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**A study on the utilisation of small- scale hydropower  
for rural electrification in Malawi**

by

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in  
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Date: *2nd February, 2008* .....

## **DEDICATION**

To my wife Chisomo

To my parents Loti Taulo and Elida Mphepo

To my children Ian and Tadala

**YOU ARE A BLESSING TO ME**

## **ACKNOWLEDGEMENTS**

I would like to express my profound gratitude to my supervisor, Professor Kevin Bennett, for his valuable guidance from the beginning of this project until the end. You always provided positive constructive feedback, created an environment that promoted learning, and enabled me to access your wisdom and intellect on energy issues.

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## ABSTRACT

This study explores the potential of utilising small-scale hydropower as an alternative source of rural electrification in Malawi. Approximately 7.5% of the country's population has access to electricity. In rural areas, the electricity access rate is 0.8%. A number of factors such as the cost of infrastructure, dispersed nature of the population, low consumption and poor load factors have prevented the majority of the rural population from getting connected to the national electricity grid. The study seeks to answer a key question such as "what is the potential of utilising small-scale hydropower to increase the electrification level and reduce green house emissions in Malawi?" An *ex ante* study has been conducted in Nkolokosa village, to estimate the energy consumption, income levels and willingness to pay. Using the relationship between number of households in that village and estimated peak demand, a regression model to forecast future electricity demands has been derived. The capital cost of such a rural electrification project, unit cost of generation, and unit cost of electricity to the user are analysed. Emission reductions for green house gases have been estimated. A preliminary economic analysis of the cost of supplying power to the village has been presented. The study results indicate that small-scale hydropower would be a favourable option. The results show that providing 85kWh/year of electricity per household increases the national electrification level by 2.3%. About 230,000 people in rural areas would have access to electricity. A typical 40 kW small-scale hydropower plant would serve about 110 households. This corresponds to about one fifth of total number of households found in a typical village in Malawi. The specific construction cost per kW is MWK 2,216,992.86 (US\$15,835.66). The net present value was found to be MWK 4,490,389.08 with an 8% discount rate, and the economic rate of return (EIRR) was 5.98%. The benefit cost ratio was 6.25. The break- even tariff is MWK 44.80 per kWh. The average willingness to pay is MWK 5.58/kWh. The project would deliver 192,337 kWh/year of electricity and result in avoided emissions of 59.62 tons CO<sub>2</sub>/year. The results show that significant increase in electrification using small-scale hydropower alone is not achievable. However, the evaluation seems quite promising and, with some refined costing at each potential site, small-scale hydropower projects should be implemented.

## TABLE OF CONTENTS

|   |           |
|---|-----------|
| Declaration.....  | i         |
| Dedication.....   | ii        |
| Acknowledgements.....   | iii       |
| Abstract.....   | iv        |
| Table of contents.....  | v         |
| List of figures.....  | ix        |
| List of tables.....   | x         |
| List of appendices.....   | x         |
| Acronyms and abbreviations.....                                     | xi        |
| Glossary.....   | xiii      |
| <b>CHAPTER 1: INTRODUCTION.....</b>                                 | <b>1</b>  |
| 1.1 Rural energy and international development context.....         | 1         |
| 1.2 Energy issues facing Malawi.....                                | 4         |
| 1.3 Small-scale hydropower development in Malawi.....               | 7         |
| 1.4 Research Problem.....   | 8         |
| 1.5 Research objectives and questions.....                          | 9         |
| 1.6 Study hypothesis.....   | 11        |
| 1.7 Scope of work.....  | 11        |
| 1.8 Assumptions.....  | 11        |
| 1.9 Significance of the study.....                                  | 11        |
| 1.10 Limitations of this study.....                                 | 12        |
| 1.11 Structure of the thesis.....                                   | 13        |
| <b>CHAPTER 2: REVIEW OF ENERGY AND POWER SECTORS IN MALAWI.....</b> | <b>14</b> |
| 2.1 Geography and Demography.....                                   | 14        |
| 2.2 Energy Situation.....   | 16        |
| 2.2.1 Overall present energy situation.....                         | 16        |
| 2.2.2 Energy demand and supply projections.....                     | 21        |
| 2.3 National Energy Policy.....                                     | 23        |
| 2.4 Hydropower resource potential and development in Malawi.....    | 24        |
| 2.5 Rural Electrification.....                                      | 25        |

|            |  |    |
|------------|--|----|
| CHAPTER3:  | RURAL ELECTRIFICATION: CONCEPTUAL FRAMEWORK .....            | 27 |
| 3.1        | Energy poverty and rural electrification .....               | 27 |
| 3.1.1      | Energy Poverty.....  | 27 |
| 3.1.2      | Definition of Rural Electrification .....                    | 28 |
| 3.2        | Rural electrification objectives .....                       | 29 |
| 3.2.1      | Economic objective.....                                      | 30 |
| 3.2.2      | Socio-economic objective.....                                | 30 |
| 3.2.3      | Poverty alleviation objective.....                           | 30 |
| 3.3        | Social and economic benefits of rural electrification .....  | 31 |
| 3.3.1      | Social Benefits .....  | 31 |
| 3.3.2      | Environmental Benefits .....                                 | 33 |
| 3.3.3.     | Economic Benefits.....                                       | 34 |
| 3.1        | Key Success factors for rural electrification.....           | 35 |
| 3.2        | Case studies.....  | 38 |
| 3.7.1      | Long term planning and government commitment.....            | 45 |
| 3.7.2      | Policies and strategies .....                                | 45 |
| 3.7.3      | Decentralised approach for small hydropower development..... | 46 |
| 3.7.4      | Capital investment and financial support mechanisms.....     | 46 |
| 3.7.5      | Standardisation of small-scale hydropower plants .....       | 47 |
| CHAPTER 4: | THEORETICAL CONSIDERATIONS .....                             | 49 |
| 4.1        | Basic concepts of hydropower .....                           | 49 |
| 4.2        | Energy conversion principles.....                            | 50 |
| 4.3        | Small-scale hydropower system components .....               | 51 |
| 4.4        | Small-scale hydropower scheme configurations .....           | 52 |
| 4.4.1      | Run-of- river type .....                                     | 52 |
| 4.4.2      | River power plants .....                                     | 53 |
| 4.5        | Water Turbines .....   | 53 |
| 4.5.1      | Choice of water turbine.....                                 | 54 |
| 4.6        | Resource assessment and evaluation .....                     | 55 |
| 4.7        | Flow Duration Curve .....                                    | 55 |
| 4.7.1      | Hydrological flow indices.....                               | 55 |
| 4.7.2      | Environmental flow considerations .....                      | 56 |
| 4.7.3      | Capacity Factor .....  | 57 |
| 4.7.4      | Energy output from a power plant .....                       | 57 |
| 4.7        | Stream flow characteristics.....                             | 57 |

|   |   |           |
|---|---|-----------|
| 4.8   | Estimation of stream flow characteristics at ungauged sites ..... | 59        |
| 4.9.1   | Catchment-Area Ratio .....  | 60        |
| 4.9.2   | Flow correlation method .....                                     | 61        |
| 4.9.3   | Regression Equation Approach.....                                 | 61        |
| 4.10  | Economic analysis .....   | 61        |
| 4.10.1  | Tools for economic analysis .....                                 | 61        |
| 4.10.2  | Costing .....   | 62        |
| 4.11  | Tariff Setting.....   | 64        |
| 4.12  | Consumption patterns and load forecast.....                       | 65        |
| 4.12.1  | Consumption patterns .....  | 65        |
| 4.12.2  | Load forecasting.....   | 66        |
| <b>CHAPTER 5: MATERIALS AND METHODS .....</b>   |   | <b>69</b> |
| 5.1   | Study Area .....  | 69        |
| 5.2   | Methods .....   | 71        |
| 5.2.1   | Research Design.....  | 71        |
| 5.2.2   | Data Collection Methods .....                                     | 72        |
| 5.2.3   | Field surveys .....   | 73        |
| 5.3.4   | Analysis of stream flow data from gauged site.....                | 76        |
| 5.3.5   | Demand Forecasting .....  | 77        |
| 5.3.6   | Results output.....   | 77        |
| <b>CHAPTER 6: RESULTS AND DISCUSSIONS .....</b> |   | <b>78</b> |
| 6.1   | Socio-economic characteristics of households .....                | 78        |
| 6.1.1   | Demographics .....  | 78        |
| 6.1.2   | Household Income .....  | 79        |
| 6.1.3   | Energy sources and end uses.....                                  | 80        |
| 6.1.4   | Household energy expenditure .....                                | 80        |
| 6.1.5   | Household energy consumption.....                                 | 80        |
| 6.1.5   | Household willingness to pay for electricity .....                | 81        |
| 6.1.6   | Appliances and end-uses of electricity .....                      | 83        |
| 6.1.7   | Behavioural attitude towards electrification project.....         | 83        |
| 6.1.8   | Community Participation .....                                     | 84        |
| 6.2   | Hydrological Study .....  | 85        |
| 6.2.1   | Meteorological data .....   | 85        |
| 6.2.2   | River flow rate data.....   | 86        |
| 6.2.3   | Flood Flow .....  | 89        |
| 6.2.4   | Flow Correlations.....  | 90        |
| 6.2.5   | Water Availability.....   | 91        |

|  |  |     |
|--|--|-----|
| 6.3  | Energy Demand Study .....                          | 92  |
| 6.3.1  | Maximum Power Demand .....                         | 92  |
| 6.3.2  | Peak load .....                                    | 93  |
| 6.3.3  | Required Output of Power Station .....             | 95  |
| 6.4  | Estimation of future electricity consumption.....  | 95  |
| 6.5  | Economic Analysis .....                            | 96  |
| 6.5.1  | Capital costs .....                                | 96  |
| 6.5.2  | Annual energy production.....                      | 97  |
| 6.5.3  | Fixed Annual Operating and Maintenance Costs ..... | 97  |
| 6.5.4  | Fuel cost .....                                    | 97  |
| 6.5.5  | Unit energy cost .....                             | 98  |
| 6.6  | Sensitivity Analyses.....                          | 98  |
| 6.7  | Green house gas emissions (GHG).....               | 104 |
| 6.7.1  | CO <sub>2</sub> Emissions .....                    | 104 |
| 6.7.2  | Non- CO <sub>2</sub> Emissions .....               | 104 |
| 6.7.3  | Emission reductions .....                          | 105 |
| 6.8  | Scenario analysis.....                             | 106 |
| 6.8.1  | Business as Usual (BAU).....                       | 106 |
| 6.8.2  | Basic Electricity for Pro-poor (BEPP).....         | 108 |
| 6.9  | Installed capacity and number of households .....  | 111 |
| 6.10   | Electrification rates .....                        | 112 |
| CHAPTER 7: CONCLUSIONS AND RECOMMEDATIONS..... |  | 113 |
| 7.1  | Summary of principle findings .....                | 113 |
| 7.2  | Recommendations.....                               | 117 |
| REFERENCES .....                               |  | 120 |
| ANNEXES.....                                   |  | 131 |

## LIST OF FIGURES

|             |  |     |
|-------------|--|-----|
| Figure 2.1  | Location map of Malawi.....  | 15  |
| Figure 2.2  | Distribution of energy sources.....  | 17  |
| Figure 2.3  | Total energy use by various sectors.....   | 21  |
| Figure 2.4  | Total primary energy supply.....   | 22  |
| Figure 2.5  | Final energy demand.....   | 22  |
| Figure 4.1  | Hydrological cycle.....  | 49  |
| Figure 4.2  | Components of a small-scale hydropower plant.....                                | 51  |
| Figure 4.3  | Selection of turbine.....  | 54  |
| Figure 5.1  | Location of the study area and catchment of the project site.....                | 70  |
| Figure 5.2  | General plan of the proposed scheme.....   | 71  |
| Figure 5.3  | Survey of river cross section at the proposed weir site.....                     | 75  |
| Figure 5.4  | River discharge measurement using velocity area method.....                      | 76  |
| Figure 6.1  | Categories of households.....  | 78  |
| Figure 6.2  | Distribution of household income groups.....                                     | 79  |
| Figure 6.3  | Maximum connection fees and in-house wiring costs.....                           | 81  |
| Figure 6.4  | Willingness to pay for monthly electricity consumption.....                      | 82  |
| Figure 6.5  | Desired end-uses of electricity.....   | 83  |
| Figure 6.6  | Behavioural attitude towards electrification project.....                        | 84  |
| Figure 6.7  | Willingness to contribute to project activities.....                             | 84  |
| Figure 6.8  | Thyolo monthly and yearly rainfall (1962-2006).....                              | 85  |
| Figure 6.9  | 10-day flow duration curve for Nachipere River at Nkolokosa.....                 | 87  |
| Figure 6.10 | Relationship between average annual yield, rainfall and average daily flow.....  | 88  |
| Figure 6.11 | Flow duration curve at intake on Nachipere River.....                            | 89  |
| Figure 6.12 | Flood frequency analysis for Nswazi and Nachipere Rivers.....                    | 90  |
| Figure 6.13 | Hydrograph for Nachipere River.....  | 92  |
| Figure 6.14 | Power demand under different household sizes.....                                | 94  |
| Figure 6.15 | Average daily load curves for Nkolokosa village.....                             | 94  |
| Figure 6.16 | Variation of capital costs with rated capacity.....                              | 99  |
| Figure 6.17 | Variation of unit costs of electricity with rated capacity.....                  | 99  |
| Figure 6.18 | Variation of investment level and interest rate on unit cost of electricity..... | 100 |

|             |   |     |
|-------------|---|-----|
| Figure 6.19 | Variation of unit cost of electricity with different plant load factors.....  | 100 |
| Figure 6.20 | Variation of annual operating hours and maintenance costs of electricity..... | 101 |
| Figure 6.21 | Variation of unit cost of electricity with discount rates.....                | 101 |
| Figure 6.22 | Sensitivity analysis of IRR with different plant load factors.....            | 102 |
| Figure 6.23 | Estimated non-CO <sub>2</sub> emissions by source categories.....             | 105 |
| Figure 6.24 | Final energy demand by source.....  | 107 |
| Figure 6.25 | Estimated emissions under business as usual scenario.....                     | 108 |
| Figure 6.26 | Final electricity demand for Nkolokosa.....                                   | 109 |
| Figure 6.27 | Estimated emissions under BEPP scenarios.....                                 | 110 |
| Figure 6.28 | System capacity and number of households connected under BEPP scenario....    | 112 |

## LIST OF TABLES

|           |  |    |
|-----------|--|----|
| Table 2.1 | Key energy indicators for Malawi.....  | 16 |
| Table 3.1 | China small-scale hydropower stations by installed capacity.....                           | 39 |
| Table 3.2 | Installed capacity for small-scale hydropower in Nepal.....                                | 43 |
| Table 3.4 | Comparison of results of rural electrification programme in China,<br>Nepal and India..... | 44 |
| Table 4.1 | k-values for calculation of total project costs.....                                       | 63 |

## LIST OF APPENDICES

|          |   |
|----------|---|
| Annex A: | Energy resources, imports statistics and consumption    |
| Annex B: | Typical examples of rural electrification benefits      |
| Annex C: | Estimation of power potential and economic concepts     |
| Annex D: | Household energy demand questionnaire and site surveys  |
| Annex E: | Results of socio-economic survey and hydrological study |
| Annex F: | Results of energy demand study                          |
| Annex G: | Results of economic analysis                            |
| Annex H: | Computations of greenhouse gas emissions                |

## ACRONYMS AND ABBREVIATIONS

|                  |   |
|------------------|---|
| AAR              | Average Annual Rainfall                                       |
| AAY              | Average Annual Yield  |
| ADF              | Average Daily Flow  |
| AEPC             | Alternative Energy Promotion Centre                           |
| ANC              | Antenatal care  |
| BCR              | Benefit Cost Ratio  |
| BEPP             | Basic Electricity for Pro-Poor                                |
| BHA              | British Hydropower Association                                |
| CCGT             | Combined Cycle Gas Turbine                                    |
| CFL              | Compact Fluorescent Light                                     |
| CH <sub>4</sub>  | Methane   |
| CIA              | Central Intelligence Agency                                   |
| CO               | Carbon Monoxide   |
| CO <sub>2</sub>  | Carbon Dioxide  |
| CoG              | Cost of Generation  |
| DANIDA           | Danish International Development Cooperation Agency           |
| DFID             | Department for International Development                      |
| DoEA             | Department of Energy Affairs                                  |
| EnPoGen          | Energy Poverty and Gender                                     |
| ERI              | Energy Research Institute                                     |
| ESAP             | Energy Sector Assistance Programme                            |
| ESCAP            | Economic and Social Commission for Asia and the Pacific       |
| ESCOM            | Electricity Supply Corporation of Malawi                      |
| ESHA             | European Small Hydropower Association                         |
| GHG              | Green House Gas   |
| GNESD            | Global Network on Energy for Sustainable Development          |
| GoM              | Government of Malawi  |
| HDI              | Human Development Index                                       |
| HRC              | Hangzhou Regional Centre (Asia-Pacific) for Small Hydro Power |
| IDS              | Institute of Development Studies                              |
| IEA              | International Energy Agency                                   |
| IH               | Institute of Hydrology  |
| IPCC             | Inter governmental Panel on Climate Change                    |
| IPP              | Independent Power Producers                                   |
| IRR              | Internal Rate of Return                                       |
| ITCZ             | Inter Tropical Convergence Zone                               |
| JICA             | Japan International Cooperation Agency                        |
| MDGs             | Millennium Development Goals                                  |
| MEM              | Ministry of Energy and Mining                                 |
| MoIWD            | Ministry of Irrigation and Water Development                  |
| MPRS             | Malawi Poverty Reduction Strategy Paper                       |
| MWK              | Malawi Kwacha   |
| N <sub>2</sub> O | Nitrous oxide   |
| NECO             | National Electricity Council                                  |

|                 |  |
|-----------------|--|
| NMVOC           | Non Methane Volatile Compounds   |
| NO              | Nitric Oxide   |
| NO <sub>x</sub> | Nitrogen oxide   |
| NPV             | Net Present Value  |
| NSO             | National Statistical Office  |
| O&M             | Operation and Maintenance  |
| PESD            | Programme on Energy and Sustainable Development                        |
| PNC             | Postnatal care   |
| REDF            | Rural Energy Development Fund  |
| REN21           | Renewable Energy and Policy Network for the 21st Century               |
| RoR             | Run-of-River   |
| SADC            | Southern Africa Development Community                                  |
| SHP             | Small-scale hydropower   |
| SO <sub>2</sub> | Sulphur Dioxide  |
| SPSS            | Statistical Package for Social Scientists                              |
| TAMS            | Tippetts-Abbot-McCarthy-Stratton                                       |
| TERI            | Tata Energy Research Institute   |
| TT              | Tetanus Toxoid   |
| UN/DTCD         | United Nations Department of Technical Cooperation for Development     |
| UNDP            | United Nations Development Programme                                   |
| UNESCAP         | United Nations Economic and Social Commission for Asia and the Pacific |
| UNFCCC          | United Nations Framework Convention on Climate Change                  |
| UNIDO           | United Nations Industrial Development Organisation                     |
| USAID           | United States for International Development                            |
| VDC             | Village Development Committee  |
| WACC            | Weighted Average Cost of Capital                                       |
| WEC             | World Energy Council   |

#### Units

|     |                                      |
|-----|--------------------------------------|
| kW  | kilowatt                             |
| kWh | kilowatt-hour                        |
| MW  | Megawatt                             |
| MWh | Megawatt- hour                       |
| GWh | Gigawatt- hour                       |
| TWh | Terawatt- hour                       |
| GJ  | Gigajoules = 10 <sup>9</sup> Joules  |
| TJ  | Terajoules = 10 <sup>12</sup> Joules |
| PJ  | Petajoules = 10 <sup>15</sup> Joules |
| Gg  | Gigagrams= 10 <sup>9</sup> gram      |

#### Exchange Rates

145 MWK = 1 USD

8.26 Yuan = 1 USD

Rs.46 (Indian Rupees) = 1 USD

## **GLOSSARY**

|                         |  |
|-------------------------|--|
| Small-scale hydropower: | hydropower usually run-of-river with capacity up to 10 MW  |
| Gross potential         | : the annual energy potentially available, when all natural run off in a country is harnessed down to the sea level (or to the border of the country) without any energy losses.       |
| Technical potential     | : the total hydropower potential at a station wall of all sites, this could be, or have been developed, considering current technology, regardless of economic and other restrictions. |
| Economic potential      | : that portion of technical potential, which can, or has been developed, at costs competitive with other resources   |
| Exploitable potential   | : the portion of the economic potential, which can be expected to be harnessed considering environmental or other special restrictions.  |
| Fore bay                | : a reservoir upstream from a power house, used to regulate the flow of water into the power house   |
| Head                    | : vertical distance between the surface of a reservoir or other intake location and the power house  |
| Hydrograph              | : a chart or table that depicts the water volume as a function of time   |
| Load                    | : the amount of electric power delivered or required at any point on a system  |
| Run –of- river          | : a hydropower project that generates at the rate of inflow without change as a result of storage in a reservoir   |
| Tail race               | : a structure through which a power house discharges flow into the river or other receiving water  |
| Power house             | : a structure that contains the turbine and generator of a hydropower project  |
| Demand factor           | : a ratio of the maximum demand of a system to the total connected load on the system. It is always less than 1.   |
| Diversity factor        | : the ratio of the sum of the individual maximum demands of various parts of a power distribution system to the maximum demand of the whole system. It is usually more than 1.         |

## CHAPTER 1

### INTRODUCTION

---

#### 1.1 Rural energy and international development context

In recent years, there has been an increased awareness of the importance of energy for rural development. The provision of efficient, affordable, reliable and clean energy to rural areas has been identified as one key challenge to be addressed with a view to reduce poverty in developing countries. Moreover, improving access to electricity in rural areas is claimed to be key to economic growth and increased quality of life.

