices using an
inflation rate of 75%). Engine data: APE Ltd. (prices converted from begin 1986 prices using an inf
cases described in POL 83. It is assumed that a dual-fuel engine could be sold for the same price a
further that the biogas is produced in a plant of 12 m³ at X 0.915/m³ (compare with table E.10).
Base data
Daily water consumption in critical month April: 700 m³/day
Annual water demand: 74,600 m³
Submersible electric pump, 30 m elevation: 11.2 kW
Pump efficiency 40%, efficiency electromotor 80%
Operating period: 16.0 hours/day in peak month; annual operating hours: 3054
Annual energy consumption: 30 m elevation 34200 kWh
Rate of discharge: 43.8 m³/hour
Lifetime pump set: about 20,000 hours (6.5 years)

Fixed costs
Pump (plus electromotor) = X 35100
Accessoires = X 5900
Borehole = X 24800

Annual financing cost
Pump set (pump and accessoires, n=9.5) = X 10304
Borehole (n=20) = X 3960
Maintenance (7% of investment costs pump set) = X 2870
TOTAL = X 17134

Annual energy costs
Direct grid connection: charge = X 0.07/kWh = X 2394 = X 19530
economic cost = X 0.18/kWh = X 6165 = X 33300
Extension, 100% load, at = X 0.515/kWh = X 17613 = X 34750
at = X 0.625/kWh = X 21375 = X 38510
10% load, at = X 4.52/kWh = X 154584 = X 171720
Diesel-generated electricity (HL6) = X 1.20/kWh = X 41040 = X 51874
(TS1) = X 2.07/kWh = X 7094 = X 87930
Solar (unit cost of capacity) = X 6.37/kWh = X 216830 = X 239960
(unit cost of consumption) = X 14.79/kWh = X 505820 = X 522950
Woodgas-generated electricity, case 1 = X 1.65/kWh = X 41040 = X 42750
case 2 = X 3.03/kWh = X 103626 = X 120760
Biogas-generated electricity = X 1.69/kWh = X 77700 = X 74830

TABLE E.20 Cost analysis of electrical waterpumping for irrigation of a plot of 25 ha, for an elevation head of 30 m. It is assumed further that the water pumped is also used for domestic purposes. Electricity rates: see table E.3 (grid), E.15 (diesel), E.6 (woodgas), E.10 (biogas), E.11 (solar).
Assumed data of pump based on information provided by A.W. Tarry Ltd., Lusaka.

E.2.10 Wind energy, technical details
Base data
Pump, pump efficiency 30%: lifetime 20,000 hours
Operating period peak month: 16 hours/day; annual operating hours: 3054
Diesel engine: 30 m elevation, 11.9 kW
Lifetime engine: 15,000 hours; overhaul every 1500 hours
Fuel consumption (K 1.743/litre): 0.93 litre/hour (10 m)
2.67 litre/hour (30 m)
Oil consumption: 20 ml/hour, K 14.16/litre
Rate of discharge: 43.8 m³/hour
Biogas: annual consumption 24600 m³, K 0.631/m³, unit cost of cap.
K 1.055/m³, unit cost of cons., table E.10)
Annual wood consumption 1.4 kg/kWh at K 0.0363/kg

Fixed costs
Gasifier, case 1 X 134160
case 2 X 33540
Pump and accessories X 26500
Diesel engine X 54200
Overhaul X 18070
Borehole X 24800

Annual financing cost (i=15%)
Pump (n=9.5) X 6660
Diesel engine (n=7.1) X 16170
Overhaul (n=2.4) X 12817
Borehole (n=20) X 3960
Maintenance (7% of investment pump + engine) X 5649
TOTAL X 45256
Gasifier (n=6). case 1 X 35445
case 2 X 8661
Maintenance gasifier (10% of inv.cost), case 1 X 13416
case 2 X 3354
TOTAL, INCLUSIVE GASIFIER case 1 X 94117
case 2 X 57271

Annual fuel/lubricant cost
DIESEL ENGINE
Diesel X 17620 - 21450
Oil X 1000
DUAL-FUEL
Biogas (at unit cost of cap.) X 15650
(at unit cost of cons.) X 26160
Diesel X 5815
Oil X 1000
DUAL-FUEL
Wood X 1854
Diesel X 5086
Oil X 1000

Total annual costs Diesel engine (at retail price) X 63870
(at economic price) X 67706
Biogas (unit cost of cap.) X 65720
(unit cost of cons.) X 76230
Wood gas (case 1) X 65210
(case 2) X 102057

TABLE E.21 Cost analysis of diesel/biogas/woodgas powered waterpumping for irrigation of a plot of 25 ha.
Engine data: AFE Ltd., Lusaka. It is assumed that a dual-fuel engine could be sold at the same price as a comparable diesel engine. Gasifier data: see paragraph E.2.4.
Pump data compiled from information given by AFE Ltd. and A.W.Tarry Ltd., Lusaka.
\[ P(v) = \frac{1}{2} \rho A v^3 \]

with:

\( A \): area swept by the rotor blades of the windmill
\( \rho \): air density (= 1.29 kg/m\(^3\))
\( v \): wind velocity (m/s)

As the wind power \( P(v) \) is proportional to \( v^3 \) it is necessary to select a good site for the windmill. Wind conditions at a given site are determined by wind speed and wind direction.