The linkages between energy and poverty have been a subject of discourse on international development agenda. This is reflected in the growing number of publications addressing the linkages between energy and poverty as an integral component of poverty reduction strategies. For instance, Rebelo (2003) mentions United Nations, World Bank and other bilateral donor country publications such as "Energy after Rio" (UNDP, 1997), "Energy services for the World's Poor" (World Bank, 1999), "Energy and the challenge of sustainability" (UNDP, 2000), "Energy for the poor-Underpinning Millennium Development Goals" (DFID, 2002), "Energy for Sustainable Development" (UNDP, 2002), just to cite but a few. Most of these reports emphasize the importance of improving access to modern energy sources with a view to achieving poverty alleviation.

Rebelo's (2003) study provides a comprehensive list of other relevant publications that this study has consulted. More elaborated overviews and for references for further reading can be found in, inter alia, UNDP(2005); WEC(1999); IEA(2002); and Chaurey et al.(2004:1693-705). In addition, major energy poverty nexus analyses and studies show that energy has close links with sustainable development, human development index (HDI), Millennium Development Goals-poverty, gender disparity, and environmental quality (UNDP, 1997; DFID, 2002).

A number of impact and case studies have demonstrated that energy has a direct impact on the welfare of people. Electricity in particular, facilitates productive activities such as agro-industrial

production that create jobs and generate income (Kanagawa and Nakata, 2005). It provides social services like safe drinking water, adult and child education, public health care, gender equity (Chullakesa, 1981; Ramani et al., 1993) and contributes to overall environmental sustainability. There is no doubt therefore, that the provision of electricity to rural areas helps alleviate poverty and facilitates economic development. In this context, rural electrification is one of the main infrastructure development requirements that deserve to receive significant attention.

While efforts have been made to improve access to electricity in urban areas, services in rural areas remain largely inadequate. The majority of the world's population lacks a number of facilities because of poverty and insufficient access to energy. According to the International Energy Agency (IEA), about 1.6 billion (30%) people in the world lack access to electricity (IEA, 2002). More than 80% of these people live in rural areas, mainly in Sub-Saharan Africa and South East Asia. As a result, the major conditions necessary to satisfy basic needs and socio-economic development as mentioned in the preceding paragraphs cannot be fulfilled.

Major reasons given for this low access range from low demand for power in rural areas to dispersed population in villages which make it impossible to set up transmission and distribution systems, high costs of production and distribution and the costs of subsidies and capital (Kanagawa and Nakata, 2005; Chullakesa, 1981; IEEA, 2005). Given this alarming situation, it is apparent that rural energy problems in most developing countries and sub-Saharan Africa in particular, will continue to be the major causes of underdevelopment and poverty unless timely interventions are made. Alternative approaches for providing modern energy services for economic and social development should be investigated.

Additionally, projections for the next three decades show that the problems of access to modern energy will continue to grow. According to the World Energy Council, the world's population is likely to reach 8 billion in 2020 and 10 billion in 2050. The energy needs to supply this population would be more than 50% higher than at present. An annual growth rate of 1.6% is expected (WEC, 2005).

Similarly, the 2002 IEA report observes that without additional effort, by 2015, the number of people depending on biomass fuels would grow from 2.4 billion in 2002 to 2.5 billion in 2015 (2.6 billion in 2030), mostly in India and Africa. IEA cites rapid population growth and increasing rate of urbanization as major reason for this increase. Population in Africa is projected to grow by 27% from 583 million in 2002 to 823 million in 2030 (IEA, 2002).

Furthermore, the use of traditional biomass fuels (wood, charcoal, crop residues and animal wastes) to a greater degree contributes to deforestation or indoor and outdoor air pollution (WEC, 1999). Indoor air quality exposes women and children to high levels of toxic smoke and leads to respiratory ailments (UNDP, 1997; World Bank, 1999; UNDP, 2000; DFID, 2002; UNDP, 2002; UNDP, 2005; WEC, 1999, IEA, 2002). Examples of respiratory ailments associated with indoor air pollution include acute respiratory infections (ARI), chronic pulmonary diseases, asthma, lung cancer, eye irritation (cataract) and reduced birth weight.

Analytical results available show that indoor air pollution causes 1.6 million deaths each year and accounts for 2.7% of the global burden of diseases (GNESD, 2006). It is further estimated that by 2030, about 10 million premature deaths among women and children will be caused by smoke from wood fires used for cooking (Bruce et al, 2007). Malawi, with high infant and maternal mortality rates is no exception. There is no doubt that a significant proportion of the high mortality rates is caused by indoor air pollution.

Moreover, the traditional energy sources force women and children to spend time collecting fuel. Studies conducted in South Indian villages found that women and children spend between 2 to 6 hours each day collecting wood and walk an average of 4 to 8 km (DFID, 2005). A 1994 pilot integrated rural transport project in Malawi found that women and girls spend annually about 143 hours travelling to collect wood (Semu & Mawaya, 1999).

Similar studies in Nepal have reported between 200 and 300 person days per year per household. This undermines their efforts to engage effectively in productive activities or improve the quality of life (Barnes and Floor, 1996:497-530). There are also risks to health from carrying heavy loads and dangers from landmines, snake bites, and violence. Children are at risk of burns and

scalds, resulting from falling into open fires and knocking over pots of hot liquid (World Bank, 2001). In spite of these, people in rural areas have little choice but to meet their basic energy needs in this environmentally unsustainable and unhealthy manner. Consequently, satisfying the basic human needs and achieving poverty alleviation cannot be done without improving access to better energy services.

For the specific case of Malawi, it is estimated that only 7.5% of the population has access to electricity, and only 0.8 % of rural population enjoy the benefits attributed to electricity (DoEA, 2006:4). The objective of this study is to promote increased access of the population to electricity in rural areas of Malawi. A study of this nature is in tandem with international commitments on poverty and the need to improve energy access for the poor. These include among others, the Millennium Declaration, Johannesburg Plan of Implementation, New Partnership for Development and the Kyoto Protocol (DFID, 2002; UNDP, 2005; UNDP, 2002).

The present study concentrates on the utilisation of small-scale hydropower as an option for rural electrification in Malawi. Specifically, the study estimates the hydropower potential of a site; undertakes a survey to estimate energy consumption of the target community; makes a rough technical design of the hydro electric power plant; estimates the investment and operation and maintenance costs; and finally, compares implementing a small hydro-based rural electrification project with other alternatives such as diesel generation and a diesel-hydro hybrid system. The study has taken a typical village in Malawi as a representative case study to investigate feasibility of small-scale hydropower based electrification, taking into consideration technical, socio-economic and environmental factors.

## **1.2 Energy issues facing Malawi**

Approximately 93% of Malawians are currently without access to commercial energy and therefore, depend on firewood and crop residues for cooking and water heating, and paraffin for provision of light (Gondwe & Chipofya, 2000:2437-2440; MEM, 1997:11-16). The use of traditional forms of energy is however, contributing to environmental degradation through deforestation, soil erosion and emission of gaseous and particulate matter (GoM, 2002:19).

Moreover, the traditional forms of energy deprive rural people of basic social services such as safe drinking water, education, and health care. The fuels have adverse effects on health, including causing acute respiratory illnesses in women and children (Melillo, 1996:293-310). The need for alternative forms of energy supply to these areas is becoming increasingly apparent.

Numerous studies in African, Asian and South American countries confirm that providing electricity to rural areas can substantially contribute to improved living conditions and development. These have been widely discussed in several papers (Barnes & Floor, 1996:497-530; Sinha & Kandpal, 1991:441-8; Cabraal et al, 2005:117- 44; Ramani, 2005; Martinot et al, 2002:309-348; Srinivasan, 1981). Most of these papers have argued convincingly that rural electrification could support both economic and social upliftment.

Rural economic sectors that can be supported by off-grid electrification include agricultural and domestic pumping, agriculturally related industries (woodworking shops, vehicle and farm-equipment repair shops, vegetable and fruit processing shops, food and commercial shops (Chullakesa, 1981). Examples of the social sectors are residential lighting and public lighting, radio– television education for children and adults, health and medical facilities, the water–supply system and domestic appliances (irons, fans, refrigerators, cookers, radios, televisions etc) (ibid). It is therefore highly desirable that efforts should be made to ensure that all people are provided with electricity at some stage so that they can share in its benefits.

As stated at the beginning of this chapter, the current level of electrification continues to be woefully low, a clear indication that electrification programmes implemented since independence have registered little progress. Estimates by the Department of Energy Affairs place the national electrification level at 7.5 %. This translates to 30% of urban and 0.8% rural population, respectively (DoEA, 2006:4). Compared with other Southern Africa Development Community (SADC) countries, equivalent proportions are: Zimbabwe, 35%, Zambia, 18%, Tanzania, 10%, Mozambique, 7% to cite but a few. The SADC region has an average electrification rate of about 20 % (SADC, 2003; DoEA, 2006:4). It is therefore, a daunting challenge for Malawi to increase the electrification level in order to catch up with her peers.

Rural people in Malawi have been disproportionately disadvantaged and for a long time denied access to electricity. As a result, they lag behind their urban counterparts in terms of access to modern infrastructure and social services (e.g. education and health services). They have low disposable incomes, and make do with solid fuels and inefficient stoves whose health and economic consequences contribute to keeping them in poverty (GoM, 2002:12). There is no doubt that for the rural people to move out of the poverty trap, government needs to invest in energy infrastructure to rejuvenate rural economies. In this respect, rural electrification provides a springboard to reducing energy poverty in these areas.

Provision of electricity in rural areas through extension of the grid is one of the strategies articulated in various policy documents. These include among others, the Malawi Poverty Reduction Strategy (MPRSP), National Energy Policy and National Sustainable and Renewable Energy Programme (GoM, 2003; MEM, 1997:42-77; GoM, 2002:40-43). These documents have accorded high priority for government to improve problems affecting the energy sector in general, and rural development through on-grid and off-grid electrification.

Although efforts have been made to increase electrification levels in rural areas, it is only trading centres that are targeted. The rural electrification programme currently being implemented, extends the distribution lines to trading centres and consumers pay a high initial connection fee of more than MK10, 000 (DoEA, 2003). This is beyond the affordability of most people in and around the centre. Obviously, this approach will not address the electrification needs of the majority of households in villages. There is need to have a separate programme whose objective is purely for poverty alleviation.

Additionally, extending grids to rural areas is currently uneconomic due to the cost of infrastructure, dispersed nature of the population, low consumption and poor load factors (MEM, 1997:15). Furthermore, a severe constraint to the development of the power sector by the national utility has been the high transmission and distribution losses (estimated at 18%), difficulties in billing and collection, and continuing capacity shortages (GoM, 2001:20). These reasons contribute to making grid extension to rural areas impractical. Clearly, this shows that energy supply problems in rural areas will not be solved by grid extension through the

conventional way in the short to medium term. To help meet this need, the use of decentralized stand-alone systems such as small-scale hydropower is strongly encouraged.

### **1.3 Small-scale hydropower development in Malawi**

Small-scale hydropower presents a technically and commercially viable alternative to grid extensions. It can be exploited on a small scale; is highly reliable, cost effective and environmentally benign. The capital requirements for such small hydro schemes are lower than for large hydro (Paish, 2002:537-556). In addition, their modular nature allows even the poorest country to begin a phased energy investment program that does not strain their national financial resources or draw funds from other basic needs (Kalitsi, 2003).

Although numerous studies aimed at harnessing the hydropower potential in Malawi have been undertaken in the past, the analytical focus has been on large hydropower. For example, a World Bank sponsored study conducted by Tippetts-Abbot-McCarthy-Stratton hereinafter referred to as TAMS, investigated major hydro projects on the middle part of the Shire River, and a few sites on Bua and South Rukuru rivers (GoM, 1986:7-26). A low-cost power development study undertaken by the same consultants (TAMS) found most sites uneconomic. As a consequence, only Kapichira project (refer to chapter 2, section 2.4) has been developed. A fresh study to update the costs is likely to produce similar results.

As stated above, little attention has been paid to the development of small-scale hydropower. A United Nations Department of Technical Cooperation for Development (UN/DTCD) mission examined the possibility of constructing small hydropower stations. The mission identified 12 potential sites and these are mainly in the North of Malawi on Songwe, Rukuru (3990 kW), Bua, Lufira (1070 kW), Wovwe (1400 kW) and Kalenje (150 kW) rivers (MEM, 1998:28). However, due to paucity of hydrological data no firm conclusions were made.

More recently, JICA has assessed 35 of the 100 potential sites - for rural electrification based on the Nation Water Resources Master plan and found only 11 sites to be suitable for micro-hydro electrification. The characteristics of the sites are presented in table A.6, annex A. This study builds on and contributes to work done by JICA in order to include small-scale hydropower

generation in the energy supply mix for Malawi. The major contribution of previous studies is the thorough analysis of environmental implications of undertaking such projects.

Coincidentally, the recent national energy policy and other documents have demonstrated strong commitment from government to set up stand-alone mini- grids as a way of accelerating rural electrification. Central to these projects is detailed technical and economic data on a candidate site for its selection. A simple but purposeful decision support system in the appraisal of a site is required.

This study investigates the potential contributions expected to be derived from the available small-scale hydro resource in Malawi. It further provides the necessary technical and economic details to support informed decision making. The case studies included in chapter 3 seek to elucidate how small-scale hydropower could provide a suitable basis for: initiating electricity supply to rural communities, stimulating growth of electricity demand in rural areas for micro, small and medium enterprises, lighting, basic health and education services; easing the high pressure of foreign exchange required for rural electrification; and mitigating climate change issues.

#### **1.4 Research Problem**

Poverty in Malawi is widespread, deep and severe. More than 6.3 million people (65.3%) live in poverty<sup>1</sup> (GoM, 2002:5). The overwhelming majority of these people are characterised by low literacy level, poor health status and limited off-farm employment. These indicators are, largely, the result of relatively low consumption of commercial energy.

Around 93% of the population in Malawi is not connected to the national grid (Gondwe & Chipofya, 2000:2437-2440). These people depend on wood-based fuels for cooking and heating. However, collection of these fuels is difficult and its availability is becoming increasingly scarce. Continued use of wood fuel is contributing to an alarming deforestation (2.8% per annum) and environmental degradation (DoEA, 2006:1-5). As a result of deforestation, forest cover for Malawi has reduced from 34% in 1984 to 26% in 2004 (Zingano, 2005). Minimized use of wood fuel in rural areas where the majority of people live will invariably reduce the emissions of

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<sup>1</sup> The poor are defined as those whose consumption(food and non-food) is below 35 US cents per day

carbon dioxide and other greenhouse gases into the local environment. This study also explores the contribution of small-scale hydropower based rural electrification in reducing environmental degradation in Malawi.

Secondly, the present level of electrification (0.8%) in rural areas is undesirable. Although government aims to provide electricity to most rural households in Malawi, it appears it will not be feasible to connect them in the short and medium term. Extension of the national grid is far from the priorities of Electricity Supply Corporation of Malawi (ESCOM). The commercialization of ESCOM means that the utility is now governed by purely economic considerations. Under these circumstances, it seems that the rural economy where the majority of people are subsistence farmers, fail to provide the minimum requirements to make it financially attractive for ESCOM or other commercial investors (MEM, 1997:14-15). This clearly indicates that access to electricity will remain a major constraint in improving the living conditions for rural people.

Another method to provide electricity to rural areas would be to install diesel generating units, which have a low investment cost when compared to other sources. However, the rise in fuel costs has made the operation of diesel plants more expensive and less attractive. In addition, diesel engines emit smog-forming pollutants and their impact on public health is undesirable. Sulphur dioxide (SO<sub>2</sub>), nitrous oxides (NO and NO<sub>2</sub>) and other particulate matter (PM) emitted by diesel engines contribute to greenhouse effect (Silveira, 2007:524-535). Therefore, this study forms one step that will lead to small-scale hydropower playing a significant role in increasing electrification levels and reducing green house gas emissions in Malawi.

### **1.5 Research objectives and questions**

The overall objective is to promote increased access of the population to electricity in rural areas in Malawi. This study investigates the potential contribution of small-scale hydropower to national electrification coverage as well as improving environmental quality. It further promotes decentralization of electricity generation in Malawi.

The specific objectives are as follows:

1. To assess the feasibility of using small-scale hydropower for rural electrification;
2. To determine supply and energy demand requirements in the target communities ;
3. To examine the linkage between households income and willingness to pay for electricity;
4. To determine the green house gas (GHG) emission mitigation by the use of small –scale hydropower;
5. To identify policies and measures that promote small-scale hydropower based rural electrification programmes.

To achieve these objectives, the following tasks were undertaken:

1. Preliminary site survey and stake holder consultation on the need for the project;
2. Energy supply and demand study and socio-economic survey;
3. Assessment of the hydrology, geology and topography of the site;
4. Conduct techno-economic studies for community electrification in the target area.

### **Research questions**

The study is designed to answer the following key research question:

*What is the potential of utilising small-scale hydropower to increase electrification level and reduce green house emissions in Malawi?*

The following subsets of questions have been posed to seek answers to address the above objectives:

- How much small-scale hydropower potential exists and which category can make the best contribution to rural electrification in Malawi?
- What are the energy demands and how much of these can be met by small-scale hydropower?
- To what extent can small-scale hydropower contribute to the reduction of environmental degradation in Malawi?
- At what price should electricity be sold so that most rural households can afford connection?

## 1.6 Study hypothesis

The study is based on the following hypotheses:

1. Small-scale hydro schemes in areas with hydro potential could play a significant role in meeting energy needs of rural areas;
2. Small-scale hydro schemes can contribute to reduction in environmental degradation;
3. Rural electrification levels in Malawi could be improved through local generation of power;
4. Effective policies and measures lead to successful rural electrification programmes;
5. Income levels determine the probable source of energy used in households.

## 1.7 Scope of work

The study investigates the potential of small-scale hydropower in improving the rural electrification levels in Malawi. The study is confined to the assessment of one potential site to meet energy needs of the community surrounding the area. However, results of this study will be extrapolated to other sites listed in the Master plan for Rural Electrification in Malawi. The following future work is beyond the scope of this study but is needed before implementation of the project.

- Conduct a strategic environmental assessment<sup>2</sup> and environmental impact assessment<sup>3</sup> of the site;
- Establish a stream gauging station and monitor discharge flows for a period of not less than one year;

## 1.8 Assumptions

The following assumptions were made in the study:

- The project poses no negative impacts on the social and natural environment;
- Water abstraction at the proposed site will be licensed;
- The national utility will not electrify the area at least the next ten years.

## 1.9 Significance of the study

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<sup>2</sup> Strategic Environmental Assessment refers to issues covering a larger geographical area

<sup>3</sup> Environmental Impact Assessment has a greater focus on a particular project at a particular location

Scenario projections indicate that Malawi's primary energy use will grow at an average annual rate equivalent to 15MW<sub>el</sub> (Venendaal, 1996:11). Demand for electricity is forecast to grow at an annual rate of 6 - 8% (DoEA, 2003). The increasing trend is due to the combined effects of its expanding economy, growing population and higher disposable income, which provides a strong growth in energy demand. Increased utilisation of renewable energy technologies such as small-scale hydropower will not only boost the energy supply base but also reduce adverse environmental impacts of energy usage.

Furthermore, investing in small-scale hydropower will invariably derive important benefits at local level. The key benefits would include among others: (1) improved household food security through increased agricultural production, (2) provision of electricity for small-scale industries and social services such as education and health care. (3) Electricity, will to some extent substitute the use of paraffin and diesel for cooking and lighting, (4) it will also reduce the time spent in collecting wood fuel and this contributes to the reduction in drudgery. A study of this nature that promises to improve the quality of life among rural households cannot be overlooked. Energy planners can use results of this study as a reference in local production of energy compared to conventional energy sources.

### **1.10 Limitations of this study**

The major problems experienced in this study relate to data availability, time available for the research, and inadequate funding. This section will explore each of these in turn.

**Data:** The study is limited by the quality, consistency and extent of data available.

Meteorological data (rainfall, pan evaporation, sunshine) and topographical maps of sufficient detail for the area of interest were not available. The nearest gauging station located on Nswazi River was relocated 5 km away. This makes river flow data inconsistent. Key documents such as Evaluation of Small Hydropower Potential in Malawi and the Power Sector and Operation Study and the so-called TAMS report could not be found from ESCOM, UNDP offices or the Department of Energy Affairs. As a result, this study has used information contained in both master plans for rural electrification and water resources respectively.

**Time and Funds:** The limited funding and timeframe in which to conduct this research has affected the amount of data, available to the research. The lifespan of this project was five months. In addition, insufficient funds were made available to this research. Therefore, some activities were streamlined to accommodate the timeframe and available funding.

**Sample size:** The study was conducted in one village. This is insignificant considering that there are over 40,000 villages in Malawi. This will negatively affect the outcome of any statistical inferences drawn from results of this study.

### **1.11 Structure of the thesis**

This thesis consists of seven chapters and is organised as follows:

Chapter 1 provides background information leading to the statement of this study. It defines the objectives, methodology, scope of work and limitations.

Chapter 2 presents an overview of the prevailing energy situation in Malawi as well as water resources available that are relevant for development of small-scale hydropower for rural electrification. Also presented in this chapter, is a brief discussion on the national energy policy and rural electrification in Malawi.

Chapter 3 discusses some issues and concepts that are essential for rural electrification. It attempts to backup the study with present state of knowledge on the subject. The focus is on an international survey on rural electrification. This is very important to this study as it sets out a scene that describe conditions that led to success in the implementation of rural electrification programs cited through the case studies presented in this chapter.

Chapter 4 looks at the theoretical aspects which must be considered when assessing the hydropower potential of a site, designing and costing of small-scale hydro projects. Methods applied in carrying out the study are presented in chapter 5 and this is followed in chapter 6 by results of the socio-economic survey, energy demand study as well as hydrological studies of the site under study. Chapter 7 summarizes the research findings, results, conclusions and recommendations for future work.

## CHAPTER 2

### REVIEW OF ENERGY AND POWER SECTORS IN MALAWI

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This chapter presents a brief review of the energy and power sector in Malawi. The review is necessary in order to provide useful information to energy planners for them to assess ways of integrating the use of small-scale power generation to achieve part of the rural electrification needs of the country. An overview of the present and future energy situation and related energy policies in Malawi is provided. Energy resources, their current potential and factors affecting the resources themselves are also included.

#### **2.1 Geography and Demography**

Malawi covers a total surface area of 118, 484 km<sup>2</sup>. The country is landlocked, and borders Tanzania to the north, Mozambique to the east and south, and Zambia to the west (Figure 2.1). It occupies a narrow strip of land along the East African Rift Valley and stretches from north to south for about 900 km and its width varies from 90 to 161 km. The average elevation is about 1200m, with a maximum elevation of 2600 m in the north and 3000 m in the southern Shire Highlands (NRCM, 1999).

Lying between latitudes 9° 40' and 17° 30'S and longitudes 32°41' and 35°56'E, Malawi has a subtropical climate. There are three distinct seasons: cool and dry season (May to August); warm and dry season (September to November), and a warm and wet season in (November to April). The main rain bearing system is the Inter Tropical Convergence Zone (ITCZ). This is a broad zone in the equatorial low-pressure belt towards which the north-easterly and south-easterly trade winds converge. This produces wide spread rains throughout Malawi (Kamdonyo, 1988: 5- 9).

According to the latest Central Intelligence Agency (CIA) estimates, the population is at 13.6 million people, and 85% of them live in rural areas (CIA, 2007). This is slightly more than the projected figure of 13.2 for the year 2007. The annual growth rate is at 2.383% compared to historical average of 3.2% (NSO, 2007; CIA, 2007). However, based on the current trends, it is

projected that the population will reach 22,245,431 million by 2023 (NSO, 2007). This increase in population will undoubtedly present major challenge to the energy sector in Malawi.



Source: Banks & Gondwe (2005:85)

Figure 2.1: Location Map of Malawi

## 2.2 Energy Situation

This section gives an overview of the present energy situation in Malawi.

### 2.2.1 Overall present energy situation

The energy situation is characterised by a huge gap between supply and demand, high domestic consumption, insufficient electricity supply and expensive commercial fuels. This leads to extreme dependence on non-commercial fuels, high pressure to use biomass fuels and environmental degradation. The country's key energy indicators presented in the table 2.1 below illustrate the low energy development, in terms of either consumption or connection to the grid.

**Table 2.1 Key Energy Indicators for Malawi**

|   |                           |
|---|---------------------------|
| Total primary energy supply/capita/year   | 0.29 toe/capita (1998)    |
| Electricity consumption/capita/year   | 88.362 kWh/capita (2007)  |
| Percentage of people connected to the electricity grid  | 7.5% of the population    |
| Average annual growth rate of electricity use   | 6%                        |
| Percentage of energy consumption met through biomass energy   | 93%                       |
| Percentage of renewable energy in total consumption based on primary energy use (excluding biomass and large hydro) | 0.2% solar and geothermal |

Source: DoEA (2001:9), DoEA (2006:4), CIA, 2007

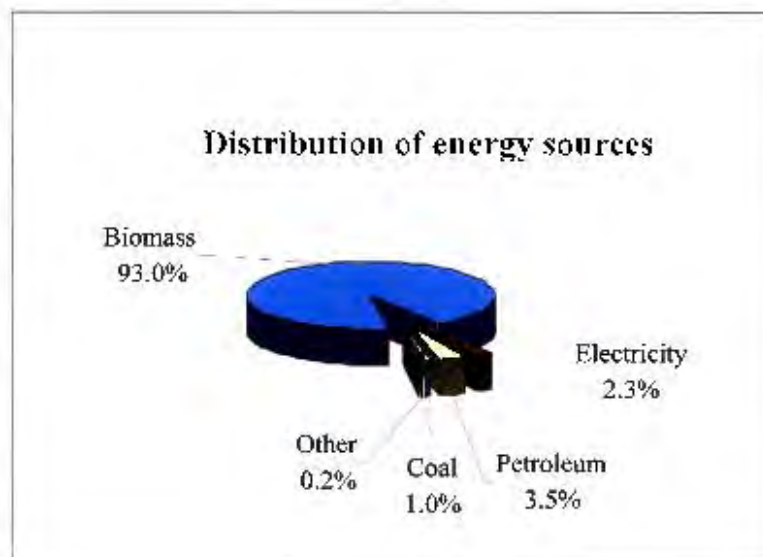
### Energy Markets and Governance

As stated above, Malawi has a population of about 13.6 million people and a GDP of about US\$170 per capita. Hence, its energy consumption per capita is relatively smaller than most SADC countries and therefore, has a small energy market. The Electricity Act, 1998, that was based on a liberal market structure, was repealed in 2004 to accommodate the reform structures proposed by the National Energy Policy of 2003. As a result, the Department of Energy Affairs, which falls under the Ministry of Energy and Mines (MEM), is now responsible for formulating policy and off-grid electrification. Electricity Supply Corporation of Malawi (ESCOM) is the government-owned entity that generates, transmits and distributes grid electricity nationally (where financially and economically viable).

The National Electricity Council (NECO) regulates the electricity sub-sector; issues licenses for generation, transmission and distribution; sets and controls electrical standards; and approves electricity tariffs. Petroleum Importers Limited (comprising BP Malawi, Exxon Mobil, Total Malawi, Caltex and Petroda) imports petroleum products in Malawi. The Petroleum Control Commission (PCC) establishes and enforces prices for petrol, diesel and paraffin.

### Energy resources and perspectives on its utilisation

As is the case in most developing countries, Malawi's energy sector comprises of three subsystems: traditional (biomass), conventional (petroleum, coal and electricity) and non-conventional (alternative) energy sources. Energy consumption is mainly based on biomass. A recent report published by the Department of Energy Affairs shows a primary energy profile in which biomass still remains the predominant source of energy and accounts for 93% (DoEA, 2006:1). Commercial fuels account for the remaining 7% in the following proportions: imported petroleum products (including ethanol) 3.5%, electricity 2.3%, and coal 1.0%. Non-conventional renewable sources (excluding biomass) are not developed and account for 0.2%. Hence, their impact on the overall energy balance is still insignificant. Figure 2.2 shows the distribution of various energy sources.



Source: DoEA, 2006:1

Figure 2.2- Distribution of energy resources

## Coal

Energy resources in the country are substantial and diverse but little has been exploited so far. Probable coal reserves are estimated at 1 billion metric tonnes, 22 million tonnes of which are proven reserves of a bituminous type. Coal deposits occur in 12 dispersed locations in the country, the largest being at Ngana in the north, where proven<sup>4</sup> reserves have been estimated at 16 million tonnes and possible reserves of 70 million tonnes (MEM, 1996:2). Although coal mined in the country is of high quality, Malawi remains a net importer of coal mainly from Moatize in Mozambique. Table A.1 presents details of coalfields, quality and estimated quantities. Major factors limiting maximum utilization of this resource include; thin coal seams covered by thick overburdens which makes excavation expensive, lack of appropriate technology for use in household settings, and due to the fact that most of coal users are located in Blantyre (900 km to the south). Moatize is only 90 km from Blantyre. In addition, poor road infrastructure and lack of suitable ships makes transportation of coal very expensive (MEM, 1996:2).

The landed cost of coal is uneconomic relative to substitute fuels. For example, in 1997, the landed cost of coal from Mchenga coal mine in Blantyre was US\$55 per tonne. This was three times higher than coal from Moatize which was at US\$17 per tonne (MEM, 1997:13). Furthermore, the TAMS report found it uneconomical for Malawi to consider using this coal for thermal power stations (UNDP/GoM, 1986:39).

## Petroleum

Malawi has no known oil or gas reserves and thus imports 97% of its petroleum products (diesel, petrol, paraffin, LPG, jet-A1 and avgas). The remaining 3% is met by ethanol, produced locally and blended (20:80 ratio) with petrol (GoM, 2001:25). The prices for the imported fuels are strongly dependent on the global economic and political conditions and threaten the energy security of the country. For example, in 2004, Malawi spent about MWK11 billion (USD75, 940 million) for 258.5 mega litres, which represents around 10% of its foreign exchange on oil imports (MoEPD, 2006). The total annual cost for paraffin imports is around MWK862.92 million (USD 5.95 million) for 22.026 mega litres. Tables A.2 and A.3 show the annual fuel

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<sup>4</sup> Proven reserves are those for which further exploration is not required for mine planning

imports and associated costs from the year 2000 to 2005. As is evident from the table A.3, energy imports significantly drain the scarce foreign exchange for this poor country.

### **Renewable energy resources**

Renewable energy resources (except for large hydropower and biomass) account for 0.2% of the country's total energy consumption (GoM, 2003). However, Malawi has abundant solar energy resources. The whole country receives an annual total insolation that exceeds 2139 kWh/m<sup>2</sup> with more than 3000 hours of sunshine a year (ibid). Average solar radiation is 21.1 MJ/m<sup>2</sup> (244 W/m<sup>2</sup>). The level of solar radiation is highest during November-December with an average of 300 kWh/m<sup>2</sup> and lowest June-July 210 kWh/m<sup>2</sup>. Peak hourly solar radiation is more than 1000 kWh/m<sup>2</sup> during November – December (Chima, 1998:3-8).

Hydropower potential is assessed at 900 MW. A major assessment of the prospects for large scale production of biomass for energy has been carried out. The assessment shows that plantations could be established on about 53,000 hectares of land. If that much biomass were solely to generate electricity using gasifiers, it could provide 50 MW of electricity per year (SADC, 2003). However, this figure seems to be inaccurate since the calculations were based on Viphya plantations only. Given that forest area covers 37% of total land area in Malawi, the potential is more than what has been reported in literature.

### **Electricity**

Electricity is generated locally at the following hydroelectric plants: Nkula Falls (124 MW), Tedzani (91.6 MW), Kapichira (64 MW), Wovwe (4.5 MW) and thermal plants; gas turbine unit (15 MW), three diesel units (6.4 MW). At present, the total national installed capacity is 355.3 MW. ESCOM's total combined installed electricity capacity is 304 MW. Out of this, 285 MW (94%) comes from hydropower and 51.3 MW from thermal. ESCOM has a length of 8,500 km of distribution lines (4500 km for 33kV and 11kV, and 4000 km for 0.4 kV and 0.23kV lines) and 1800 km of transmission lines (960 km for 132 kV and 820 km for 66 kV) and currently maintains the above power stations serving just over 100,000 customers nationwide (DoEA,2003). Electricity from photovoltaic (PV) systems is relatively insignificant; about 4582 systems, equivalent to 165kWp has been installed (Banks &Gondwe, 2005).

### **Energy consumption in Malawi**

A summary of consumption per fuel group is given in table A.4. The figures show an increase in annual total primary energy consumption from 177 PJ in 1997 to about 207 PJ in the year 2003 (DoEA, 2007). The per capita energy consumption is only available for 1998 and is estimated at 0.29 toe per year (GoM, 2001:9). This is significantly lower than the SADC per capita energy consumption average which is estimated at 0.65 toe per year (SADC, 2003). As is evident from table A.4, biomass meets 93.7% of the energy needs followed by petroleum (4.4%), electricity (1.6%), coal and other renewables (0.3%) respectively. There is a slight increase in the consumption of biomass and petroleum, largely attributed to increase in population. Electricity consumption has decreased significantly from 2.3% to 1.6% at the end of the reference period. A probable explanation to this reduction is lack of a comprehensive database on energy production and consumption.

According to DoEA, biomass comprises firewood (80%), charcoal (8.8%) and crop/ industrial residues (11.2%) and satisfies 99% of household energy. The remaining 1% comes from electricity (lighting and cooking), paraffin and candles (lighting). At present, electricity consumption in Malawi is estimated at 930.6 GWh and represents an approximate per capita consumption of 88.362kWh/year (CIA, 2007). Estimates show that electricity demand has been growing at 6-8% per annum. About 60% of electricity is consumed by the industry and large commercial consumers, while domestic users account for 25% (GoM, 2001:19).

### **Sectoral consumption of energy**

Figure 2.3 shows the breakdown of energy consumption by sector. The household sector accounts for 84% of total consumption. The remaining 16% is used in agricultural and natural resources sector (8%), transport (4%), industry, construction and mining together (2%), and 2% for other social services. Of commercial energy (liquid fuels, electricity and coal), transport is the largest consumer (43%), followed by industry and mining (19%), other services (18%), agriculture (12%) and households (8%) (GoM, 2001:17).

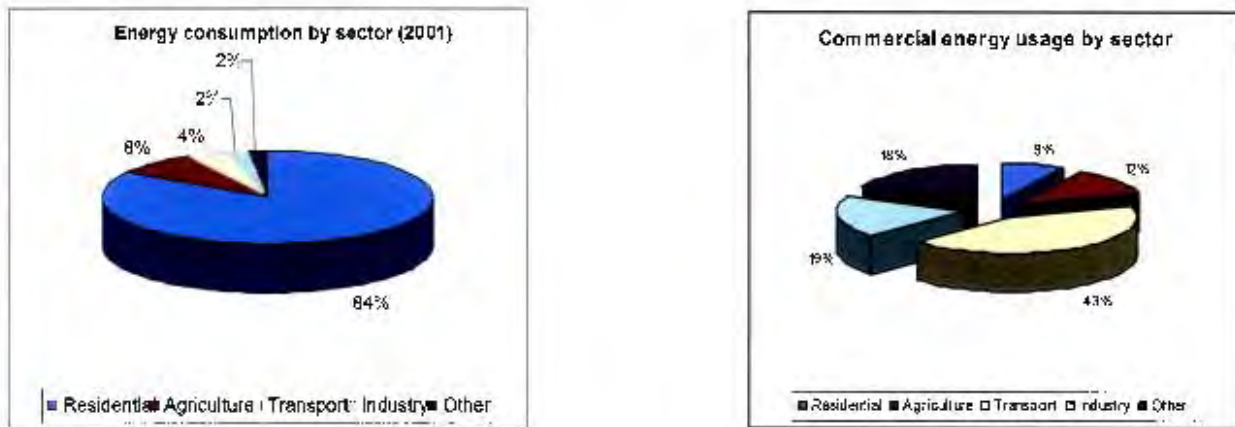
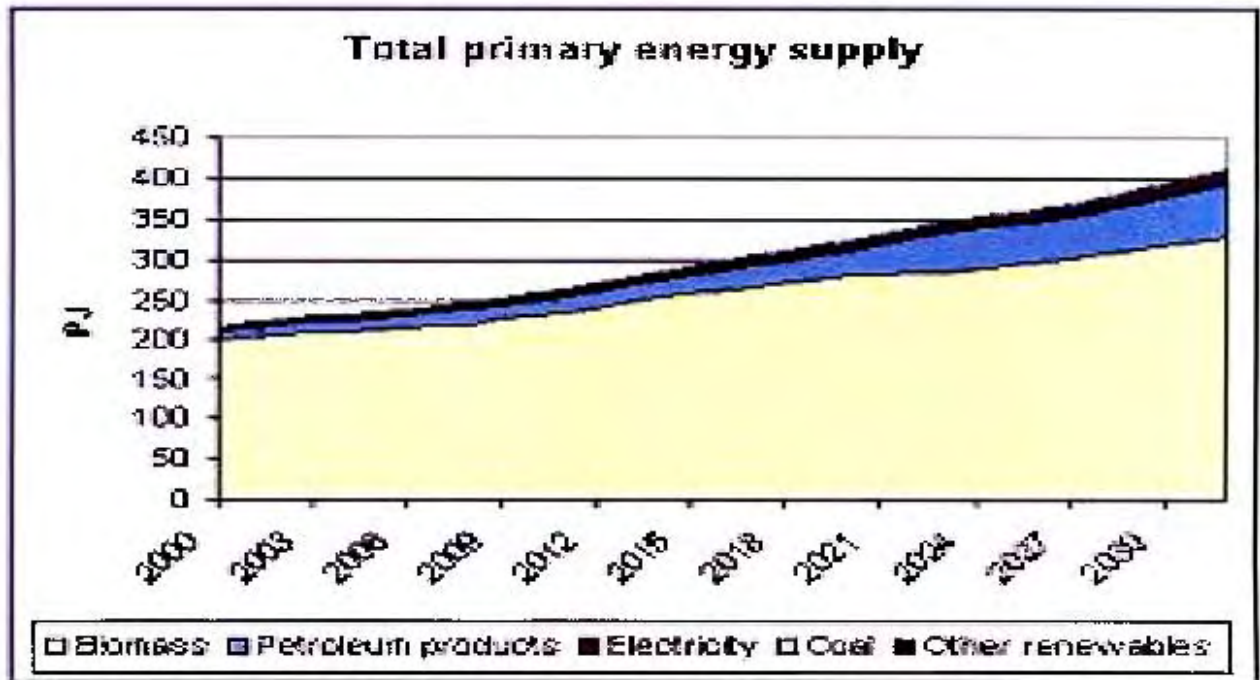


Figure 2.3: Total energy use by various sectors in Malawi

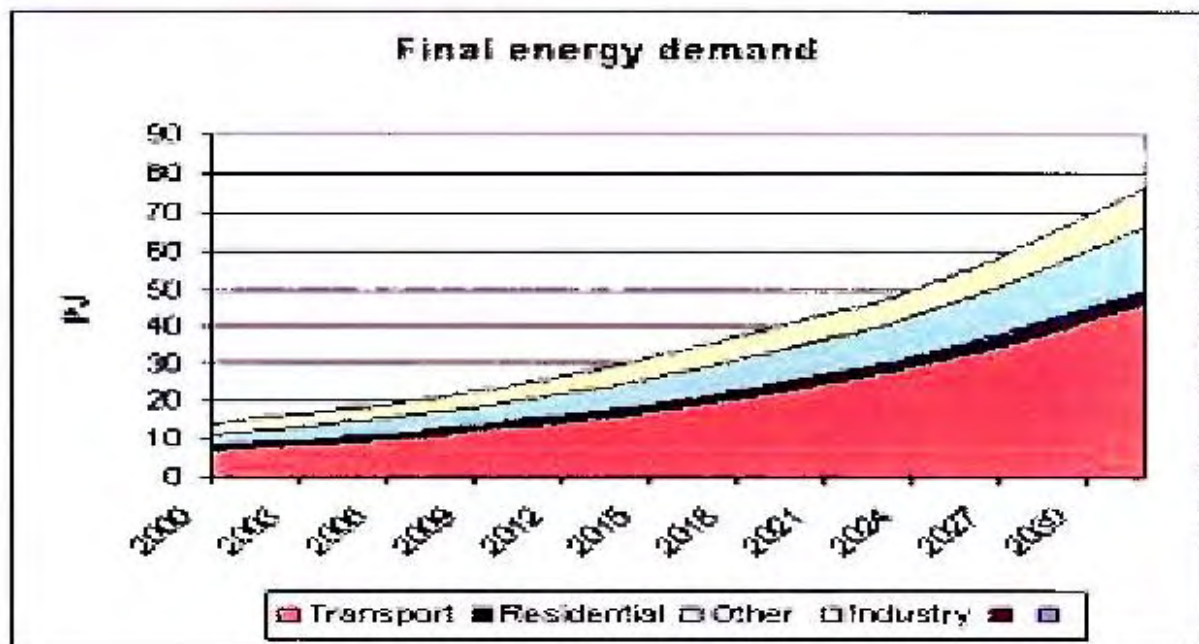
### 2.2.2 Energy demand and supply projections

Figures 2.4 and 2.5 present the projected energy demand and supply situation in Malawi over a period of 35 years. Detailed discussions of the scenarios for particular demand and supply sectors are provided by Alfstad (2005). As the forecast shows, the total primary energy supply is expected to increase from about 200 PJ to 400 PJ. Similarly, the final energy demand increases significantly from about 15 PJ to 75 PJ at the end of forecast period. A key observation to be made is that biomass will remain the dominant form of energy use in Malawi and its relative contribution to the total energy supply decreases from 93% in 2000 to 80% in 2030 (Alfstad, 2005). While this study finds difficulties in ascertaining the accuracy of data used to model the demand side, the forecast results however, suggest that energy policies will impact considerably on future energy demand in Malawi. Household income, availability of alternative fuels, their costs and availability, and affordability of rural people would determine the extent to which biomass consumption will decrease.