Various types of windmills have been developed. Windmills can be classified according to the following features:

- axis: horizontal or vertical. The advantage of vertical axis rotors is that they operate independently of the wind direction. The disadvantage is that with exception of the Darrieus-type rotor hardly lift is used as the main operating force (see further).
- operation: lift, drag or both.
- movement: rotating, oscillating, translating.

On every body placed in a flow a force is exerted, which can be divided in part perpendicular to the flow (lift \( L \)) and one in the direction of the flow and one in the direction of the flow (drag \( D \)) (see figure E.3). The relative sizes of \( L \) and \( D \) depend on the shape of the body and the angle \( \alpha \). In describing the properties of airfoils reference is usually made to dimensionless lift and drag coefficients, defined as:

\[
\begin{align*}
C_L &= \frac{L}{\rho V^2 A/2} \\
C_D &= \frac{D}{\rho V^2 A/2}
\end{align*}
\]

The windpower which can be converted into mechanical energy is given by:

\[
\frac{P_{\text{lift}}}{P_{\text{drag}}} = \left( \frac{C_L}{C_D} \right)^3
\]

\( P \): power
\( C_L = 1 \) and \( 0 < C_D/C_L < 0.1 \)

From the above formulae we can conclude that a rotor, mainly working on lift is to be preferred, as more power can be generated compared with drag machines.

For a given mill geometry (rotor blade shape, number of blades) the behaviour of the mill rotor is described by: air velocity \( v \), radius of rotor area \( R \), rotating speed \( \Omega \), air density \( \rho \), and, torque at the axis \( M \). At the rotating axis of a mill windpower is converted into mechanical power \( P = M\Omega \).

Characteristic values of a windmill are:

- performance coefficient \( C_P \), representing the rotor efficiency: the ratio between the mechanical power \( P \) attained and the wind power,

\[
C_P = \frac{P}{(\rho V^2\pi R^2 V/2)}
\]

For physical reasons the power extractable has a theoretical maximum, the Betz maximum:

\[
C_{P,\text{max}} = \frac{16}{27} = 0.593.
\]

- torque coefficient \( C_M = M/(\rho V^2\pi R^2 R) \), which is the ratio between the torque at the rotor and a reference torque.
- tip speed ratio \( \lambda = \Omega R/v \). The following relation holds: \( C_P = \lambda C_M \).

Windmills can be classified in two categories by their \( \lambda \)-value at Betz
Basis for cost comparison

A) Savonius rotor
B) American wind wheel (16 blades)
C) Sail-WEC (triangular sail, 6 arms)
D) Rotor made of twisted metal blades (4 arms)
E) 3-blade rotor with aerodynamic profiles
F) 2-blade rotor with aerodynamic profiles

FIGURE E.4 Comparison of various rotor systems.
Source: WIN 83, figure 3.

FIGURE E.5 The ideal output curve (left) and two typical output curves of wind turbines.
Source: LYS 83, figure 8.4.

FIGURE E.3 A body placed in a (uniform) flow experiences a
force $F$, that is generally not parallel to the undisturbed flow
direction. Source: LYS 83, p.56.
maximum: slow-runners, \( \lambda = 1 \) to 2 and fast-runners, \( \lambda > 4 \). Figure E.4 illustrates the characteristics of 4 types of windmills. Usually fast-runners have a higher \( C_p,_{max} \), a lower \( C_M \) and a lower blade-surface density (number of blades) than slow-runners.

- efficiency \( \eta \). The effective power delivered by the equipment (i.e. including e.g. a generator, pump, gear-box) is given by:

\[
P_{out} = c_p \eta \rho A v^3 / 2
\]

This is the output curve of an ideal installation (pictured in figure E.5). The cut-in wind speed \( V_{in} \) is the speed at which the installation starts to generate power. The rated speed \( V_r \) is the speed at which maximum power is generated (rated power). The furling speed \( V_{out} \) is the speed at which the rotor automatically stops to avoid damage to the windmill. In practice the \( P_{out} \) output curve can take any shape between \( V_{in} \) and \( V_r \) (linear, quadratic, cubic, etc.). For waterpumpers there is only one speed at which rotor and load fit well: the design speed \( v_d \). For electricity generators this concept is of lesser importance, because if the machine is properly designed, rotor and load fit well over a range of speeds. Because of this, energy conversion in water pumpers is bad compared with electricity generators.