Source: Alfstad (2005)

Figure 2.4: Total primary energy supply



Source: Alfstad (2005)

Figure 2.5: Final energy demand

### 2.3 National Energy Policy

The national energy policy was finalised in 2003 and approved by cabinet in 2004. The overall goals of the energy sector are: *to promote overall socio-economic development; improve Malawi's competitive edge in the global economy; and contribute to poverty reduction through sustainable provision of reliable, efficient, affordable and equitable energy services in a liberalised market and; efficient utilisation of the available energy resources without compromising environmental, health and safety concerns* (GoM, 2003).

The policy stresses the significant role of rural electrification in improving the quality of life in the rural areas. At the same time, the task of electrifying the rural areas is left to DoEA-with neither a mandate nor an appropriate budget provision from core government sources. Such inconsistency is reflected in the unsatisfactory performance of rural electrification programmes. However, government has an ambitious plan of increasing the level of contribution of renewable energy technologies in the energy mix from 0.2% in 2000 to 7.0% in 2020. National electricity coverage of 30% is expected to be achieved during the same period (GoM, 2003). It has identified solar photovoltaic (PV) and small-scale hydropower as potential contributors to off-grid electrification in rural areas.

The government has enacted legislation, which allows private power generation, transmission and distribution. It encourages small electricity generation capacity of up to 5 MW by the private sector. Despite this enabling policy and legislation, there is virtually no private sector generation now. Major reasons given include (1) lack of interest, (2) restrictive tariffs currently set for the country's national utility and monopoly in distribution, and (3) lack of clarity on market arrangements, asset ownership, and regulation (DoEA, 2001:54). No comprehensive study has been undertaken to analyse the current policy documents and advise government on the best way to motivate private power generation.

With respect to small-scale hydropower development, the Energy Policy White Paper (2001:55-58), recognises the need to reduce green house gas emissions. It seeks to promote the use of clean fuels to replace high green house gas emitting fuels e.g. diesel power generating systems; and develop programs for carbon trading under the Clean Development Mechanism (CDM). Five

mini/micro hydro projects are expected to be implemented by 2020. However, going by the current electrification statistics, it appears the targets set are quite ambitious and unattainable. The policy is not clear about the effective mechanism through which the programme can be delivered.

#### **2.4 Hydropower resource potential and development in Malawi**

Hydropower potential in Malawi is relatively small, and limited. The estimated gross theoretical hydro potential is estimated at 15 000 GWh per annum. Technically and economically feasible hydro capacity has been estimated at 6000 and 7000 GWh per annum, respectively (WEC, 2002). Previous studies have concluded that there exists a significant potential for development of all categories of hydropower in the short and medium term in specific areas of the country. Table A.5 summarises the characteristics of large scale hydropower in Malawi. However, there is a large discrepancy in hydro resource development potential estimates for Malawi. DoEA conservatively estimates that the hydro resource is 900 MW (GoM, 2003). International publications show the potential to range from 900–1600 MW. This study has calculated the potential to be about 982 MW, which is reasonably within the 900–1600 MW limit estimated for Malawi.

As concluded by the past studies, analysis of results confirms that indeed, hydropower potential of Malawi is concentrated on Shire River. The capacity ranges from 18 MW to 140 MW. The estimated hydro potential of Shire River is about 600MW, equivalent to an annual production of 3500 GWh. Several smaller rivers such as the Songwe, South Rukuru, Dwangwa and Bua (figure 2.1), have limited potential at a number of sites estimated to total about 300-400 MW.

A number of government publications have given the impression that Malawi is relatively well endowed with huge micro and mini hydropower resource. The reports however, appear to be inaccurate and misleading. A study on hydropower potential in Malawi carried out by Kennedy and Donkin (MEM, 1997) clearly showed that there few micro, mini, and small hydropower generating sites along the rivers of the country. The potential project sites identified are shown in table A.6. Most of the sites are located in the northern part of the country. These have a capacity

potential of 7 MW which corresponds to an annual energy production of 28 GWh (DoEA/DANIDA, 1999:11). Lack of specific details posed a major challenge to come up with reasonable calculations and vet findings of the DANIDA study. As a result, the study has adopted Kennedy and Donkin's findings to represent practical mini hydro potential for the country.

## **2.5 Rural Electrification**

Rural electrification projects have been implemented in phases, since 1964. The first phase installed a total of 600 km of high voltage transmission and distribution lines. The second phase developed the 4.5 MW Wovwe Mini-Hydro Plant located in Karonga (in northern Malawi), with a total of 212 km of transmission and distribution lines completed by 1996. The third phase focused on major trading centres and tobacco growing areas. This project involved the installation of both high and low voltage distribution lines and utilized soft loans from Spain. The fourth phase however, has not been completed partly due to the commercialization of ESCOM in 1995. ESCOM found the project uneconomic and therefore, had no obligation to continue with rural electrification due to its large social component with low returns on investment. The Department of Energy has since then assumed responsibility for managing rural electrification.

DoEA is now implementing phase five of the rural electrification project guided by the master plan developed with technical and financial support from the Japanese Government. This master plan has been developed to serve as a roadmap to prepare action plans for achieving the national target of 30% electrification by 2020. A total of 249 trading centres are planned expected to be connected to the national grid, by the year 2020. 52 trading centres will be electrified in each phase. Given that a large proportion of investment costs is to be provided by donor funds, in the form of grants, it is unlikely that the plan will be achieved within the planned period.

### **Summary and conclusion**

An overview of the energy situation in Malawi has been presented. The overall energy situation, particularly in rural areas, is undesirable. The energy indicators illustrate high dependence on biomass, low energy consumption and access to electricity. The current pattern of energy consumption and the growing energy requirements on account of economic growth, and population increase is clearly unsustainable.

The review has shown that Malawi has significant energy resources that could be utilised to meet specific energy demands for the majority of people living in rural areas. Among these energy resources, small-hydropower has been identified as an option for rural electrification. The potential for large -scale hydropower is considerable. In contrast, there are few sites suitable for micro and mini hydro development, especially in the southern and central parts of the country. Although it is impractical to provide all energy needs of people in rural areas through small-scale hydropower, the available potential is significant, when considering that many villages in Malawi can not be economically supplied from the national grid in the medium to long term.

## **CHAPTER 3**

### **RURAL ELECTRIFICATION: CONCEPTUAL FRAMEWORK**

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The first two chapters of this thesis provided relevant background information and stressed the growing importance of electricity to achieve rural transformation, increase rural incomes and eradicate poverty. This chapter presents a brief review of some of the concepts of rural electrification. The first part of this chapter discusses the linkages between poverty and rural electrification. It then reviews the literature on social and economic impacts of rural electrification. The study also looks at some key factors that contribute to successful program design and implementation. The second part examines three case studies that have demonstrated that small-scale hydropower offers one of the promising approaches for rural electrification and socio-economic development. The case studies focus on China, India and Nepal.

#### **3.1 Energy poverty and rural electrification**

This section discusses the linkage between poverty and rural electrification.

##### **3.1.1 Energy Poverty**

Reddy(2000:44) defines energy poverty “as the absence of sufficient choice in accessing adequate, affordable, reliable, quality, safe and environmentally benign energy services to support economic and human development.” This definition entails the use of traditional fuels such as biomass, dung and paraffin to meet basic energy services typically: cooking, lighting, space heating and drying among others. Traditional fuels require considerable expenditure of time for their collection and processing, and are known to have low energy content per unit volume. In contrast to these fuels, modern energy forms such as electricity has other applications that make it more convenient to use. Cooking using electricity however, tends to be unaffordable to most people, and consequently, they resort to using biomass, which is freely available.

Lack of energy services correlates with many elements of poverty. These include low education levels, inadequate health care and limited employment possibilities (Karlsson and McDade, 2001:7-8). Rural electrification contributes indirectly to poverty reduction through economic growth (DFID, 2002; TERI, 2001). It plays a vital role in the living standards of people, ecological environment protection as well as increasing employment opportunities. There is a clear indication that availability of energy services determines the level of poverty among rural people.

As Cecelski (2003: 8) points out, “the poor use energy and other scarce resources to eke out livelihood strategies. Poverty influences and determines which source of energy is chosen in a household. It is also one element that can enhance or detract from survival strategies of the poor”. This is particularly true for the poor as they hardly maintain the survival demand because of their economic status. There are few opportunities for them to engage in productive activities and thus increase income. They can only choose more convenient energy sources when their incomes grow. It is therefore a great challenge for the government to solve the energy requirements of the poor to help them move out of poverty and develop the economy.

However, it is important to note that electrifying rural areas does not reduce household poverty but promises to power appliances that increase income. In this context, small hydropower-based electrification is expected to play an active role in addressing poverty issues.

### **3.1.2 Definition of Rural Electrification**

Several authors have defined rural electrification in different ways. Monerasinghe (1992:395) defines rural electrification as the “provision and use of electricity in rural areas, whether through the central grid or as a result of decentralised generation.” This definition is more encompassing as it includes the use of electricity in agriculture, in rural industries and in homes.

Vogel (1993), cited in Zomers (2001: 40), argues that the definition should not be confined to rural areas as defined in country statistics but should rather include small to medium-sized

towns which are service centres for the surrounding rural areas in a given region. The use of statistical data to delimit urban and rural areas is inaccurate and to some extent unreliable. In the same report, Maillard *et al.*, (1985) propose a definition that looks at all activities aimed at enabling users situated outside major cities to have access to electricity.

Zomers (2001:40) study quotes a number of definitions that have broader applications. He has compiled definitions given by Munasinghe (1987), Vogel (1993), Maillard *et al.*(1985), Mason(1990), Yason *et al.*(1994) and Barnes (1988) and Foley (1990). He further argues that rural electrification should encompass areas that show specific features and opportunities. This agrees with Mason's (1990) definition which considers areas that require special financing, technical and institutional approaches.

According to the Rural Electrification Act (2004:6), rural electrification refers to “grid extension or off grid electrification and/or renewable energy resources electrification whose internal rate of return is 6% per annum and line capacity is lower than 66 kV and/or generation capacity is up to 5 MW. The definition clearly places emphasis on utilities to make a return on investment and therefore, does not have socio-economic or poverty alleviation as the main objective. It limits the amount of power supplied to an area; while it does not define areas suitable for such electrification.

This study suggests that from a poverty reduction perspective, a broader definition of rural electrification must be adopted in Malawi. The definition should consider the use of multiple criteria such as (1) electricity infrastructure made available in each village (2) public facilities such as schools, clinics and dispensaries, trading centres, and community centres that are connected to electricity (3) at least a conservative figure of 1% of the village households should have access to electricity. This will ensure that by 2025, all households are electrified. Vigorous efforts are required to deploy decentralised power generation technologies in areas that are not financially and economically viable.

### **3.2 Rural electrification objectives**

Reviewed literature shows that motivations for rural electrification programs are fourfold: economic, social, political and environmental (Gaunt, 2003: 45-50; Munasinghe, 1987:45;

Zomers, 2001: 44-46). As a result, the objectives vary from country to country. The section gives a brief discussion of these objectives.

### **3.2.1 Economic objective**

This requires that users meet the cost of electricity supply in full (Gaunt, 2003:45-50). Electric energy supplied contributes to productive output (ibid). This approach, however, fails to recognise the strategic role which electrification can play in developing rural areas, as well as neglecting the encouragement of a demand driven approach to electrification. In addition, the majority of rural people cannot afford to pay initial connection cost demanded by the utility. For instance, the cost of connection for some projects in Nepal averages US\$35 while the minimum cost of internal wiring is at US\$25 (ESCAP, 2005:117). Combined costs paid in advance for connection are more than 10% of the average annual household income (ibid). This clearly shows that such electrification is meant for people with moderate incomes.

### **3.2.2 Socio-economic objective**

This kind of electrification assumes that electricity will derive tangible social and economic benefits to the rural communities. The full costs of electrification are borne by both consumers and government in the form of capital subsidies. It aims at supporting employment creation, or extending the scope of productive activities, or improving agricultural productivity (Gaunt, 2003:45-50).

A relevant observation made by Saunders *et al.* (1980:134-136) is that rural electrification objectives has to look at the uses and benefits of electricity to rural people, and how the net benefits depend upon investments and policies in other fields. This raises the issue of how to quantifying non-monetary benefits. In this context, socio-economic driven rural electrification has to be based on meeting the needs of the rural population.

### **3.2.3 Poverty alleviation objective**

Rural electrification with a view to alleviating poverty provides electricity to rural areas for consumptive purposes only. According to Gaunt (2003, 48-50), this kind of electrification does not in any way make significant contributions to financial or economic development to the supplier, but rather, avails important social benefits to the poor. These benefits, among others, include ability to refrigerate food and medicines, lighting for households, power for

small electric motors, and provision of education and communication opportunities for the rural population.

Sceptics argue that social electrification is “a social ‘hand-out’ with desirable side effects which might reduce population growth rates, and trigger investments in other areas. They observe that rural electrification is far too expensive to be considered the least-cost energy option and would be used for little more than lighting for which paraffin lamps, candles, or even for a small community, small generators would suffice” (Saunders et al.,1980:134-136). The arguments carry considerable weight in the face of available evidence. However, if one considers the poor living conditions of people in rural areas and the gain in benefits accruing from electrification, these deserve more merit than casual dismissal. This study argues that economic development is necessary to alleviate poverty through growth, which in turn, improves the living conditions of the poor. Therefore, government must at all costs, provide electricity to rural areas based on socio-economic, poverty alleviation objectives or both.

### **3.3 Social and economic benefits of rural electrification**

This section details some of the benefits of rural electrification. These are broadly categorised into two: direct and indirect benefits. Various authors have discussed the benefits of rural electrification and these include Ramani and Heijndermans (2003:61-99), Munasinghe (1987: 85-88), Foley (1990: 89-101) and Ramani (1992: 39-49). A table summarising these benefits is provided in Munasinghe (1988:85) and is reproduced in appendix B of this report.

#### **3.3.1 Social Benefits**

##### *Improvement in the quality of education*

There is a distinct positive effect on the quality of life in rural areas through the introduction of electricity, especially in the form of improved lighting. Studies show that when rural consumers are newly connected, lighting becomes their first priority (Ramani & Heijndermans, 2003:65; Barnes & Waddle, 2004: 9; Foley, 1990:32). Lighting plays a significant role in the education sector. Barkat *et al.*, 2002:219) found that lighting improves the quality of education. Children have more time available for study after sunset. Sufficient light and fans for comfort improves the quality of that study time.

Access to television strengthens their knowledge base and this in turn increases the appetite for learning. In addition, parents devote more time in assisting children's education compared to before electricity (Barkat *et al.*, 2002: 219; Barnes & Waddle, 2004:9). For instance, in Bangladesh, the average time spent on study after sunset (6 pm) was 126 minutes in the electrified households. It was 16% less in the non-electrified households of the non-electrified villages (109 minutes), and 22% less in the non-electrified households of the electrified villages (Barkat, 2004:19). Further, around 51% of women reported that they now give, on average 37 minutes more time assisting children's study as compared to before electricity (*ibid*). The overall literacy rate was at 70.8%, 54.3% and 56.4% for electrified households, electrified villages and non-electrified villages (Barkat, 2004:19).

The introduction of electricity to communities results in increased use of appliances such as radios, television, cookers, refrigerators, irons and small power tools, to cite a few (Ramani & Heijndermans, 2003:65; Barnes & Waddle, 2004: 9; Foley, 1990: 99-101). However, due to disparities in income level for these people, only few people could afford to purchase any of these appliances. Use of electricity for appliances varies from place to place. For example, in Indonesia, televisions and irons are the two most common appliances identified (Barnes & Waddle, 2004: 9).

#### *Health care*

Greater availability of entertainment facilities like television enables dissemination of crucial public health issues to both urban and rural population. Examples of public health issues include, among others, sources of knowledge, disease and treatment patterns, health care, attendance at child delivery, access to antenatal care (ANC) and postnatal care (PNC), tetanus toxoid (TT) immunization, maternal morbidity, child immunization, infant death and use of family planning (Barkat, 2002:220). Awareness of these invariably influences people's behaviour and health practice. For instance, a study conducted in Bangladesh found that 56% of those having knowledge on public health issues attributed television as the main source. It was 28% in the non-electrified households in electrified villages and 17% in the non-electrified villages (Barkat, 2004:21). This is a clear indication that at household level, rural electrification increases the knowledge base in public health issues among the poor.

Additionally, access to electricity enables rural hospitals and clinics to operate refrigerators, store medicines and other vaccines as well as provide modern diagnostic facilities. Where applicable, electricity replaces or has the potential to replace the use of traditional energy sources. Subsequently, this reduces the adverse health effects, emanating from continued use of these sources of energy.

### *Security*

Electricity provides safety and security benefits to women in rural communities. In Indonesia, the World Bank's EnPoGen study found that most women attributed lighting to have improved security in the streets at night, as well as freedom from fear of fire from kerosene lamps (Madon and Gardener, 2002:11-13). A similar study undertaken by USAID to assess the impact of rural electrification programs in Bangladesh found that 98 % of the sampled households irrespective of electricity access highly valued electricity to improve in security (Barkat *et al.*, 2002:223).

### **3.3.2 Environmental Benefits**

Environmental quality is one major benefit accrued through the use of electricity. Electricity provides clean and virtually pollution - free energy when used for lighting, cooking and other domestic purposes. As a result, shifting from the use of traditional biomass-based fuels to electricity promises to improve indoor air quality, lower wood fuel consumption, and consequently reduce deforestation (Barnes & Waddle, 2004; Foley, 1990: 98). Field studies however, reveal that electrification of rural areas does not have any impact on fuel wood consumption.

A fuel switch study conducted in eight countries found that rural people rarely use electricity for cooking. It is the upper rural deciles who are potential candidates for fuel switching. The results do help to confirm the hypothesized "energy ladder" model which suggests that "with increasing affluence, a progression is expected from traditional biomass to more advanced and less polluting fuels" and that income and relative fuel prices are the main driver affecting the movement up in the energy ladder (Heltberg, 2004: 869-887). This is a clear indication that the ability of rural people to make an energy transition is invariably circumscribed by their economic status. Unless the income levels of these people grow, fuel switching and consequently saving in wood-fuel and preventing deforestation is a pipe dream.

Commenting on the same, Davis (1998: 207-217) concludes “evidence exists that the presence of an energy transition in rural households, is largely driven by income. Access to electricity affects the nature of this transition, but there is weak evidence to suggest that it accelerates the process”. Given that the majority of people in developing countries have relatively low incomes, it is clear therefore, that rural electrification will not reduce deforestation during the early years after electrification.

### **3.3.3. Economic Benefits**

#### *Increased incomes and improved productivity of businesses*

The most obvious benefit derived from rural electrification programmes is income generation and job creation. Several authors unequivocally conclude that electricity stimulates the emergence and growth of businesses. Productive use of electricity raises incomes, creates jobs and leads to increased productivity of businesses. For example, Khan (2001:29-33) has demonstrated the significance of lighting for increased income generation attributable to extension of business hours into the evenings. In Bangladesh, women with tailoring businesses at home worked an additional four hours, which increased their income by 30% (Khan, 2001:33). Shops increased trading hours by three more hours on each day. He concluded that adequate lighting is a deciding factor in whether or not people opened home-based business (ibid).

Foley (1990:91) adds that increased economic activity and higher living standards follow electrification and concludes “the arrival of an electricity supply in certain areas seems to be a crucial factor in precipitating decisions by local entrepreneurs to invest in a variety of productive uses.” This assertion provides ample evidence that indeed, providing electricity to rural areas leads to significant economic and social benefits to rural people.

Commenting on micro-enterprises and rural electrification, Allderice and Rogers (2000:3-4) add “access to even limited amounts of electricity for micro-enterprises in areas not connected to the grid can be important for the establishment and growth of businesses. New electricity supplied to rural areas can increase the number of operating hours and thus generate more income, offer cleaner and safe working conditions, facilitates the preservation of products for export or retail, ease the use of machinery.” This implies that the use of small amounts of energy like pico-hydropower cannot be overlooked.

### *Poverty Reduction*

With regards to poverty, there is strong support that shows supplying electricity is likely to reduce poverty. IDS (2001:9) asserts that the “vicious cycle of poverty will only be broken by combining improved energy services with end-uses that generate income”. China’s example reinforces these claims. Investment in rural infrastructure, specifically electricity supply reduced the number of poor people from 260 million (27.2% of total population) in 1978 to 30 million (2.3% of total population) in 2000 (Yang, 2003:283-295). Increased incomes that contributed to the reduction in poverty were attributed to increased agricultural productivity (ibid). However, Yang notes “electrification is not a panacea for poverty, since other conditions must be satisfied in order to take advantage of the benefits from which access to electricity offers”. Thus, rural electrification alone is unlikely to reduce poverty. There is need to integrate other infrastructure programmes. Examples of such programmes among others include roads and transport services, health facilities, rural markets, potable water and communication facilities.

### **3.1 Key Success factors for rural electrification**

Studies have shown that success or failure in the implementation of rural electrification programs largely depends on the policies, management systems and strategies adopted. Examples of such factors include: clearly defined goals, favourable income-growth conditions and integration with complementary programs (Barnes & Floor, 1996:504; Barnes & Waddle, 2004:46).

Zomers (2001: 269-278) has aptly summed up critical factors for successful rural electrification programmes. These are: (1) a politically and socially stable environment, (2) proper administrative conditions (appropriate legislation, regulation and subsidy schemes), (3) support from the international community, (4) integration with other complementary programs, (5) a well developed strategy which might include among others; close relationship with all stakeholders and deployment of renewable energy technologies, and (6) decentralized programmes with operational autonomy. The following section discusses the factors in detail.

Institutional frameworks are necessary in the implementation of rural electrification programs; such frameworks include the use of a separate rural electrification authority, enabling the establishment of independent power producers, establishing a rural

electrification department within the utility (Barnes & Floor, 1996:497-530; UNESCAP, 2005:41-48; Barnes & Foley, 2004: 1-17). Having a separate rural electrification authority within the utility ensures clearer lines of responsibility and to some extent achieves financial discipline (Foley, 1990:126-127). However, this depends upon circumstances and organizational preferences for a particular country.

There is also need to set up clearly defined criteria to rank areas for electrification. Capital investment, the level of contributions, the number and density of consumers and the likely demand for electricity are among the factors normally taken into account (Barnes & Waddle, 2004:46). As an example, Thailand developed a numerical ranking system taking into account the variety of factors such as level of income, number of commercial enterprises and the government's plans for other infrastructural investments in the area. Costa Rica used population density, level of commercial development and potential for electricity load. Vietnam considered proximity to the grid and number of potential consumers.

Financing the up-front costs of connections is central in ensuring that rural people access new electricity supply (Saghir, 2005:12). This is because the up-front costs of acquiring a service as well as per-unit rates that are charged once they have the connection are absolutely beyond the affordability of the rural poor. For example, World Bank studies have shown that connection fees to grid electricity in developing countries ranges from US\$20 to US\$1000 (ibid). The costs are prohibitive for rural households with relatively low disposable incomes. As a result, they have to depend on subsidies or get loans from micro-financing institutions. In the case of Malawi, it is indispensable for government to subsidise rural households in order to access small hydro based electricity.

Local participation in the planning, design and implementation of rural electrification program is imperative. Studies have shown that voluntary participation by local people enhances the project sustainability, as a sense of ownership is developed (World Bank, 2005; Barnes & Waddle, 2004:49). Therefore, projects have to ensure that there is active participation of local people to achieve desired results and long-term viability.

Another key factor identified in the literature is decentralization of rural electrification projects. A growing body of knowledge seems to suggest that rural people must be drawn into the decision-making process so that decisions can be better informed and reflect rural

people's needs (ESCAP, 2005:72-75; Barnes and Waddle, 2004: 51). As stated by Barnes and Waddle (2004: 51), decentralization should involve setting up of rural electrification committees drawn from the local community.

Decentralised planning and operation whether at national, provincial, district or village level facilitates smooth implementation of the program. For example, in Sri Lanka, decentralization of generation technologies (wind power, micro and mini hydro, solar PV systems, etc) is attributed to the remarkable increase in electrification levels from 44% in 1990 to 63% in 2000 (ESCAP, 2005:72). However, it has to be noted that the programme mainly focused on lighting, communication and refrigeration.

Cost recovery is another aspect that has to be considered in the implementation of rural electrification programs (Barnes & Waddle, 2004: 47). Projects which recover operation and maintenance costs are more likely to succeed than those that do not. Given the low level of income for rural people, the need to set realistic tariff levels plays a significant role.

High up-front costs are a major barrier that prohibits rural people from accessing electricity once supplied to the areas. Innovative approaches such as micro-financing and subsidies could contribute to an increase in electrification level in a country. However, the design of subsidies that benefit the rural poor presents a major challenge. Specific policies on connections fees and monthly tariffs are essential to ensure that low income rural households access electricity.

Additionally, community participation and decentralised rural electrification programs are some of the conditions necessary for their success and sustainability. Community participation reduces the costs of small hydro plants. This is achieved in the form of contributions (land or labour). Involvement of the whole community enables the richer people (maize mill owners, shop owners) in that community to shoulder a substantial part of the costs and thereby make a service available to the poorer people in the community.

Furthermore, increasing the number of people involved in small-scale hydro schemes invariably reduces the cost to everyone when the scheme exhibits economies of scale. In view of the above reasons, it is highly desirable that active involvement of communities in small hydro schemes is encouraged.

### 3.2 Case studies

This section presents case studies on small-scale hydro systems in developing countries. The case studies have been carefully selected based on the success achieved in the recent past and availability of information on small-scale hydropower based rural electrification. Unfortunately, however, due to difficulties in accessing information on rural electrification in virtually all African countries, the study has been forced to consider other developing countries outside this continent. This study, therefore, examines rural electrification programs in China, India and Nepal. The concluding section summarises the key findings that provides lessons for Malawi.

#### China

In the early 1949's, about 0.6% of the Chinese living in rural areas had access to electricity (PESD, 2006). The wide dispersal of the un-electrified communities made large-scale centralized generators and extension of electric grid networks uneconomic and therefore, impractical. Due to the continued low level of rural electrification, the Chinese government initiated the rural electrification programme with special focus on small-scale hydropower. An administrative agency of small hydropower was established in 1953 under the then Ministry of Agriculture to coordinate the programme.

The electrification programme has been implemented in stages. The first stage (1949-1978) focused on domestic lighting and agro-products processing (HRC, 2007:1). The second stage (1979-1998) encompassed large-scale development of small hydropower. The focus was on poverty-relief in poor areas. Each year, China allocated about 100 million Yuan (US\$12m) for subsidies for primary electrification in selected counties<sup>5</sup>. The third stage (1999-2004) concentrated on reforms, consolidation and upgrading (PESD, 2006:15-21).

The implementation of small-scale hydro based electrification has resulted in higher levels of electricity access. Within 50 years of implementation, over 900 million people have accessed electricity (Peng and Pan, 2006: 71-84). Access rate increased from virtually zero in the late 1940's to 86.9% (rural townships), 61.1% (villages) and 53.3 % (households) by late 1970's (PESD, 2006: 26). Small hydropower sector employs about 1.2 million people and supplies

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<sup>5</sup> County is third administrative level hierarchy. China divides its administrative system into province, prefecture, county, town and village.

electricity to 300 million people across 760 counties (Jiandong, 2003: 97-102; Hicks, 2004: 36-40).

In the early 1949, there were only 33 small hydropower stations in rural areas with a total installed capacity of 3.63 MW. This figure has significantly increased to 26,262 MW in 2002 (HRC, 2004). A summary of the number of small-scale hydropower stations and their installed capacity is given in table 3.1 below.

Table 3.1 China SHP stations by installed capacity (2001)

| Type               |        | Micro  | Mini   | Small  | Total  |
|--------------------|--------|--------|--------|--------|--------|
| Station            | Number | 18,944 | 19,609 | 4427   | 43,027 |
|                    | %      | 44     | 45.6   | 10.4   | 100    |
| Installed capacity | MW     | 687    | 7171   | 18,404 | 26,262 |
|                    | %      | 2.6    | 27.36  | 70.1   | 100    |
| Annual output      | GWh    | 1860   | 20,245 | 65,036 | 87,141 |
|                    | %      | 44     | 45.6   | 10.4   | 100    |

Source: Renewable Energy World, Jan-Feb 2006:130

As can be seen from table 3.1, there were over 43,027 small hydropower stations installed across the country by the end of 2003. These had an aggregate installed capacity of 26,262 MW and generated 87.1 billion kWh annually (Jiandong, 2003: 97-102; Hicks, 2004: 36-40). By the end of 2004, the total installed capacity had increased to 34.661 GW, generated more than 110 billion kWh of energy, and accounted for about 40% of the installed capacity and annual output of combined large and small hydro in China.

The programme played a significant role in the restructuring of the economy. Industrial output in the typical agricultural counties increased from 36.6% in 1985 to 77.5% in the year 2000. Area under irrigation increased by 1,686, 700 ha, with a corresponding increase in grain yield of 30 billion kg (ERI, 2005:33). Electrification of 100 isolated pilot-districts by 700 MW produced by SHP plants resulted in supplying 580,000 families with electricity, and savings of over 400,000 tonnes/year of wood fuel (HRC, 2007:5). This contrasted findings of most studies which concluded that rural electrification does not have any effect on wood fuel consumption.

In addition, about 90 million tons of carbon dioxide (CO<sub>2</sub>) and other greenhouse gas (GHG) emissions resulting from burning of coal were avoided. An equivalent of 130,000 ha of forests which could have been felled was reduced as a result of about 20 million households in the small-scale hydropower supply areas utilising electric stoves (ibid). Thus, rural electrification has the potential to positively impact on the local and global environment.

There is copious literature that discusses reasons for China's success in its electrification programme. Barnes and Floor (1996: 497-530) have cited the creation of a decentralized development and management system that focused on economic, social and environmental benefits to local stakeholders, favourable policies that support and encourage local governments and local people to develop their nearby, rich small hydro power resources under the policy delivery mode of "self-construction, self-management and self-consumption."

Yang *et al.* (2003: 283-295) observes that it was the central government's favourable policy that encouraged the development of rural electrification. Peng and Pan (2006:71-84) advance the argument that it is "the use of funds from multiple channels, multiple levels and under multiple modes" that led to the development of rural electrification. They contend that the "effect of institutional structure and its reform on different investors would have been overlooked if the rapid progress of rural electrification had been attributed only to government investment and its favourable policy". Given the amount of evidence by several authors, it appears the policy played a significant role. Therefore, by extension, the multiple channels, levels and modes argued by Peng and Pan are implied in the policy.

Barnes and Floor (1996: 497-530) have cited localized manufacturing whereby rural entrepreneurs have built and run small-scale hydropower stations with funding from agricultural banks. Standardization of the small-scale hydropower (SHP) industry has also facilitated interconnection of multiple stations into country level grids (ibid).

In China, the total investment required for a small hydropower station with an installed capacity of 10 MW is about US\$12 million (Hicks, 2004: 36-40). Studies have also shown that average specific construction costs for large thermal power plant is 4000-5000 Yuan/kW; that for SHP, 6000-8000 Yuan/kW; wind power generation is 9000-12000 Yuan/kW. The average specific energy cost (in Yuan/kWh) is 0.20-0.30, 0.30-0.40, and 0.40-0.50 for large

thermal power, SHP and wind power respectively (HRC, 2007:1-7). The studies however, do not state whether externality costs are considered. Nevertheless, they demonstrate that SHP is among the least expensive stand-alone electrification options.

Rural electrification in China faces a number of challenges. First, the decentralized management mechanism is not in agreement with the development of the market economy. Given that there are multiple investors, it is difficult to optimize the allocation and restructuring of resources. As a result, there is no competition in the market (HRC, 2007:1-7). Second, there is severe shortage of funds for exploitation. HRC (ibid) further cites the traditional nature of management as a major reason for increase in costs and low efficiency. This in turn results in prolonged period for capital accumulation and circulation, consequently, causing slow development and expansion through self-generated funds.

### **India**

About 474,982(80.8%) out of 587,556 inhabited villages in India were electrified by the end of March 2004. About 78 million people (56.6% of rural households) had no access to grid-supplied electricity. A further 24,500 villages were classified in the category of remote villages where extension of conventional electricity grid supply may not be possible in the near future (Banerjee, 2006: 101-111).

In order to overcome the situation, the Indian government through the Ministry of Power (MoP) and Ministry of Non-conventional Energy Resources (MNES) embarked on a rural electrification programme. As reported by Chaurey *et al.* (2004: 1693-705), the programme attempts to: trigger economic development; generate employment by providing electricity as an input for productive uses in agriculture and rural industries; and improve the quality of life of rural people through lighting of rural homes, shops, community centres and public places in all villages.

The MoP also launched a Rural Electricity Supply Technology Mission with an annual resource allocation of Rs.20 billion (US\$435m). The mission's primary objective is to accelerate electrification through both grid and stand-alone distributed generation options, and to encourage decentralized management by rural cooperatives and non-governmental organizations (ibid).

By the year 2004, the total installed small hydro capacity in India was estimated at 1693 MW. Estimates of MNES place the potential at 15,000 MW (Banerjee, 2006: 101-111; Chaudhuri, 2007:23). Information on small hydro's role in rural electrification in India is however, scanty. Nouni *et al.* (2006: 1161-1174) show that 11 SHP electrification projects were implemented by the MNES in 2001 and 2002 in the states of Uttaranchal and Arunachal Pradesh. Twenty four electrification projects are under consideration.

The cost of generation of electricity from small-scale hydropower in general and micro hydro under Indian conditions has been studied and reported in literature. A recent study conducted by Nouni *et al.* (2006: 1161-1174) found that for schemes 10 to 100 kW category, the unit capital cost of 124,000-216,000 Rs. /kW (US\$2715-5095/kW). The values compare well with the range of US\$1136- US\$5630 reported for Sri Lanka, Nepal, Peru and Zimbabwe. The levelised unit cost at 40% plant load factor falls between 4.56 and 8.31 Rs. /kWh (Nouni *et al.*, 2006: 1161-1174).

Factors that impede penetration small-scale hydropower in India include, the high investment cost due to terrain inaccessibility and lack of suitable transportation linkages in locations where the potential exists Gosh *et al.*(2002: 481-512). In addition, MNES cites regular maintenance expenses, employees cost, repair and maintenance costs, interest on working capital and taxes as issues contributing to higher operational and maintenance (O&M)expenses for small hydro.

### **Nepal**

Nepal is an underdeveloped country having 27.6 million people, of which 85% live in rural areas (Zahnd *et al.*, 2006:2). The country is endowed with enormous hydropower resources. Gross theoretical hydro potential is estimated at 83,000 MW. Technically and economically feasible potential is about 43,000 MW (51%). However, this potential remains untapped, as evidenced from the fact that only 576 MW (1.37% of technically feasible potential) has been installed (Zahnd *et al.*, 2006:5). Currently, 40% of the population has access to grid-supplied electricity, but the rural areas estimates vary from 5 to 15% (Ross, 2001).

According to Zahnd *et al.*,(2006:4), "the geographical remoteness, the harsh climatic conditions, low population density with minimal energy demand and low growth potential

make electrification costs prohibitive and the isolated mountain villages in Nepal will not be reached within the foreseeable future through grid extensions alone.” This situation clearly calls for deliberate efforts to be made to bring electricity to rural areas with a view to improving the living conditions of the people. The Nepalese government has implemented rural electrification for the past 30 years albeit with slow progress and not at pace with population growth.

Off-grid electrification is implemented under the Ministry of Environment, Science and Technology through the Alternative Energy Promotion Centre (AEPC), Energy Sector Assistance Program (ESAP), and Rural Energy Development Fund (REDF). In addition, a number of independent power producers (IPPs) and NGOs are engaged in rural electrification largely with assistance from bilateral donors.

Small-scale hydropower has proved itself to be a major contributor to electrification for rural communities in Nepal. A general lack of statistics has made it difficult to assess what has been achieved so far. However, recent studies show that a total of 1956 micro hydro schemes (ranging from 0.5 kW to 100 kW) with an installed capacity of 13.064 MW have been installed since 1962. There are currently an estimated 576 small hydro schemes serving 76,500 people. Table 3.3 illustrates current status of small hydro installations. Average connection rating per household is 70 W (Meier et al., 2003). Schemes with capacity bigger than 20 kW are often supported by local NGOs and owned cooperatively by user groups.

According to Meier *et al.* (2003), the cost of generation for such plants range from US\$1200/kW to US\$3000 (NPR 80,000 to 145,000/kW of installed capacity) (ibid).

Table 3.2 Installed capacity for small hydro systems in Nepal

| Type                            | Total number | Installed capacity (kW) | Household served |
|---------------------------------|--------------|-------------------------|------------------|
| Traditional watermills (ghatta) | 25,000       | 12,000                  | 500,000          |
| Improved watermills (ghatta)    | 650          | 1,200                   | 50,000           |
| Micro-hydro milling             | 900          | 5,000                   | 270,000          |
| Peltric sets                    | 600          | 600                     | 6,000            |
| Micro-hydro electricity         | 300          | 4,200                   | 42,000           |
| Mini hydro                      | 35           | 8,000                   | 34,000           |
| Small hydro-on the grid         | 12           | 40,000                  | 69,000           |

Source: Pandey, 2006:4

A number of factors have contributed to Nepal’s success harnessing of small-scale hydropower. These include the availability of credit from public sector agricultural banks, simplified licensing procedures to reduce transaction costs, unrestricted power tariffs, private financing from commercial banks and government. Technical assistance provided by bilateral donors (Norway, Germany, and Sweden) and some non-governmental organizations has also led to technology development and manufacturing within Nepal’s industry (Barnes and Floor, 1996: 497-530).

A comparison of results of rural electrification programmes for China, India and Nepal is shown in table 3.3. The disparities in electrification levels, investments and generation costs are evident. As can be seen from table 3.3, China has been more successful in providing electricity to around 98.6% of the population. India and Nepal have both achieved 54% and 40% electrification access, respectively. Although the electrification rates in India and Nepal are low, they should still be viewed as positive. It has to be noted that the development of small hydropower in particular has been carried out within the case study’s background of political, economical, social and other technical features, which are not similar among themselves. However, they provide reliable evidence that small-scale hydro will undoubtedly increase rural electrification levels.

**Table 3.3 Comparison of results of rural electrification programmes in China, Nepal and India**

| Rural electrification statistics                                 | China     | India     | Nepal     |
|--|-----------|-----------|-----------|
| Implementation period (years)                                    | 50        | 30        | 30        |
| Rural electrification level in recent year (%)                   | 98.6      | 54        | 40        |
| Annual investment in rural hydro electrification ( million US\$) | 2,600     | 3,800     | n/a       |
| Capital cost (US\$)  | n/a       | n/a       | 714       |
| Investment/kW (US\$/kW)  | 600-950   | 2175-5095 | 1200-3000 |
| Cost of energy produced (US\$/kWh)                               | 0.04-0.05 | 0.10-0.18 | 0.05-0.2  |

Source: Adapted from ERI, 2005

### **3.7 Summary of key findings**

Analysis of the case studies of rural electrification programs in China, Nepal and India has identified the following general issues:

#### **3.7.1 Long term planning and government commitment**

Each of the three countries developed long-term an integrated infrastructure development programme, and rural electrification formed one major component. In each country, the government led the electrification process and made significant investment towards the development of small-scale hydropower. The driving forces were poverty reduction through economic growth, improved standards of living, and environmental and ecological quality. During the early stages of implementation, the primary focus was to provide lighting to the rural communities. The emphasis was on access as opposed to use. Economic activities were promoted as by-products of the supply of electricity. Therefore, strong government commitment is crucial in achieving significant levels of electrification.

#### **3.7.2 Policies and strategies**

A common factor shared by these successful programmes can be attributed to strong government support in terms of policies and strategies. Governments prioritised development of small-scale hydropower through regulation and favourable policies. These supported and encouraged local governments and people to develop their own nearby rich small hydropower resources. For instance, in China, government set up policy under the theme “self-construction, self-management, and self-consumption.” Local authorities were encouraged to plan and construct small hydro schemes using local resources, technologies and raw materials. The local authority or local people who invested and constructed the power stations owned them and got benefits from them. Central government provided a subsidy for rural hydro electricity.

To sustain the programme, innovative income generation methods were applied as follows: electricity was sold within the area covered by the hydropower supply; a levy of two cents for each kWh generated was allocated for rural hydropower development. Profits from small-scale hydropower and local grids were retained by the enterprise for further development. This was governed under the “electricity generates electricity” policy. Other supporting

policies formulated include: a preferential rate of value added tax rate of 6% instead of the normal 17%; loan policy where the agricultural banks provided special funds as loans for developing rural small hydropower. Government also offered loans at subsidized interest rates. Therefore, success of rural electrification depends on the policies used and the institutional structure adopted. A supportive government policy in terms of financing rural electrification is crucial.

### **3.7.3 Decentralised approach for small hydropower development**

Rural electrification was largely implemented using the county or state as a management unit and assisted and guided at provincial or county level. The countries established autonomous bodies to oversee and coordinate electrification programmes in each state or county. These bodies set design standards and monitored progress of programmes. They also laid down general policy guidelines. In every county, a rural electricity leading group led by a county governor was also established to make key decisions in the construction, fundraising and other key elements of the programme.

Project planning, development, implementation and management, equipment manufacturing and operation and maintenance were carried out at county level. In Nepal, the decentralization process focused on local participation in the form of organization development, skill enhancement, capital formation, technology promotion, women's empowerment, and environmental management. Planning was based on what communities felt they needed whereas project identification was through local participation approach.

### **3.7.4 Capital investment and financial support mechanisms**

In China, various sources of financing were used in the implementation of rural electrification projects. These included individual farmers, groups, enterprises, and to some extent, loans from the World Bank and International Monetary Fund. In India and China, the government invested in small-scale hydropower construction. Each country provided subsidies to enable more people to afford an electricity connection. In addition, development banks set up special funds for construction projects. In Nepal, agricultural development banks provided subsidies. The banks also supported small-scale hydro through credits and soft loans. Non-governmental organisations also drove the sector, and combined capacity building of the

local manufacturers with technical improvements such as electronic load controllers and the use of electric motors as generators.

### **3.7.5 Standardisation of small-scale hydropower plants**

The countries emphasised reliability, standardization and simplicity. This is view of the fact that small-scale hydropower plants are required to meet appropriate conditions in which they work. Such conditions include ability to cope with the load pattern in different climatic conditions, level of skills likely used in their operation, and capability of expansion or replacement (Foley, 1990:147). Technical standards, rules and criteria in each process of work from initial stage to construction, installation through to operation guaranteed quality, cost effectiveness and timely completion of projects. In addition, standardization of the small-scale hydropower plants enabled interconnection of multiple stations.