The total energy output of a wind installation, as presented by equation (E.8) be calculated from:

a) the output curve of the installation, given by equation (E.11)
b) the wind velocity distribution, given by monthly means of 3-hourly windspeeds given in table E.12.

Equation (E.8) can now be derived:

1) \( E_{interval} \) is calculated for each time-interval \( \Delta T = 3 \) hours, with \( v \) given by the particular windspeed for that interval:

\[
E_{interval} = \frac{1}{2} c_p \eta A v^3 \Delta T
\]

2) The daily energy output \( E \) (in Joules) calculated by summating over the time-intervals:

\[
E = \sum_{\Delta T} E_{interval}
\]

Slow-runners (low \( \Omega \), high \( C_M \), low \( C_p \)) are usually used in waterpumping. High-speed equipment (high \( \Omega \), low \( C_M \), high \( C_p \)) for electricity generation or water lifting with a centrifugal pump. Since fast-runners have higher (maximum) \( C_p \) values, the energy subtracted from the air per unit rotor area per unit time is higher than is the case with slow-runners. On the other hand low-speed equipment starts up even at low speeds, while fast runners have a poor start-up behaviour.
A classification of Zambian farming regions has been made by J. Schultz (SCH 74). He distinguishes 20 basically traditional land-use systems, which are combined in 5 groups, and 6 commercial land-use systems, combined in 1 group. It is beyond the scope of this report to discuss the various land-use systems in detail; table F.1 summarizes main characteristics of the land-use systems. The groups are named after the implements of cultivation and after the intensity of cultivation. The land-use systems are (with a few exceptions) given names of topographical origin. The following groups are distinguished:

- **shifting axe and hoe cultivation**, which is represented by the chitemene cultivation only. In chitemene the cultivation is restricted within a clearing of one or more patches, on which the cleared wood has been collected and burnt to provide fertilizer and to kill weeds. Only the ground in the layer of ashes is cultivated. Rights of possession are usually not upheld after fields are abandoned. Villages are normally small; resettling takes place less frequently than that of the fields, dependent on the woodland available.

- **semi-permanent hoe cultivation**. In this cultivation also plant material is burnt on the clearings, but as opposed to the chitemene system, occurs primarily in order to dispose of the cleared branches and tree trunks. Cropping is therefore not restricted to burnt areas. Because of the semi-permanent character land requirements per family are smaller compared with chitemene.

- **fishing and semi-permanent hoe cultivation**. The area covered follows the lakes and swamps of central and north-east Zambia. In these land-use systems fishing is the predominant activity. Fishing is also widespread in most of the parts of Zambia, but in contrast to the systems discussed here, plays a subordinate role. Cassava is usually the main crop.

- **semi-permanent hoe and ox-plough cultivation**. Cattle-raising offers the opportunity for ox-drawn activities and so for expansion and commercialisation of cultivation. Cattle dung can be used as manure, helping to preserve soil fertility. Thus cultivation can be semi- or even permanent.

- **semi-commercial ox and tractor plough cultivation**. These land-use systems form an intermediate category between the basically traditional systems and the commercial farms on State Land. In contrast to the latter no formal titles to land have developed. Characteristics are the widespread adoptions of oxen and tractors, large land holdings, permanent cultivation, made possible by application of fertilizer and manure, specialisation into a few crops.
The spatial distribution of the land-use systems is depicted in figure F.1. A disadvantage of above method of classification is that emerging farming regions, which occur locally in all farming regions are not mapped.

F.2 Livestock husbandry in Zambia

Cattle is the main source of wealth in rural areas, with other livestock playing a minor role. The functions of cattle in a traditional economy are:
- production factor in crop cultivation by providing animal draught power (ADP) and manure,
- direct production of beef and milk,
- capital investment: a savingsbank to be mobilized in times when needed cash,
- means of transport: ox-carts, bullock-carts.
- sign of wealth.

Of the about 1.9 million domestic cattle (1980 figure) about 17% are commercially kept. The remaining 1.6 million cattle are mostly in the traditional sector. In the traditional sector only a very small part out of the total cattle is sold. Commercial beef production is generally practised in a mixed cattle and maize farming system, mainly among the line-of-rail.

The indigenous cattle occur in 4 main populations:
- the southern and central areas, containing about half of the total, mainly of Tonga type of cattle. They are kept for cultivation and as a means of accumulating property.
- In Western Province 3/4 of the cattle (Barotse type) move seasonally between the flood plain and the upland grazings. The remaining group is semi-sedentary.
- in the extreme east there is a population of 200,000 Angoni cattle (sedentary and used for cultivation).
- in the extreme north-east there is about 80,000 cattle.