### **Summary and Conclusions**

This chapter has argued that rural electrification is an indispensable tool for alleviating poverty, transforming rural economies and improvement in living standards of people in rural areas. Different objectives for electrification exist i.e. economic, social and environmental. It has been observed that electrification to meet economic objectives require the use of electricity as an economic resource to maximize output and growth. This places much emphasis on the productive uses of electricity. As a result, areas which promise to generate industrial, commercial activities are favoured.

Given the need to satisfy the basic needs of rural people coupled with the desire to improve the distribution of income and quality of life in rural areas, poverty alleviation electrification is inevitable. There is no doubt that this could lead to the subsequent introduction of other services that initiate significant economic development in the long term. In the short term, rural electrification has to be approached from the poverty alleviation perspective, irrespective of whether the investment will make a return or not.

The chapter has also discussed the social and economic impacts of rural electrification. Social development issues like poverty, education, security, public health, gender are well linked to access to electricity. Briefly, electricity significantly leads to improved security, education, reduced in-door air pollution, reduced human drudgery, and increased recreation

opportunities and health services. Other impacts could be on extended working hours, improved agricultural productivity as well as the emergence, and growth of businesses. Therefore, it is highly desirable that rural people access electricity to enjoy its benefits. The benefits are both quantifiable as well as non quantifiable. Government failure to provide electricity to its rural people is tantamount to violation of the right to basic services.

Key success factors for successful implementation programmes have been discussed. Success can only be achieved if there are clearly defined goals, appropriate institutional structures as well as integration with other complementary programs. Strong government support in terms of policies, regulation, and subsidies provide the basis for improving access to electricity by rural people. However, they vary from country to country and depend on the objectives of the programme. Decentralised approach to development, programme financing of up front costs, and local participation, among others are crucial for success.

The reviewed case studies have showed that with an appropriate policy framework supported by adequate institutional mechanisms, access to electricity in rural areas could be improved. The governments paid particular attention to small hydropower development; offered a series of enabling policies; invested in SHP construction, and provided subsidies for electricity access. A major theme in the SHP development has been the effort put in to participative approaches to create, nurture capacity of local communities to build, own and operate their own small hydro schemes. The evidence shown by the three case studies suggests that strong government support for small hydro development is central to the achievement of meaningful rural electrification.

In China, government recognised the role of the agricultural sector in supporting industrial development in the form of raw materials for industrial production. In addition to household consumption, the government encouraged supply of electricity for irrigation and drainage for agricultural productivity. Economic activities were promoted as by-products of the supply of electricity in the subsequent phases. Therefore, rural electrification must begin with social objectives, mainly to provide basic needs and services for households and communities.

Finally, the varying degree of achievements of the case studies reflects need to explore cost effective electricity generation technologies to improve quality of life, economic well being and environmental quality.

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## CHAPTER 4

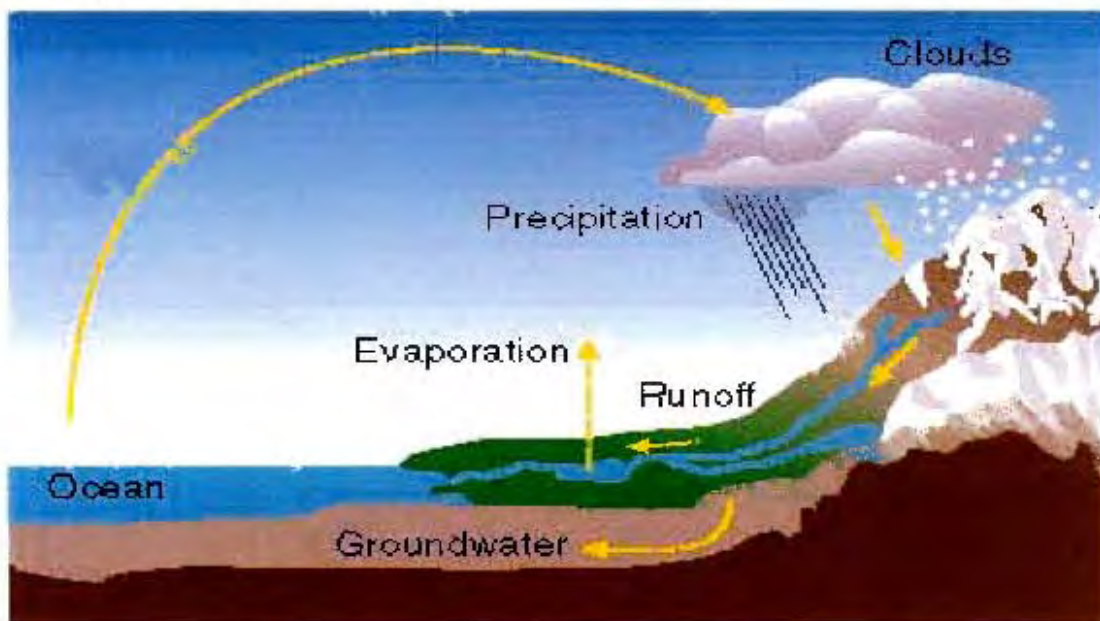
### THEORETICAL CONSIDERATIONS

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This chapter describes the theoretical and technical issues considered in the planning, design and evaluation of small-scale hydro systems. The chapter starts with a brief look at the basic concepts and principles of hydropower generation. The different hydraulic power development technologies are described, followed by a discussion on hydro resource assessment, stream flow measurement methods and economics of hydropower. The final section looks at load forecasting methods.

#### 4.1 Basic concepts of hydropower

Water constantly moves through a vast global cycle, in which it evaporates (due to the activity of the sun) from oceans, seas and other water reservoirs, forms clouds, precipitates as rain or snow, then flows back to the ocean (figure 4.1). The energy of this cycle, which is driven by the sun's energy, is tapped as hydropower.



Source: [http://www1.cerc.energy.gov/windandhydro/hydro\\_how.html](http://www1.cerc.energy.gov/windandhydro/hydro_how.html)

Fig. 4.1 The hydrological cycle

The principal advantages of using hydropower are: it is continuously renewable, non-polluting and efficient (Srinivasan, 1981). The technology is mature, and reliable. Running costs are very low as compared to thermal or nuclear power stations, hydraulic turbines can be switched on and off in a matter of minutes, and gives very high efficiency over considerable range of load (Dandekar and Sharma, 1979: 6).

According to IEA (2003), hydroelectric plants operate at efficiencies of 85 to 95%. This compares with about 55% for combined-cycle gas turbines (CCGT), 30 to 40% for coal or oil fired plants, 30% for wind power and 7 to 17% for solar photovoltaic panels. Direct conversion of mechanical energy into electricity gives higher efficiency electricity production. The disadvantages of hydropower include high initial capital costs and potential site-specific and cumulative environmental impacts. The exploitation of hydropower is dependent upon the topography, rainfall and the availability of funds, since a large capital outlay is required.

Generally, hydropower plants fall into two categories: conventional (large hydro) and non-conventional (small-scale hydro). This study will be confined to the second type. Small – scale hydropower refers to hydraulic turbine systems having capacities of less than 10 MW ([www.itdg.org](http://www.itdg.org)). The principles of operation, types of units, and the mathematical equations used in the selection of small-scale hydropower are essentially the same as for conventional hydropower. The global installed capacity is currently about 66 GW (REN21, 2006). In Malawi, small-scale hydropower covers stations up to 5 MW (DoEA, 2004).

## 4.2 Energy conversion principles

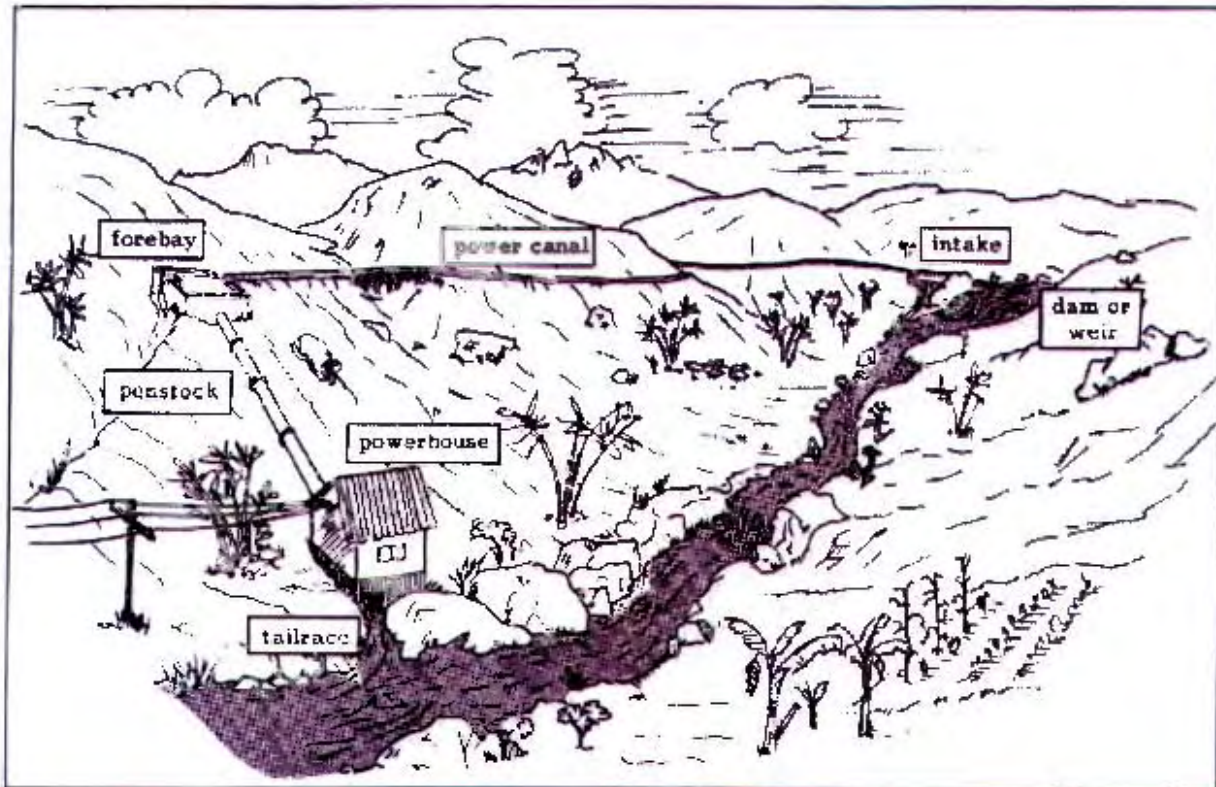
Hydropower captures the energy released from falling or moving water. Water falls due to gravity which causes the pressure and kinetic energy to be converted into mechanical energy then electrical energy. A water wheel or hydraulic turbine is used as a prime mover to transform the energy of water into mechanical energy (Twidell and Weir, 2000:183; Begamudre, 2000:259). The potential energy lost by a volume of water falling down a slope in each second is given by the equation:

$$P_o = \rho Q g H \quad \text{(Equation 4.1)}$$

The vertical head through which water falls takes into account of friction losses and is usually expressed as the effective or net head.

### 4.3 Small-scale hydropower system components

A small-scale hydropower plant consists of the following structures and essential features: weir or dam, intake structures, penstocks, power house, and tailrace. Figure 4.2 shows the sketches of the plan of small-scale hydropower plant.



Source: Inversin, 1986:63

Figure 4.2 Main components of a small-scale hydropower plant

- A dam or weir to control the flow of water and increases the elevation to create the head;
- Intake-acts as a buffer between the water supply and the hydropower electric plant;
- Power canal: conveys water from intake to the fore bay, usually made of earth or concrete;
- Fore bay: this is a tank that holds water between the power canal and the penstock;
- Penstock- which is a pipe connecting the fore bay to the power house. It conveys the water under pressure from the reservoir/fore bay to the turbine in the power station;
- Power house: is the facility for converting the fluid energy into the electrical energy. It stores and protects all the power- producing equipment and control devices;
- Turbine provides the mechanical energy from the water pushing against its blades to drive the generator;
- Generator converts the mechanical energy produced by the turbine into electrical energy; and
- Tailrace: is a channel leading back to the river below the power station into which the turbine discharges.

#### **4.4 Small-scale hydropower scheme configurations**

##### **4.4.1 Run-of- river type**

This type of project allows generation of electricity without the impact of damming the water way. A portion of water flow from a river or stream is diverted through channel to fore bay tank and then led via penstocks to drive hydraulic turbines after which, the water is redirected back to its original source (Dandekar and Sharma, 1979: 94-96). There is no water storage and the power fluctuates with the stream flow.

According to Sawyer (1986:30-39), run-of-river plants (ROR) are employed where topography, environmental concern, or other factors prohibit large reservoir construction and where natural river flows are reliable enough to justify the large capital costs that characterize hydropower. They are often suited to supply electrical needs of an isolated area or industry, if the minimum flow in the river or stream is sufficient to meet the load's peak power requirements (Dandekar and Sharma, 1979: 94-96). Compared to storage schemes, ROR have less environmental and

social impacts (Schleicher, 2003). However, at times flows become too high or too low, for the utility's capacity and this necessitates shutdowns until flows return to within the acceptable range.

#### **4.4.2 River power plants**

River power plants are built directly in the river. The water is not diverted as is the case with run-of-river projects. Usually they have a low head.

#### **4.5 Water Turbines**

A turbine extracts energy from moving water and converts it directly into rotating shaft power. Typically, a hydraulic turbine has vanes, blades or buckets that rotate about an axis by the action of water. Traditionally hydraulic turbines are classified into two types groups: impulse and reaction.

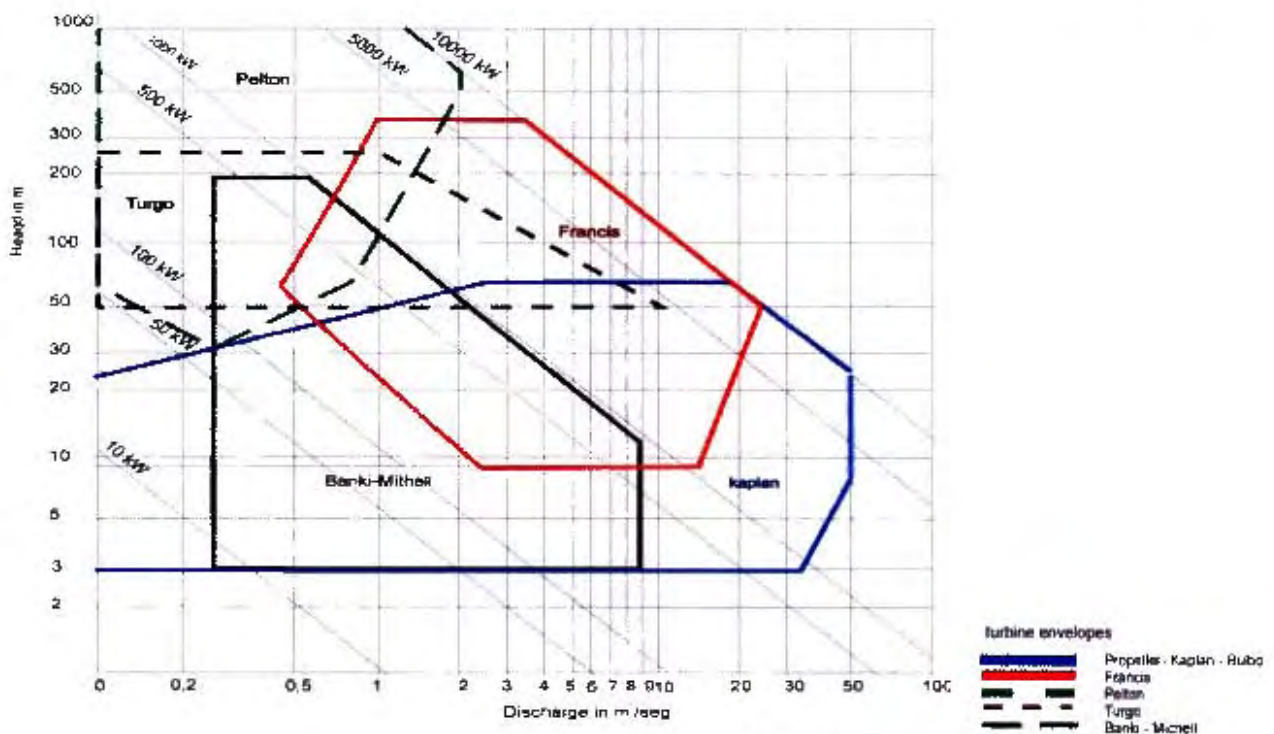
In an impulse turbine, the flow enters the runner at nearly atmospheric pressure in the form of one or more jets spaced around the rim of the runner. The force of the jet hitting the blades turns the turbine and strips the jet of its kinetic energy. Therefore, only the impulse forces being transferred by the direction changes of the flow velocity vectors when passing the buckets create the energy converted to mechanical energy on the turbine shaft. There is no suction on the downside of the turbine, and the water flows out the bottom of the turbine housing after impacting the runner. They are suitable for high head, low flow applications. Examples include the water wheel, Pelton, Turgo, crossflow and multipurpose turbines. For a complete discussion of different types of turbines, refer to Inversin (1986:171-194).

A reaction turbine creates power by reacting to the fluid's pressure or weight. It extracts energy from the water by lowering the water's pressure as it passes through the turbine. Changes in the directions of the velocity vectors of the flow through the canals between the runner blades transfer impulse force. The pressure drop from inlet to outlet of the runner is obtained because the runner is fully immersed in the water flow and closed to the outside pressure. A casing is used to direct the water flow through the turbine and contain the pressure of the flow. Examples of commonly used reaction turbine types are: Francis and Kaplan.

### 4.5.1 Choice of water turbine

The choice of water turbine for a particular site depends on the site characteristics, the dominant factor being the net head available and power required (Inversin, 1986:191; Boyle, 2004:172). Other deciding factors include range of discharges through the turbine, rotational speed, cavitation (turbine setting height) and cost. Figure 4.3 indicates which turbine is most suitable for any particular combination of head and discharge. As can be seen from this figure, reaction turbines have no limit with flow rates and work better with lower heads. For example, Kaplan turbines are well suited for low head and large discharges (e.g. run-of-river sites) and Francis turbines are usually preferred for large heads and large flows, e.g. dams. Cross flow turbines overlap between the high and low heads.

In view of the fact that small-scale hydropower sources available in most rural and remote areas are low head and small capacity, it is appropriate to use either cross flow or propeller turbines. A cross flow turbine, because of its simplicity and popularity is used for this study. A useful parameter for choosing the most suitable turbine is the shape number, described in appendix C.



Source: ESIIA, 2004:176

Fig.4.3 Choice of turbine in terms of head and discharge

#### 4.6 Resource assessment and evaluation

The water flow rate and the pressure (hydraulic) head through which the water falls are the two most important factors that determine the inherent power potential of the water flowing in a river or stream. Head may be natural due to the topographical situation or may be created artificially by means of dams. Water flow on the other hand is a direct result of the intensity, distribution and duration of rainfall, but is also a function of direct evaporation, transpiration, infiltration into the ground, the area of the particular catchment, and the field moisture capacity of the soil (Mandeville and Batchelor, 1990). The maximum amount of power available in theory from the flow is related to the speed of flow and the head. This relationship is expressed by the formula shown annex C.

#### 4.7 Flow Duration Curve

A flow duration curve represents the relationship between stream flow and the frequency of stream flow. It provides a measure of the percentage of time a given flow is equalled or exceeded over that time interval (Vogel and Fennessey, 1995:1029-1039). The curve provides a graphical and statistical view of the overall historical variability associated with stream flow and is the complement of cumulative distribution function of daily stream flow (Vogel and Fennessey, 1995:1029-1039; Lane et al, 2005:253-265). Empirical flow duration curves are constructed from daily discharge data by (1) ranking the observed daily flow values in 'ascending order' and (2) plotting each ordered observation versus its corresponding duration. There are no specific guidelines for time series. Flow duration curves are constructed for other time series such as, weekly, monthly or annually stream flows. The present study focuses on daily stream flows.

##### 4.7.1 Hydrological flow indices

According to Smakhtin (2001:147-186), important indices extracted from the flow duration curve are those that are exceeded more than 50% of the time. He notes that generally, the Q90 and Q95 flows have been used as low flow indices. However, since power available depends on discharge, four indices are useful for the calculation of the energy potential as follows:

$Q_{100}$  - Flow which is exceeded 100%. The minimum potential power computed from the minimum flow available for 100% of time (365 days or 8760 hours) is presented as  $P_{p100}$ ;

$Q_{95}$  - Flow which is exceeded 95%: small potential power computed from the flow available for 95% of time (8322 hours). This is represented as  $Pp_{95}$ ;

$Q_{50}$  - Flow which is exceeded 50%: average potential power computed from the flow available for 50% of time (4380 hours). This is represented as  $Pp_{50}$ ; and  $Q^m$  - flow which is exceeded  $m\%$ : mean potential power computed from the average of mean yearly flows for a period of 10 to 30 years, which is equal to the area of the flow-duration curve corresponding to this mean year. This is known as gross river power potential and is represented as  $Ppm$ .