(data collected from FOO 81). Husbandry mainly consists of taking animals daily in the kraal for 6-8 hours grazing and returning them to the kraal at night. Young calves are usually left in the kraals. Kraals are usually too small, deep in mud and unhealthy. Usually there is no supplementary feeding other than grazing. In Western Province cattle is often tethered on stakes during the night at sites selected for maize cultivation. About 3/4 of the cattle move seasonally between the Zambezi plain and the relatively poor upland grazings (summer). In Northern Province cattle are generally roaming free between harvest and planting time both day and night. In Eastern Province herds are essentially

**Figure F.2** Most favoured agricultural areas: distribution of traditionally owned cattle.
Source: REK 81, map 10, p.56, SCH 74, figure 10, p.56.
sedentary and oxen are used for cultivation.

Further cattle development is very important because it can be a potential source of wealth and energy supply (biogas, draught power) in the rural areas. Such development is constrained however by:

- cattle diseases. 1/3 of the country is infested by the tsetse fly, reducing severely the productivity of animals. Vaccinations are necessary to keep the situation under control,
- seasonally limited availability of grass, fodder and supplementary feeding,
- inefficient traditional management practices; improved extension services on animal husbandry are needed.

About 85% of pig production is commercially produced (total of 3200 tons/annum or 60000 pigs/annum), mainly in the line-of-rail provinces. There are very few small-scale pig farmers; total number of village pigs is estimated at 115,000 (FOO 81, Eastern 100,000, North-Western 10,000, Western 3500). Most of the village pig meat is retained for home consumption.

There are some 30,000 sheep and 300,000 goats (FOO 81) kept under village conditions (Southern 45%, Eastern 32%). 30,000 sheep are commercially held.

Poultry industry has grown rapidly in the last 20 years. The production capacity is: 6 commercial hatcheries with capacity of 2.6 million chicks per annum, broiler production and village poultry. Village poultry production is difficult to quantify, but is very important with regard to rural nutrition.

F.3 Animal and human power

Human energy expenditure

In Zambia food production relies greatly on human muscle power with the aid of simple tools. Of the chemical energy stored in food about 20-30% can be converted into mechanical energy. In humid tropics however work efficiency of men is even lower (about 10%, STO 79, p.211). Under conditions of high temperature and high humidity the human energy system is unable to dissipate heat through evaporation, radiation and convection. With a diet of 12,000 kJ/day at a conversion rate of 20%, 2400 kJ can be transformed into mechanical power. In literature figures of 60-75 W are often mentioned as rates of exertion of young male workers. These values have to be reduced for individuals in poor health, malnourished, slight stature and also for work environments with high temperature and high humidity. Often operators are women and children (e.g. handpumping). In practice length of a working day will be about 6 hours and with a power output of 50 W for manual power this means a typical daily work output of 0.30 kWh.

Of course, when exerted in short period, useful power can be much higher. Table F.3 gives an indication.
A more efficient way of using human energy is pedal power, which could be for instance for water pumping, agroprocessing or transport (e.g. bicycle-drawn trailers). Power output of pedal power may be in the range 75-105 W, so that with a working day length of 6 hours this means a typical daily work output of 0.45-0.63 kWh (PAA 81, p.11).

Animal draught power

Oxen can replace human power for ploughing, harrowing, planting, cultivating, ridging, transport of agricultural and domestic inputs and outputs and water raising. The maximum tractive force is often stated in literature as 1/7-1/10 of the animal's weight (LOW 86, p.20). Performance is however influenced by factors such as animal's condition (age, state of health), work cycle and environmental factors (temperature, humidity, time of day and season). The maximum tractive power that can be achieved for a very limited time is about 10 times the optimum level for slowing down from a dead run, down to 2 or 3 times the optimum level for overcoming inertia. Doubling the number of draught animals does not mean doubling in tractive power as animals in teams perform 10-20% below their optimum standard. The optimum tractive power and speed of various animals are as follows (LOW 86, p.20):

- donkey 250-400 W 0.55-0.70 m/s
- horse 350-800 W 0.55-1.10 m/s
- ox 300-800 W 0.6-0.85 m/s

The old European power unit "1 horsepower" corresponds to 750 W. However the tractive power of the African plow horse is rated at much lower: 260 W (LOW 86, p.21). The daily working period of the European horse is taken as 8-10 hours; for the African horses it amounts to 3-6 hours. Also for oxen and donkeys difference are quite pronounced. Typical work outputs are:

<table>
<thead>
<tr>
<th>Animal</th>
<th>Power output (W)</th>
<th>Length of working day (hrs)</th>
<th>Daily work output (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>donkey</td>
<td>120</td>
<td>6</td>
<td>0.72</td>
</tr>
<tr>
<td>horse</td>
<td>260</td>
<td>4-6</td>
<td>1.04-1.56</td>
</tr>
<tr>
<td>ox</td>
<td>240</td>
<td>4-6</td>
<td>0.96-1.44</td>
</tr>
<tr>
<td>pair of bullocks</td>
<td>400</td>
<td>6</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Miscellaneous 187

In above estimations efficiency of animal gear has been taken into account (about 50%).

For Third World agriculture draught animals constitute often the most attractive source of energy for tractive power. Mechanical power is more efficient, but in most cases is much more expensive.

<table>
<thead>
<tr>
<th>Number of farmers</th>
<th>Area planted (ha)</th>
<th>Average ha/farmer</th>
<th>Expected production (bags)</th>
<th>Average prod./farmer (bags)</th>
<th>Expected sales (bags)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIZE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>24</td>
<td>1000</td>
<td>2.33</td>
<td>12 000</td>
<td>11 640</td>
</tr>
<tr>
<td>Emergent</td>
<td>300</td>
<td>200</td>
<td>1.0</td>
<td>45 000</td>
<td>40 500</td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>212</td>
<td>100</td>
<td>0.95</td>
<td>31 800</td>
<td>21 800</td>
</tr>
<tr>
<td>Peasant</td>
<td>3410</td>
<td>1000</td>
<td>2.93</td>
<td>60 000</td>
<td>28 750</td>
</tr>
<tr>
<td><strong>SUNFLOWER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>20</td>
<td>60</td>
<td>3.0</td>
<td>720</td>
<td>12</td>
</tr>
<tr>
<td>Emergent</td>
<td>300</td>
<td>200</td>
<td>2.0</td>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>212</td>
<td>200</td>
<td>0.94</td>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>Peasant</td>
<td>3114</td>
<td>400</td>
<td>0.13</td>
<td>320</td>
<td>8</td>
</tr>
<tr>
<td><strong>COTTON</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>15</td>
<td>340</td>
<td>22.7</td>
<td>306 000 kg</td>
<td>900 kg</td>
</tr>
<tr>
<td>Emergent</td>
<td>375</td>
<td>750</td>
<td>2.0</td>
<td>525 000</td>
<td>700</td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>212</td>
<td>636</td>
<td>3.0</td>
<td>445 200</td>
<td>700</td>
</tr>
<tr>
<td>Peasant</td>
<td>2400</td>
<td>2400</td>
<td>1.0</td>
<td>1440 000</td>
<td>600</td>
</tr>
<tr>
<td><strong>SOYABEANS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>24</td>
<td>480</td>
<td>2.0</td>
<td>5360</td>
<td>11</td>
</tr>
<tr>
<td>Emergent</td>
<td>273</td>
<td>546</td>
<td>2.0</td>
<td>5460</td>
<td>10</td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>210</td>
<td>315</td>
<td>1.5</td>
<td>2520</td>
<td>8</td>
</tr>
<tr>
<td>Peasant</td>
<td>1974</td>
<td>987</td>
<td>0.5</td>
<td>4535</td>
<td>5</td>
</tr>
<tr>
<td><strong>Sorghum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>200</td>
<td>200</td>
<td>1.0</td>
<td>1600</td>
<td>8</td>
</tr>
<tr>
<td>Peasant</td>
<td>1974</td>
<td>493</td>
<td>0.25</td>
<td>2465</td>
<td>5</td>
</tr>
<tr>
<td><strong>GROUNDBUTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergent</td>
<td>173</td>
<td>159</td>
<td>0.92</td>
<td>636</td>
<td>4</td>
</tr>
<tr>
<td>Inst/Settled</td>
<td>210</td>
<td>160</td>
<td>0.76</td>
<td>640</td>
<td>4</td>
</tr>
<tr>
<td>Peasant</td>
<td>1965</td>
<td>706</td>
<td>0.36</td>
<td>2800</td>
<td>4</td>
</tr>
</tbody>
</table>

**TABLE F.5 Crop production and sales forecast 1986/87 season Magoje Block. Source: Magoje Block supervisor.**

| Units: maize, soyabean and sorghum: 90 kg bags; groundnuts: 80 kg bags; sunflower: 50 kg bags; cotton: kilograms |
|*) sales will not differ much from expected production figures |
|**) mostly sold locally |
F.4  Statistical annex Magoye area

This section provides statistical information on the following subjects:

a) crop production (tables F.4, F.5, F.6),
b) numbers of livestock (table F.7),
c) prices of farm equipment and farm inputs (table F.8),
d) climatological data Kafue Flats Polder (source: SOU 75, table 1, note: 1 Langley = 11.6277 Wh/m². 1 knot = 0.514 m/s.