In Malawi, techniques for estimating flow duration curve using the relationship between mean flow and rainfall have been developed. A study conducted by Drayton *et al.* (1980) mapped values for of the low flow statistic  $Q_{95}$ . This method enables estimation of low flow statistics and flow duration curves at any point in the country. Based on the regression equations analysed for 49 stations, the study recommended use of the  $Q_{75}$  flow statistic (flow which is exceeded 75% (Patel, 2007:41-46) and this is adopted for this study. More details of these analyses are given in Meigh and Fry (2003), and Drayton *et al.* (1980).

If the specific run-off method is used, the flow duration curve is expressed in normalised form, i.e. relative to the mean flow. The mean flow  $\bar{Q}$  is calculated as:

$$\bar{Q} = RA_D \quad (\text{Equation 4.17})$$

where  $R$  is the specific run-off and  $A_D$  is the drainage area. Then the actual flow data  $Q_n$  ( $n = 0.5, \dots, 100$ ) is computed from the normalised flow data  $q_n$  extracted from country database

through

$$Q_n = q_n \bar{Q} \quad (\text{Equation 4.18})$$

#### 4.7.2 Environmental flow considerations

For environmental reasons, there is need to allow a portion of flow in a river or stream to by-pass the small hydro plant. This caters for aquatic life in the streambed between the intake to the power plant and the outlet where the flow is returned to the stream. There are no specific restrictions on the amount of residual flow required, but generally, it varies from site to site and with specific site concerns. BHA (2005:8) gives an estimate of between  $Q_{90}$  and  $Q_{99}$  values of

river flow. This residual flow  $Q_r$  is subtracted from all values of the flow duration curve for the calculation of plant capacity, firm capacity. The available flow  $Q'_n$  ( $n = 0, 5, \dots, 100$ ) is then defined by:

$$Q'_n = \max(Q_n - Q_r, 0) \quad (\text{Equation 4.19})$$

### 4.7.3 Capacity Factor

For run-of-river schemes, the turbine design flow is normally smaller than the mean flow and therefore, not environmentally acceptable and economically attractive (BHA, 2005:9). There is need to choose a design flow that takes into account of the recommended capacity factors. The capacity factor is calculated using the formula given below:

$$\text{Capacity Factor (CF)} = \frac{\text{Energy generated per year (kWh/year)}}{\text{Installed capacity (kW)} \times 8760 \text{ hours/year}} \quad (\text{Equation 4.20})$$

The capacity factor varies with design flow. For example, given the design flow at  $Q_{\text{mean}}$ , the capacity factor is 40%, at  $0.75Q_{\text{mean}} = 50\%$ ,  $0.5 Q_{\text{mean}} = 60\%$ ,  $0.33Q_{\text{mean}} = 70\%$ . Values between 50 and 70% would give satisfactory return on investment (BHA, 2005:10). Typically most turbines operate between 20 – 40% of their rated flow. The rated or peak power is estimated from the design flow  $Q_0$  and the head as follows:

$$P(\text{kW}) = 7 \times Q_0 \left( \frac{\text{m}^3}{\text{s}} \right) \times H(\text{m}) \quad (\text{Equation 4.21})$$

with  $P$  = net power and  $Q_0$  as the arithmetic mean discharge.

### 4.7.4 Energy output from a power plant

The energy output is then estimated using the capacity factor ( $CF$ ) as follows:

$$\text{Energy (kWh/year)} = P(\text{kW}) \times CF \times 8760 \quad (\text{Equation 4.22})$$

## 4.7 Stream flow characteristics

The purpose of hydrologic evaluations is to provide accurate values for river or stream flow. The values of flow have to be taken for over a long period usually at least one year and preferably eight to ten years (Feibel, 2003: 21). It is however, seldom the case that adequate historic data is

available to a developer when specific site investigation commences. In this case, on-site stream flow measurements are necessary.

There are several methods of measuring flows in rivers or streams. Five methods, namely the velocity-area, the salt dilution method, bucket method, the weir, and slope-area etc are described in Inversin (1986:9-20), ESHA (1998:57-65) and Harvey et al (1993:51-60). Accordingly, the velocity-area methods employ the principle that the volume of water passing a particular point per second in a known cross sectional area is equal to the product of average velocity of the fluid at that point and the cross section area. Velocity is measured by a floater or current meter (propeller or electromagnetic) (ESHA, 1998:57-62). It is an expensive but more accurate method.

According to ESHA (1998:62-63), the dilution technique “involves the injection of a chemical into the stream and sampling of the water some distance downstream after complete mixing of the chemical in the water has occurred. The chemical is added by constant-rate injection until the sampling downstream reveals a constant concentration.” The technique is expensive and specialised (ESHA, 1998:62) and has negative implications on the ecology. However, recent development in use of salt seems to offer a better alternative with respect to ecological concerns. With this new method, the discharge is measured by gradually discharging a known volume of a strong salt solution into the stream at a known rate, and measuring at short intervals, the change in conductivity of the water at the downstream end of the mixing length.

The weir method involves construction of a low wall or weir across the stream to be gauged, with a notch through which water in the stream flows (Inversin, 1986: 16). Several types of notch are used: rectangular, vee, or trapezoidal etc. The weir method is regarded as the most accurate means of measuring discharge over a long period. Similarly, flumes are used. With flumes, the stream is channelled through a particular geometrically regular channel section for some distance before entering a length of different cross section.

The slope –area method depends on hydraulic principles and is useful for high flows where other methods discussed above are impractical (ESHA, 1998: 65). The method uses Manning’s equation given below:

$$Q = \frac{AR^{2/3}S^{1/2}}{n} \quad (\text{Equation 4.23})$$

where  $S$  is the water slope,  $A$  is the cross- section area,  $R$  is the hydraulic radius of the section ( $A/P$ ),  $n$  is the roughness coefficient and  $P$  is the wetted perimeter in metres. This equation utilises a roughness coefficient that depends on the characteristics of the channel and is subject to errors (ESHA, 1998:65). This study utilises the velocity- area method to establish the stream flow in the study area as well as the slope-area method in the design of the headrace.

#### 4.8 Estimation of stream flow characteristics at ungauged sites

Estimates of daily stream flows are required for a number of water-related applications such as water supply, irrigation, hydropower, recreation and watershed management (Patel, 2007:41-46; Vogel et al., 1999:148-157). However, the majority of streams particularly in remote areas are not gauged. Practically, it is impossible to gauge all rivers and streams in a country because the size of many potentially interesting catchment areas does not warrant the cost of operating a regular flow monitoring station (Naidas, 2005:48-66). As a result, systematically recorded flow data at the site of interest is unavailable.

A common approach used is the regionalisation of hydrometric zones, which seeks to transfer hydrological information from gauged sites to ungauged ones. The approach identifies regions with similar behaviour so that the hydrological effects can be compared. According to Smakhtin (2001:147-186), such hydrological effects may include unit run off from the catchment area, average monthly flow distribution, duration of certain flow periods, frequency and magnitude of high and low-flow events in similar sized catchments.

Flow characteristics at ungauged sites are estimated by applying a predictive equation developed for a particular hydrometric zone (IH, 1980). However, concerns have been raised that catchments that belong to the same hydrometric zone, do not necessarily have similar hydrological responses since geographical proximity is not considered as a sufficient condition

for hydrological homogeneity (Acreman & Sinclair, 1986:365-380). Therefore, it is crucial that homogenous regions of catchments with similar characteristics are well defined.

Hosking & Wallis (1993:1745-1752) present several statistics that can be applied to assist with the process of defining regions of reasonably homogenous sites. Furthermore, working with a homogenous region enables “historical data available within that region to be pooled to get an efficient estimate of parameters of a chosen distribution and hence a more robust quantile estimate” (Kachroo & Mkhandi, 2000: 437-447).

The delimitation of regions with hydrological responses has been done using multivariate techniques such as multiple regression, cluster and discriminant analysis. Nathan & McMahon (1990:217-238), and Burn & Boorman (1993:429-454) observe that catchments that influence flow characteristics should be used for cluster analysis. This enables determination of membership of ungauged catchment characteristics, to a region with a known relationship between flow and catchment characteristics.

There are several methods for estimating stream flow characteristics from gauged to ungauged catchments. These include (1) a catchment or drainage-area ratio relation, (2) a correlation of measured stream flows with concurrent daily-mean stream flows from nearby continuous-record stream gauging stations, and (3) regression equation relating stream flow statistics to drainage basin characteristics (Flynn, 2003:7-8).

#### **4.9.1 Catchment-Area Ratio**

This method is used to estimate low-flow statistics at an ungauged site on the basis of low-flow values from stream gauging stations on the same stream (Flynn, 2003:7). It assumes that the catchment basin for a proposed site displays characteristics (topography, land use, geomorphology, and lithology) similar to those of the gauged site in the vicinity, on either the same stream or one in a neighbouring catchment. The low flow values are transferred from a gauged site to ungauged site using the following formula:

$$Q_{ungauged} = Q_{gauged} \left( \frac{A_{ungauged}}{A_{gauged}} \right)^n \quad (\text{Equation 4.24})$$

where  $Q_{ungauged}$  is the discharge value at the ungauged site,  $Q_{gauged}$  the discharge statistic of interest at the stream gauging station,  $A_{ungauged}$  and  $A_{gauged}$  are the catchment areas at the ungauged site and the gauged site respectively,  $n$  is an exponent that is computed by analysing low flow characteristics at paired long-term continuous –record stream gauging station.

#### 4.9.2 Flow correlation method

A number of discrete measurements of discharge are made at the ungauged site. The flows are then related to the concurrent flows at a nearby gauging station by regression analysis to determine the flow statistic at the ungauged site (Flynn, 2003:7). A correlation of measured stream flows with concurrent daily mean stream flows from a nearby stream gauging station requires numerous measurements of stream flow in order to establish a relation between low flows at the stream gauging stations and a partial-record location.

#### 4.9.3 Regression Equation Approach

Regression equations that relate stream flow statistics at gauged stream-gauging stations to basin and climatic characteristics are used to estimate stream flow statistics for ungauged sites. Ries and Friesz (2000:26) have described the multiple non linear regression models for estimating stream flow characteristics from gauged to ungauged site. Details are given in the annex C.

### 4.10 Economic analysis

#### 4.10.1 Tools for economic analysis

In order to make informed decisions about investing in small-scale hydropower development, potential investors need to know all relevant cost factors. These factors include plant data, such as its initial capital cost, operation and maintenance costs, predicted lifetime and load factor (Boyle, 2004:186). There is also need to consider other external factors such as the discount rate, or the cost of borrowing money over a period. A number of criteria are used for evaluating projects from the economic point of view. These include the net present value (NPV), internal

rate of return (IRR) and net benefit cost ratio (Subroto *et al.* (1981:339-342). A brief discussion of the tools used for the economic analysis hydropower projects is presented in annex C.

#### 4.10.2 Costing

There are two categories of costs in small-scale hydropower development: investment and annual costs (Hosseini *et al.*, 2005:1948-1956). Investment costs include civil costs, electromechanical equipment, power transmission line, and other indirect costs. Annual costs include the depreciation of equipment, O&M, and replacement costs (Nouni *et al.*, 2006:1161-1174). The specific investment cost depends on the type and size of the small hydropower project. Generally the smaller the hydropower scheme under consideration, the higher the specific costs, i.e. per kW installed, are likely to become.

The power generation cost  $C_h = P_h \times C_u$  (Equation 4.31)

where  $P_h = 9.81 \times Q H e_h$  is the power output of the site (refer to equation 4.2)

$C_u = \frac{(C_{LCC})}{(F_d \times D \times 365)}$  is the unit cost of power (US\$/kW)

$F_d = \text{discounted factor} = \frac{((1+r)^n - 1)}{i(1+r)^n}$ ,  $i = \text{discounted rate or project cost escalation rate } (i_r)$

$n = \text{number of years}$ ,  $D = \text{systems daily demand (kW)} = \text{unit consumption} \times \text{community size}$   
and  $C_{LCC} = \text{Life Cycle Cost (US\$)}$ .

The cost of the equipment, including the turbine, generator and transmission equipment constitute 20% to 40% of project costs, site related civil costs generally vary between 50% and 70% of project costs, while 5% to 15% is devoted to engineering costs (Gordon and Noel, 1986). Given that site specificity of hydropower (hydrology, geology, topography) influence the investment cost, a formula that incorporates all site-specific conditions is more useful than its current form. Gordon and Penman (1983:30-37) proposes an empirical specific cost correlation, based on the cost of previous projects as follows:

$$C_p = k \cdot 10^3 (h_r^\alpha)^\beta \quad (\text{Equation 4.32})$$

where  $C_p$  = total initial project cost,  $P$  is plant capacity (kW),  $h_f$  design head over turbine (m),  $k$  is a constant (US\$) and depends on installed capacity and head,  $\alpha$  exponent ( $\alpha = 0.3$ ), and  $\beta$  power component ( $\beta = 0.82$ ). Table 4.1 gives  $k$  values based on 1983 prices.

**Table 4.1 k-values for calculation of total project costs**

| Project type according to installed capacity | Project type according to design head | Factor | Max   | Average | Min  |
|--|---------------------------------------|--------|-------|---------|------|
| Pico to micro-hydro<br>(1 kW – 100 kW)       | $h_f > 50$ m                          | K      | 46.25 | 12.04   | 5.63 |
|  |                                       | S      | 5.14  | 1.33    | 0.63 |
|  | $15 < h_f > 50$ m                     | K      | 49.10 | 10.93   | 3.05 |
|  |                                       | S      | 5.46  | 1.22    | 0.34 |
|  | $h_f < 15$ m                          | K      | 39.57 | 6.77    | 2.22 |
|  |                                       | S      | 4.40  | 0.75    | 0.25 |
| Mini to Small-hydro<br>1 MW – 10 MW          | $h_f > 50$ m                          | K      | 46.79 | 24.53   | 8.38 |
|  |                                       | S      | 5.20  | 2.73    | 0.93 |
|  | $15 < h_f > 50$ m                     | K      | 58.77 | 28.38   | 9.33 |
|  |                                       | S      | 6.53  | 3.15    | 1.04 |

Source: Adapted from Ramesh (2004:39)

Equation 4.32 is adjusted to suit the conditions in Malawi and becomes as follows:

$$C = 10930 \times kW^{0.82} \times h^{-0.3} \quad (\text{Equation 4.33})$$

where  $C$  = minimum capital cost in Malawi Kwacha,  $kW$  installed capacity of turbine in kW, and  $h$  net head in metres. As a basis for comparison, the standard plant is taken as a diesel plant. Subroto *et al.* (1981:339-342) has provided a formula for calculating the annual fuel cost as follows:

$$\text{Annual fuel cost} = C_{kWh} \times 8760 \times \alpha \times P \quad (\text{Equation 4.34})$$

where  $C_{kWh} = 860 \times \frac{f}{\eta}$  = cost of fuel (US\$/kWh), 860 = conversion factor,  $\alpha$  = annual utilization factor (97%),  $\eta$  is annual average operating efficiency (35%), and  $f$  = cost of fuel per K cal (US\$/ $10^3$ Kcal).

Factors which influence the economic analysis for the small hydropower plant include service life, period of construction and financing expenditure schedules, interest rates and O&M costs (Subroto et al. (1981:339-342; Hosseini *et al*, 2005:1948-1956). The service life for SHP is 35 years, 15 years and 40 years for diesel power plant and transmissions and substations. These have to be taken in consideration.

#### 4.11 Tariff Setting

Small-scale hydropower projects require an organised system to collect payments from users. Payments must be sufficient to cover the operation and maintenance costs. An inflow of revenue is necessary to ensure that a project can continue to meet its recurrent costs without being continually being subsidised. To determine the appropriate tariff, there is need to have some form of regulation. Various regulatory methods have been discussed by Conteh (2003). This study adopts return on investment method since it covers the cost of delivering an energy service.

The price of electricity is calculated from the following formula:

$$RR = [(V - D) * r] + E + d + T \quad \text{(Equation 4.35)}$$

where:  $RR$  = Revenue requirement;

$V - D$  = book value of the useful fixed asset (rate base);

$V$  = original book value of plant;

$D$  = accumulated depreciation;

$r$  = allowed rate of return (weighted average cost of capital);

$E$  = operating expenditure;

$d$  = annual depreciation expenses; and

$T$  = taxes paid by the utility.

The revenue requirement is expressed by the formula below:

$$\text{Revenue} = \text{Price (in kWh per unit of currency)} \times \text{Quantity (quantity of units sold in kWh)} \quad \text{(Equation 4.36)}$$

Depreciation is assumed constant and is calculated from the formula:

$D_t = \frac{P - F}{n}$ , where  $D_t$  is the depreciation charge per year,  $P$  = original cost of asset,  $F$  is the salvage value, and  $n$  is the estimated life. Given that the asset is financed by both equity and debt capitals (Conteh, 2003), the rate of return is determined based on the weighted average cost of capital (WACC), computed from the formula given below.

$$WACC = [(1 - g) \times r_d] + [g \times r_e] \quad (\text{Equation 4.37})$$

where  $r_d$  is the cost of debt finance;  $r_e$  is the cost of equity finance; and  $g$  is the level of gearing or leverage in the utility i.e. proportion of debt in the total capital structure. The actual average tariff is given by:

$$\text{Average Price} = \frac{\text{Revenue requirement}}{\text{Total sales volume (kWh)}} \quad (\text{Equation 4.38})$$

## 4.12 Consumption patterns and load forecast

### 4.12.1 Consumption patterns

Three aspects that are treated as important in as far as the determination of consumption patterns of a community is concerned are the penetration rate, peak factor, and load factors. According to Feibel (2003:42), the penetration rate indicates the percentage of the population, commercial establishments and other consumers which are connected to the system. He observes that few people can afford a connection once electricity is introduced to the rural community. Therefore, the power supply system has to be designed with adequate consideration of the proportion of the population at a planning horizon in year  $x$ , when the total of the installed loads on the consumer side is expected to finally reach the plant capacity.

Clearly, this entails that the number and size of all installed loads and the consumer behaviour in applying these loads must be known. He further observes the need to know at what time of the day and in what combination the applications are used (ibid). The peak factor represents this degree of simultaneous use.

$$\text{peak factor} = \frac{\text{maximum of loads(really) switched on simultaneously [kW]}}{\text{average daily consumption / 24h [kW]}} \quad [-]$$

(Equation 4.39)

If the demands of the loads actually switched on is replaced by potential load (maximum possible), the result is the reciprocal of load factor. By definition, the load factor is the ratio of energy actually consumed  $E_{act}$ [kW] to the potential demand for energy if power were consumed continually at peak levels  $E_{pot}$ [kW]:

$$load\ factor = \frac{E_{act}}{E_{pot}} \cdot 100 = \frac{load\ (consumption\ time / day)}{maximum\ load\ installed \cdot 24h} \cdot 100\ [%] \quad (\text{Equation 4.40})$$

Feibel (2003:42) defines the load factor “as the time aspect, according to the number of hours per day that the different loads are switched on.” In other words, if all loads installed in the system were continuously switched on 24 hours a day the factor would be 100%. The reference value is the total kW load installed on the consumer side and not on the generation side since this would be the reference value for the so-called plant factor or plant utilization. The plant utilization is the ratio of consumed kWh’s to producible kWh (ibid). It is affected by the load factor, the growth of population and the penetration rate.

#### 4.12.2 Load forecasting

Load forecasting develops from estimates of actual population, population growth and household size, percentage of people connected and consumption per connection (Feibel, 2003:45). Three types of electricity demand forecasting methods are extensively covered in literature. These are trend analysis, end-use analysis and econometrics. A brief description for each method is presented below:

##### *Trend Analysis*

Trend analysis uses historical consumption data and extends into the future by applying numerical analysis tools to identify trends, seasonal changes and other patterns (Feibel, 2003:45). It focuses on past changes or movements in electricity and uses them to predict future changes in electricity demand. It is however, appropriate for short-term forecasts and produces only one result-future electricity demand. But does not explain why the demand behaves the way it does

nor provides the means to accurately measure how changes in energy prices or policies influence electricity demand.

#### *End-Use Analysis*

This method works based on the idea that demand for electricity depends on what it is used for. Historical data is studied to find out how much electricity is used for individual electrical appliances in homes. This appliance rating is multiplied by the projected number of appliances in each home. The result is further multiplied by the projected number of homes; an estimate of how much electricity will be needed to run all household appliances in a geographical area during any particular year in the future can be determined. It identifies exactly where electricity goes, how much is used for each purpose.

Reddy et al. (2001:94) relates the total electricity consumption in a household  $i$  and the appliance-wise consumption using the formula below:

$E_i = \sum_j E_{ij}$  where  $E_{ij}$  is the electricity consumed by the  $j$ th appliance in the  $i$ th household. Also in the  $i$ th household,  $E_{ij} = X_{ij} \times U_{ij}$ , where  $U_{ij}$  is the electricity consumption of the  $j$ th appliance category and  $X_{ij}$  is the number of electrical appliances in the  $j$ th category.  $U_{ij}$  can be written as  $U_{ij} = W_{ij} \times h_{ij}$  where  $W_{ij}$  is the wattage of the  $j$ th appliance category and  $h_{ij}$  is the number of hours per month for which the  $j$ th appliance is being used. Substituting  $U_{ij}$  in the previous equation, the following expression is obtained for the electricity consumption of the  $i$ th household:

$$E_i = \sum_j X_{ij} \times W_{ij} \times h_{ij} \quad (\text{Equation 4.41})$$

One disadvantage of this method is that it assumes a constant relationship between electricity and end-use. This mostly holds true over a few years, but over 10 years or so, it is highly likely that energy prices or technologies change and the relationship will not remain constant. The method also requires extensive data since all the relationship between electricity loads and many end-uses are calculated.