Crop production figures for the 1986/87 deviate from other seasons, especially maize production. This is due to varying rainfall and other climatological circumstances (drought in 1986/87).

<table>
<thead>
<tr>
<th>Type of cattle</th>
<th>Peasant farmers</th>
<th></th>
<th>Emergent farmers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Average</td>
<td>Total</td>
<td>Average</td>
</tr>
<tr>
<td>Bulls</td>
<td>287</td>
<td>0.1</td>
<td>171</td>
<td>0.4</td>
</tr>
<tr>
<td>Cows and heifers</td>
<td>8170</td>
<td>3.7</td>
<td>4658</td>
<td>11.8</td>
</tr>
<tr>
<td>Oxen and toures</td>
<td>7522</td>
<td>3.4</td>
<td>3555</td>
<td>9.0</td>
</tr>
<tr>
<td>Calves</td>
<td>3185</td>
<td>1.5</td>
<td>2146</td>
<td>5.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18958</td>
<td>8.7</td>
<td>10530</td>
<td>26.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goats</th>
<th>Pig</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6102</td>
<td>267</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE F.7 Number of animals per type of farmer, 1987.**

Sources: District animal husbandry officer; Magoye Block Headquarter

*) estimated average per farmer
### Crop Production Forecast 1987/88 Season Magaye Block

Source: Magaye Block supervisor.

<table>
<thead>
<tr>
<th>Type of Farmer</th>
<th>Number of Farmers</th>
<th>Normally Planted Ha</th>
<th>Crops Grown in Hectares</th>
<th>Production of Crops per Hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maize</td>
<td>Cotton</td>
</tr>
<tr>
<td>Commercial</td>
<td>24</td>
<td>865</td>
<td>380</td>
<td>346</td>
</tr>
<tr>
<td>Emergent/settlement</td>
<td>265</td>
<td>1980.3</td>
<td>716.8</td>
<td>846</td>
</tr>
<tr>
<td>Peasant</td>
<td>1974</td>
<td>2826.5</td>
<td>1482</td>
<td>692.5</td>
</tr>
<tr>
<td>Institutions</td>
<td>7</td>
<td>10.4</td>
<td>7.2</td>
<td>1.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2268</td>
<td>5682.2</td>
<td>2586</td>
<td>1889.5</td>
</tr>
</tbody>
</table>

### Table F.4

Crop production forecast 1985/86 season Magaye Block

Source: Magaye Block supervisor.

<table>
<thead>
<tr>
<th>Type of Farmer</th>
<th>Maize (90 kg)</th>
<th>Cotton (kg)</th>
<th>Sunflower (50 kg)</th>
<th>Soyabean (90 kg)</th>
<th>Sorghum (90 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>40</td>
<td>1000</td>
<td>30</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Emergent</td>
<td>25</td>
<td>500</td>
<td>15</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Peasant</td>
<td>15</td>
<td>300</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
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Appendix F

Kouldboard plough
Plough spares (SPCKU):
wheel
mouldboard
handles
beam
Hoe
Axe-head
Cultivator
Planter
Wheelbarrow (steel)
Maize sheller (hand)
Maize sheller (engine)
Ox-cart: steel
wood
Trailer
Grinding mill: hand
gravity mill (5.6 kW, 10C kg/hr)
hammermill: small (11 kW, 250 kg/hr)
large (22.5 kW, 700 kg/hr, with 22.5 kW electromotor)

Seeds
Maize (50 kg MM605/3)
Sunflower (25 kg hybrid)
Soyabens (50 kg)
Sorghum (50 kg)
Cotton (20 kg)

Fertilizer
Maize mixture R.D.C (50 kg)

Producer prices crops
Maize (90 kg)
Sunflower (50 kg)
Soyabens (90 kg)
Cotton (1 kg)
Sorghum (90 kg)

---

**TABLE F.8** Prices of farm inputs and equipment.

**ABOVE** Prices, 1988, of various farm implements, as sold by SPCKU, Lenco (Lusaka), Lusume Services Workshop Magoye, Northland Engineering Ltd (Ndola), Turning & Metal Ltd. and AW Tarry Ltd.


*: estimated from price 1987/88 season, assuming an inflation rate of 60%.
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**KAFUE POLDER**

LAT. 15°46'S, LONG. 27°55'E, ALT. 987 m
F.6 Data acquisition fieldwork

SURVEY VARIABLES

The data outlined in this survey were obtained from key-informants, having a considerable knowledge of local conditions, such as agricultural officers (district, block, camp level). Quantitative information was obtained from the block supervisor and district animal husbandry officer. Before undertaking the survey, available data and information in literature and maps was consulted. Finally information, mostly qualitative, was obtained by interviews of farm households, using the questionnaire as a guideline. An important aspect of the survey was to gain insight in the problems in agriculture, transport and energy supply.

Physical-geographical data

1) Location of villages; a map of the area; roads
2) Morphology/topology:
   - land-use pattern (forest, grassland, cultivated area)
   - topology
3) Water resources:
   - type of resource (streams/rivers, ground water, reservoirs, etc.)
   - suitability for hydro-power (flow and head, seasonal variation).
4) Climatic conditions:
   - rainfall (annual average, monthly variation, evaporation)
   - duration of seasons (hot-cold, wet-dry)
   - solar insolation (monthly variation, sunshine hours per day)
   - season temperatures
   - wind speed distribution

General socio-economic data

1) Population
   - number of people (by sex)
   - number of households
   - tribe(s)
2) Major economic activities (defined as main source of income)
   - number of households involved in activity
3) Commercial and public services available
   - number of retail shops/marketplaces
   - religious places
   - post, telephone, telegraph offices
   - health clinics or hospitals
   - schools (primary, secondary)
   - industrial activities (e.g. maize milling)
   - others (specify)
4) Rate of literacy in the area
Miscellaneous

5) Available artisanal skills in area (tinsmiths, blacksmiths, carpenters, masons, mechanics, co-operative workshops, charcoal burners, etc.)

6) Activities of (non-)governmental organisations in the area:
   - agricultural (+ veterinary) extension work (area of coverage of camps, number of extension workers)
   - agricultural inputs supply (credit, seeds, fertilizer, insecticides, herbicides, pesticides, equipment)
   - marketing of agricultural outputs
   - facilities: crop storage, crop and livestock sales points
   - membership of organisations, conditions of services offered

7) Administration of the area
   - day-to-day running of the area and villages
   - traditional

8) Cultural aspects
   - role pattern
   - land tenure pattern
   - belief system
   - kinship pattern

Agricultural data

1) Types of farmers
2) Cultivated crops per type of farmer
   - cash crops
   - subsistence crops
   (average hectare, production, sales, price per unit)
3) Inputs per type of farmer per hectare
   (amounts of fertilizer, seeds, chemicals used; price per unit)
4) Method of land preparation per type of farmer (ploughing, ridging, harrowing, cultivating, planting)
5) Method of irrigation per type of farmer
6) Method of harvesting per type of farmer
7) Method of crop processing per type of farmer
   (threshing, drying, milling, grinding, etc.)
   (4-7: by hand tools, animal-powered or engine-powered machines)
8) Method of marketing (private, marketing organisation)
9) Description of tools and engines used per type of farmer (tractors, ox-drawn implements, hoes and spades, maize sheller, other)
10) Livestock:
    - number of animals
    - number of farmers, actually owning that type of animal
    - draught power (owned oxen, ox-hiring)
    - purchases, sales, slaughtering, births, deaths, gifts of animals
    - purchase and sales price per unit
11) Crop calendar

Industrial and artisanal data

Per type of activity:
- description of methods of processing
- inputs (raw materials, equipment, price per unit)
- products (sales, price per product)
- energy-use (source of energy used)

Institutions
- current use of energy: amounts and types of energy used in each sector
- institutions involved in energy supply in the area

Transport system
1) In- and off-farm transport of in- and outputs (mode of transport, owned or hired
2) Personal trips

Household energy supply
1) Types of households (per main source of income, type of farming)
2) Traditional fuels used (fuelwood, charcoal, dung, residues or other). Source of fuel, distance from which fuels are obtained, how they are transported.
3) Commercial fuels used (fuelwood, charcoal, kerosene, diesel, gasoline, electricity, other). Source of fuel, local price of fuel.
4) Water facilities (household consumption, garden and cattle watering).

Farm household income
1) Income, variable and fixed costs in agricultural production
2) Others sources of household income and amount, apart from farming (handicraft, charcoal, beer brewing, wage labour, fishing, other)
3) Expenditures households
4) Retail prices shops.

QUESTIONNAIRE FARM HOUSEHOLDS

1) Name camp and village: __________________________________________
2) Name respondent=----------~------------------------~Age:________
3) Total number of people in household: adults (male/female)________
   children (male/female)________
4) Are there any other activities besides farming you can earn income with (such as handicrafts, wage labour, fishing, beer brewing, others)?
5) Are there any of your family members working elsewhere?________

Agriculture
6) What crops did you grow last season?______________________________
7) Can you give an estimation of the hectarage of land?
   a) Total land__________________________________________________
b) Total land cleared for cropping?

Hectareage per crop, last season?

Maize ____________________
Cotton ____________________
Sunflower ____________________
Other ____________________

---

c) Pasture land ____________________
d) Other ____________________

e) Do you have a vegetable garden? ____________________
f) Do you have fruit trees? ____________________
g) Do you grow trees for other reasons? (specify) ____________________

8) Farm inputs.
Did you use any of the following? (Y/N)

Seeds  If yes, for which crop? ______
Fertilizer - basal dressing  If yes, for which crop? ______
- top dressing  If yes, for which crop? ______
Chemicals: - insecticides  If yes, for which crop? ______
- herbicides  If yes, for which crop? ______
- pesticides  If yes, for which crop? ______

9) Which and how many of the following livestock do you own?
a) Cattle  Cows __________
- Calves __________
- Oxen __________

Goats __________
Pigs __________
Poultry __________

b) Can you indicate changes in the numbers since last year?
(purchases, sales, births, gifts, deaths, slaughtered) __________

10) Which of the following sources of power do you employ?

Hand tools  Ox-power  Tractor
- Family labour  Hired  Owned  Hired  Owned

- ploughing
- cultivating
- harrowing
- weeding
- planting
- harvesting
- transportation of inputs
- outputs

11) What means of transport do you own?
(bicycle, ox-carts, wheelbarrow, others? If so, how many? ______

12) If you hire means of transport, what are the charges you have to pay? ______

14) What and how many equipment/tools do you possess?
- Ox-drawn implements (ploughs, harrows, edgers, planters, cultivators, ox-carts, others) ______
- Hoes/spedes
- Maize shellers
- Engine-driven machinery
- Others (specify) ______

Can you give estimation of life-times of implements? ______

15) Did you obtain a credit in the last 2 years? ______
If so, from whom? ______
Did you receive the amount applied for? ______________________________________
Did you get the credit in time? ____________________________________________
Do you need additional credit? ____________________________________________
If so, for what?

16) Do you seek information on
   nutrition and diseases ______________________________
   livestock-keeping ______________________________
   crop growing ______________________________
   tree growing ______________________________
   other subjects? ______________________________
Do you think the information on these subjects is sufficient? ______________

18) Have you received training in these subjects? ____________________________

19) What problems arise in obtaining:
   - fertilizer ______________________________
   - seeds ______________________________
   - chemicals? ______________________________

20) What do you see as problems in:
   a) crop production, storage and sales ______________________________
   b) livestock husbandry? ______________________________
   c) purchase and maintenance of equipment ______________________________
   d) transport of agricultural in- and outputs? ______________________________
   e) personal transport? ______________________________
Are you satisfied with the inputs and services offered by
   - the SPCMU ______________________________
   - credit agencies ______________________________
   - veterinary department? ______________________________
If no, why? ______________________________

Household

21) What source of fuel (firewood, charcoal, dung, residue, kerosene or other) do you use for:
   - cooking ______________________________
   - baking ______________________________
   - water-heating ______________________________
     For which purpose do you heat water? ______________________________
   - lighting ______________________________
     What method of lighting do you use? ______________________________
     For how many hours is lighting used? ______________________________
   - space heating ______________________________
   - other domestic activities using energy? ______________________________

22) Indicate per fuel:
   - way of procuring (collecting/buying) ______________________________
     if collected, who collects (male/female/children) ______________________________
     and from where (+ distance in km) ______________________________
     using what means of transport ______________________________
   - if purchased, where, at which price per unit? ______________________________

23) What is your source of water
   - in the dry season ______________________________
   - in the rainy season ______________________________
Give location of the source? ______________________________
What do you think of the condition of the water? ______________________________
For what purposes do you use the water (drinking, garden watering, or others)? ______________________________

24) Do you see as problems in:
- household energy supply
- water supply
- food situation (staples (and meal), vegetables, fruit, chicken/meat, eggs, milk, salt, sugar, cooking oil, others)
- supply and prices of items, as medicines, clothing, school expenditures, groceries?

Have these problems increased/decreased since the past?
What do you see as possible solutions?

Artisans

25) What products do you manufacture? Do you work alone?

26) Could you give a list of the products you sell, if possible with prices and an estimation of sales?

How do you sell your products?

27) What raw materials do you need and where do you obtain these from?

28) What means of transport do you have?

29) What machines, tools and appliances do you use?

What sources of energy do you have?

If you are not using engine power, would you think of electricity or diesel-engines as an improvement for your business?

30) What do you see as problems in

- obtaining raw materials
- selling products
- transport
- use, maintenance and purchase of tools and equipment
- energy/fuel supply?

Have there been changes in the past in these problems?
What do you see as possible solutions for your problems?
### Crop Calendar

For each operation the number of mandays per hectare is given. One manday is equal to seven hours. Source: Planning Division, WAND.

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