*Econometric methods*

Econometric methods estimate the relationships between multiple variables. The basic assumption is that the behaviour of a dependent variable such as electricity consumption is described as a function of several independent variables including population, gross domestic product and electricity price (Feibel, 2003):

*Consumption = function (population, gross domestic product, electricity price...)*

It aims to find the data series and the form of equation which best explain the historical data and thus allow an optimized forecast. However, for rural areas not electrified, data is unavailable, so that it is impossible to find the relationship that provides a forecast. Based on the issues raised in the preceding paragraphs, it appears the end-use analysis is more appropriate and employed in this study.

**Summary and Conclusions**

Small-scale hydropower is the most environmentally benign means to produce electricity for rural electrification. This is why it has been extensively developed in China, Nepal, Philippines, Papua New Guinea, Indonesia, Colombia and Peru, to cite but a few. It is a resource well proven that is there for taking to increase electricity access levels. The adverse effects of large hydropower on the environment and local people can be prevented if small scale hydropower is developed. These would invariably cause minimal changes in natural habitats. Therefore, for evaluation of projects, it is essential to identify and consider all direct and indirect benefits and costs, including environmental costs.

The economics of small hydro systems are highly dependent on specific site conditions such as topography, hydrology and geology and the energy requirements of a particular community. The cost per kWh of energy produced is significantly higher than conventional large hydro, or thermal stations. This is largely due to the initial capital costs of the civil engineering works. In contrast, operating costs are very low because there are no fuel costs and the additional fixed costs of running the station are comparable with large hydro as well as thermal station. As a result, investments in small hydropower stations are justified in the context of the social and economic benefits to be derived by the community.

## CHAPTER 5

### MATERIALS AND METHODS

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This chapter presents an overview of the area identified for the study. It discusses the research methods used in this study. These include desk studies, onsite measurements and a field survey. Figures, which illustrate the onsite measurements, are also included.

#### 5.1 Study Area

Nkolokosa village located approximately 10 km south of Thyolo Boma<sup>6</sup> was selected for this study. It is situated on 16° 09' east latitude and 35° 13' longitude (figure 5.1). The area is densely populated (400-500 inhabitants per km<sup>2</sup>) and under close cultivation. The village under study has 457 households, with a total population of about 2758 people, of whom 60% are women (NSO, 1998). The majority of the villagers are subsistence farmers growing crops such as maize, bananas and legumes.

The proposed weir site is located on Nachipere River, which is a tributary of Nswazi River and is at an elevation of 820 m above sea level. The location of the site can be found in figure 5.1. The site is chosen because it has a steep slope (>12%) and considerable flow which creates an excellent condition for small-scale hydropower. Other factors include easy access to the site, favourable environmental conditions and geological stability. The site has a gross head of 33 m. The calculated size of the catchment area at the hydro site is approximately 21 km<sup>2</sup>. The area receives significant amounts of rainfall. The annual rainfall ranges from 800 mm to 1500 mm while the average mean annual temperature varies between 20°C and 22°C. Humidity level varies between 40% and 80%. The potential evaporation estimated by the Penman method is 1483 mm/year (Department of Meteorological Services, 2007).

A geological map of the area was obtained, and it indicates that the area is dominated by intense faulting associated with the development of the southern section of the Malawi Rift Valley

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<sup>6</sup> Local name for district administrative head quarters

(Geological Bulletin No.22:17). The village forms part of the greater area, which is underlain by impervious rocks. Red-brown and residual clay are the most significant soil types identified on the site. According to the Department of Geological Surveys, the site selected for the construction of hydraulic structures is stable and there is no danger of landslides. However, there is need to dig test pits and study the conditions of the soil, in view of the fact that it will be used as base soil for the foundation of buildings.

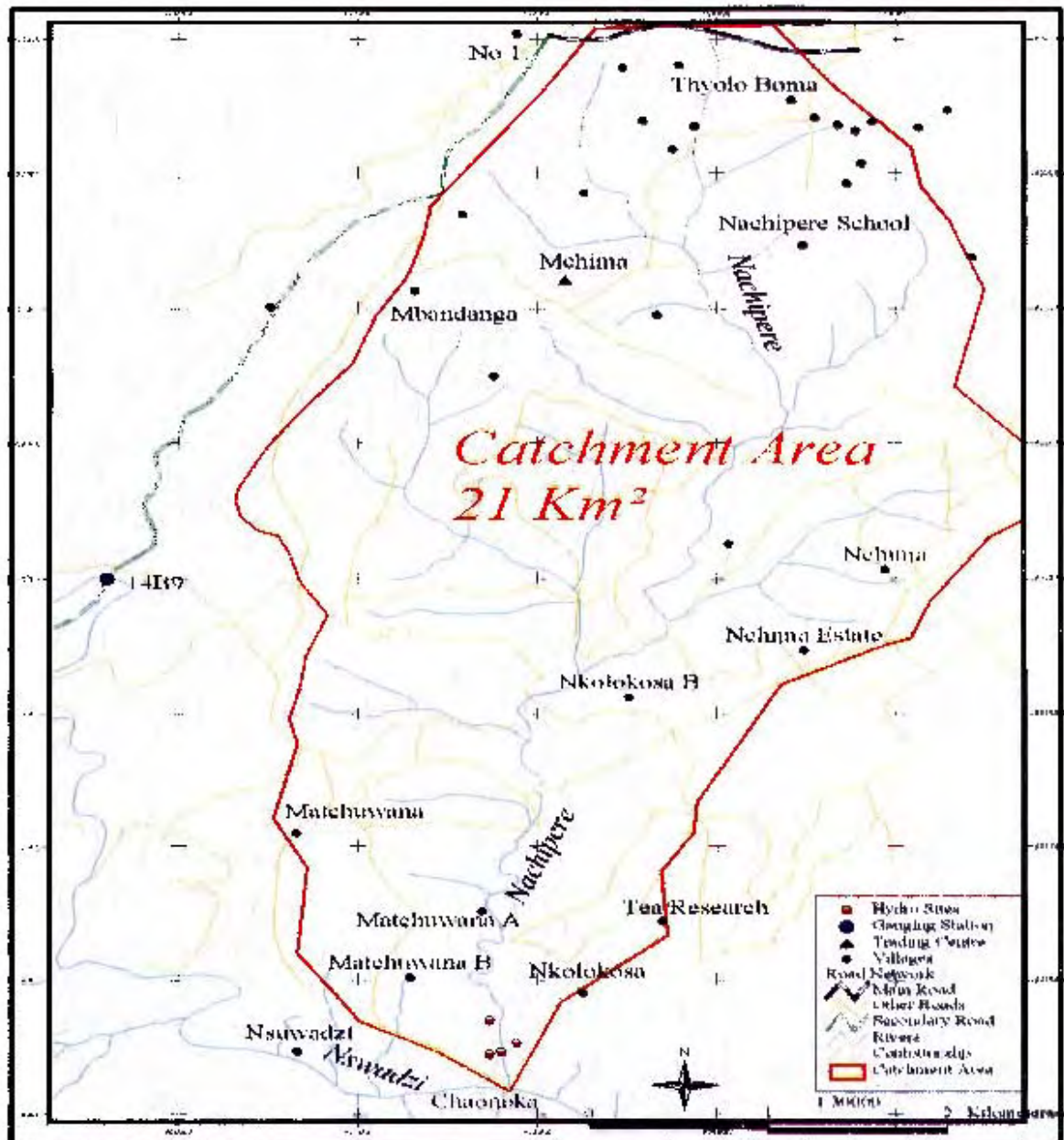


Figure 5.1: Location of the Study Area and Catchment Area of the Project Site

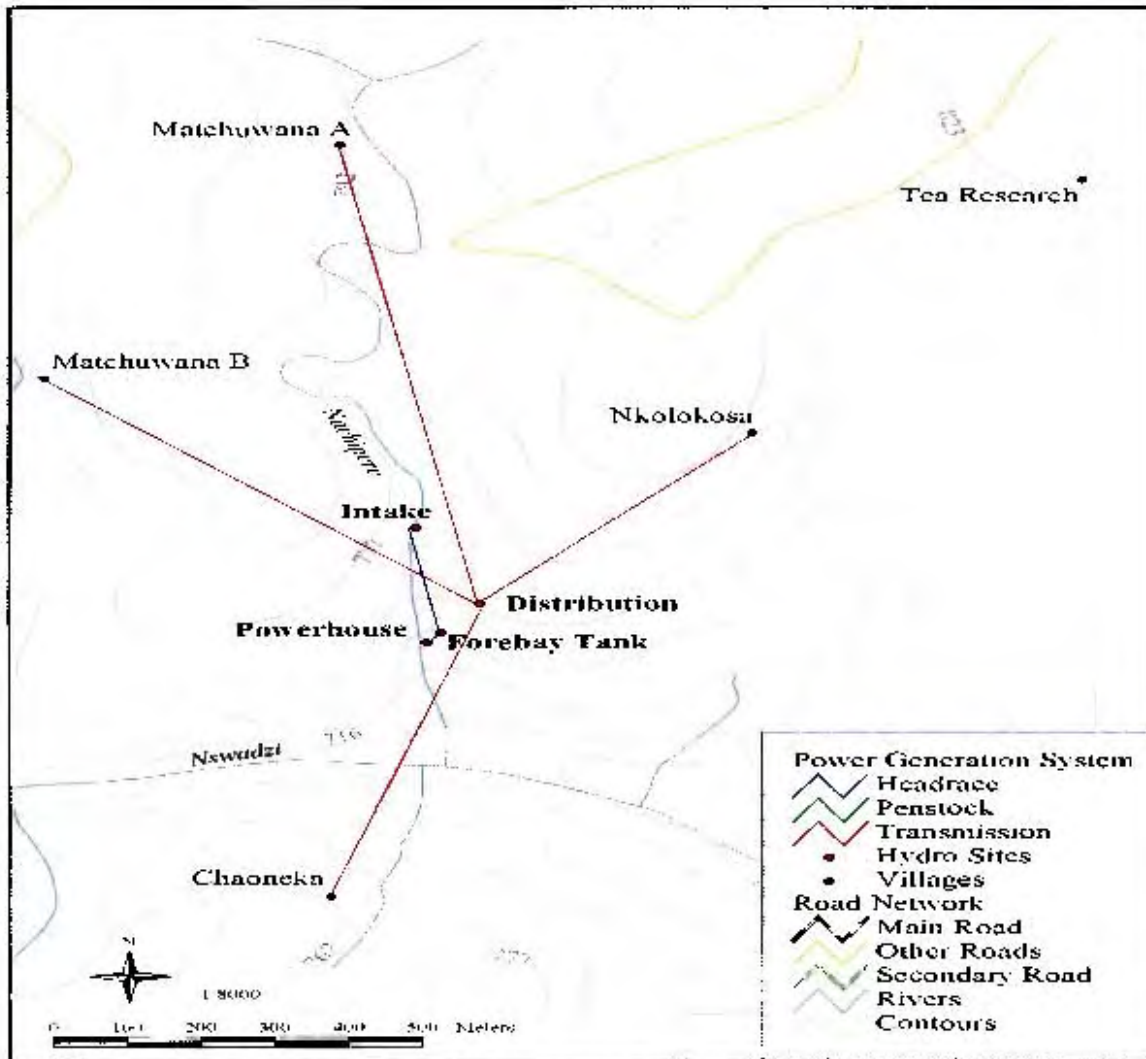


Figure 5.2: General Plan of the Proposed Nkolokosa Hydropower Station

## 5.2 Methods

This section describes the methods of study used to estimate the hydropower potential of the site, energy consumption of the village and forecast demand. Specific descriptions of the various methods are detailed in the respective sections.

### 5.2.1 Research Design

This study has pursued a quantitative approach to explore some of the objectives of this study. Gall *et al.* (2003:287-431) define quantitative research as “a formal, objective, systematic process in which numerical data are utilized to obtain information about the world.” It is inclined

to be deductive. Put simply, it tests theory. In carrying out this research, quantitative data on demographics, hydrology and socio-economic has been collected to test the null hypothesis “small -scale hydropower can increase electrification levels in rural areas.” In the event that the collected data does not support the hypotheses, the theory will be modified to take into account of the findings.

### **5.2.2 Data Collection Methods**

The data in this study were collected using the following approach:

#### *Desk study*

The first step of this research process was review of literature on small-scale hydropower, rural energy and development and rural electrification. The study used both primary<sup>7</sup> and secondary data<sup>8</sup> sources. Most literature was obtained from online journals, conference proceedings, theses, government policy documents, published books as well as project reports. Specific information for the area under study was obtained from the following key government ministries and departments: Department of Energy Affairs (DoEA), Ministry of Irrigation and Water Development (MoIWD), National Spatial Data Centre, Department of Geological Services, Meteorological Department, and National Statistical Office. Information collected from the above sources included: (1) topographical and geological maps, (2) meteorological data (rainfall, sunshine, temperature, evaporation, and wind), (3) demographic data (population), (4) digital elevation model (DEM- land use/cover, soil types and classes), (5) stream flow gauging data, and (6) energy balances (1999-2005), energy policy and the rural electrification act of 2004.

#### *Topographic map studies*

A topographical map on a scale of 1:50 000 that includes the planned area, was obtained. The study was conducted according to the “THYOLO MALAWI 1:50 000 SHEET 1635A1. The map was used to provide information such as location of the village, slope of the river, catchment area of the site and access roads. Digital data was collected from Water Department, National

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<sup>7</sup> Data collected through observations, questionnaires, interviews, and focus group discussions.

<sup>8</sup> Information by others which is in archived form

Spatial Data Centre and Compass II. This data was then processed using GIS software which was used to calculate the catchment area, slope and identify soils at the proposed site.

#### *Site selection*

A preliminary study of sites listed in DoEA's Master plan for Rural Electrification in Malawi was carried out. Due to funding constraints, only five sites were visited. The sites visited were Nswazi at Sandama, Zoa Falls on Ruo River, Ruarwe in Nkhata Bay, Lingoni falls on Nswazi and Nachipere site near the Tea Research Foundation in Thyolo. The purpose of the visit was to (1) assess the gross head at each site (2) consider access problems (3) identify possible consumers of electricity within one kilometre radius, and (4) consider the proportion of flow in the river that was likely to be available for power. Nachipere, a site located near Tea Research Foundation (figure 5.1) met the above criteria and was selected for this study.

#### *Stakeholder consultation*

The study also held a round table discussion in May 2007. The purpose of this meeting was to alert various stakeholders of the study, its broad objectives and the kind of information that the study would usefully provide to the actors in both policy arena and programs. The stakeholders for this meeting were drawn from the district assembly, local community organizations working in the areas as well as representatives from village development committee (VDC) and an irrigation committee.

### **5.2.3 Field surveys**

This section outlines specific activities carried out during field surveys. Included are the socio-economic study, topographic survey and on site stream flow measurements.

#### **5.2.3.1 Socio-economic study**

One of the hypothesis of this study was that small-scale hydro in areas with potential could play a significant role in meeting energy needs of rural areas. It was therefore important to assess the energy requirements of the community and evaluate their ability to sustain the scheme. Determining the energy requirement for each household would be useful in matching the demand with exploitable potential available on site. It is also useful in formulating the rural household

energy demand prediction model. Understanding their socio-economic status would direct the study to assess issues like affordability and sustainability of the project in the wake of abject and pervasive poverty existing in rural areas in Malawi. In order to elucidate this knowledge, structured interviews with close-ended questions were used.

### *Questionnaire*

A household energy questionnaire was developed to gather data on household energy use, and other socio-economic characteristics. The questionnaire included six sections; (1) general information about each household; (2) income and expenditure on energy sources; (3) information on fuels the household was using; (4) future indication of appliances the household will likely purchase once electricity is introduced and (5) individual attitude on expected benefits of electricity and (6) household willingness to contribute towards project construction costs. The questionnaire is provided in an annex D1.

### *Sample Selection*

The sample survey included 118 (24%) representative households. These were randomly selected from total household population of 457 registered in that village. The survey on energy consumption interviewed a representative of the family who had a good knowledge and understanding of incomes and expenditure. To process data to 95% level of confidence, the margin for error was set not to exceed  $\pm 10\%$ .<sup>9</sup> The minimum number of household samples required for the survey was calculated using the equation below:

$$n = \left[ \frac{N}{\left( \frac{\varepsilon}{1.96} \right)^2 \times \frac{N-1}{\pi(1-\pi)} + 1} \right] + 1$$

<sup>9</sup> This means that for a any given random sample there is a 95% chance that the true value  $x$  being measured will fall within the interval  $\hat{x} \pm 10\%$ , where  $\hat{x}$  is the estimate of  $x$  derived from the sample data. More generally, the relationship between sample size, confidence level, and margin of error are given in terms of proportions is described by the formula:  $n = \left( \frac{Z_{\alpha} \sqrt{p(1-p)}}{C_p} \right)^2$  where  $n$  is the sample size,  $Z_{\alpha}$  is the standard normal value for confidence level  $\alpha$ ,  $C_p$  is the margin error and  $p$  is the population proportion. The true proportion is unknown. The standard way to handle this is to set the value of  $p$  to the proportion that would result in the largest sample size. This occurs when  $p=0.5$

where  $n$  was necessary sample size,  $N$  = population,  $\varepsilon$  = target (0.1), and  $\pi$  represented the sample proportion ( $\pi = 0.5$ ). Computing into the above formula the minimum number of households is 96. Therefore, the 118 surveyed households were representative.

#### *Data Analysis and Presentation*

The survey data collected from households through the questionnaire were coded in Excel and converted for use in Statistical Package for Social Scientists (SPSS) where it was analysed and presented in tables and charts. Inferences were used to explain the cause-effect relationship between income and fuel use as well as willingness to pay. A t-test was used in establishing statistical significance of mean differences.

#### **5.2.3.2 On-site measurements**

##### *Measuring head*

The head between the intake point and the fore bay tank and between the fore bay tank and outlet position was measured. A level was set at the centre of a line between two points. Staves were placed vertically at these points and a telescopic sight was levelled. The height difference between the two points was calculated as the difference of the relative height of each of these two points to the level. Figure 5.3 below shows survey of weir and fore bay tank. Results of the topographic survey are given in tables D.1 and D. 2. The results were also verified with GPS readings.



Fig 5.3 Survey of river cross section at the proposed intake weir site

### *Measuring discharge*

The most important aspect of the field measurement was to determine the total flow rate of the river. The method to measure discharge is one of several described by Inversin (1986). This study used the grid point method, commonly known as velocity-area method. To measure discharge, flow velocity and cross section was required. A convenient position was selected along the river. Two rivers banks connected by a scaled tape or rope were used. Using a graduated meter, depths were taken across the river and recorded. The section profile was scaled on paper and uniformly the grid points were located at uniformly lateral vertical points. A current meter was then lowered at different points across the river and the number of revolutions was recorded. A stop watch was used to time the number of revolutions. Elemental flow on each area was given by equation:  $\delta Q = V\delta A$ . The total discharge was then calculated from the equation  $Q = \sum \Delta Q = \sum V\Delta A$ . Results of the discharge measurements are presented in annex 7.

Fig. 5.4 below illustrates how river discharge measurements were conducted.



Fig 5.4: Measuring discharge of river using velocity-area method

#### **5.3.4 Analysis of stream flow data from gauged site**

The Nswazi River discharge data used in this study was obtained from the Ministry of Water Development, Hydrology Section. The record spans the period from 1954 to 1982 and was

processed. Due to interference with abstractions for Thyolo water supply project, the station (14B5) was in 1989 relocated 5 km upstream of the bridge on Nswazi River and it was renamed 14B9. The location of the gauging station is shown on figure 5.1. The data was computed to estimate minimum flows at the proposed project site located almost 8 km from the gauging site. The monthly as well as daily mean flows were analysed for dependability. Flood retention periods were also computed. Results of the analyses are given in the next chapter.

### **5.3.5 Demand Forecasting**

Average daily load curves per household were obtained during the field survey. The unit average daily load curve was multiplied by the number of existing facilities in the village. These were then added together to produce the daily load curves and daily peak demands were estimated. A linear regression model to estimate the forecast demand in the village was derived from the relationship between number of households and estimated peak demands.

### **5.3.6 Results output**

The results of this study are presented using, tables on one hand and graphs drawn using the primary and secondary data in Microsoft Excel and Statistical Package for Social Scientists (SPSS) spreadsheets. Data, not shown in the text for presentation purposes, can be found in the appendices.

## CHAPTER 6

### RESULTS AND DISCUSSIONS

This chapter presents the findings of this study, structured into five sections. It provides answers to the research questions posed in accordance with the objectives of the study. The first section gives the analysis of data collected from the household energy survey. The second section discusses results of hydrological evaluations, followed in section three by results of the energy demand study. Section four provides a summary of the economic analysis of hydro, diesel and hybrid energy supply options. The last section presents results of calculations of greenhouse gases emitted through use of different energy sources.

#### 6.1 Socio-economic characteristics of households

##### 6.1.1 Demographics

Survey estimates indicate that the average household consists of 5.3 people, with the highest number of people being 9, and the lowest 1. This is higher than the national average of 4.1 (NSO, 1998). The population structure is 39% male and 61% female. About 74.6% of households are subsistence farmers, while the rest 25.4% own micro-enterprises (figure 6.1) Thus agricultural activities play a major role in that rural economy as the main source of income.

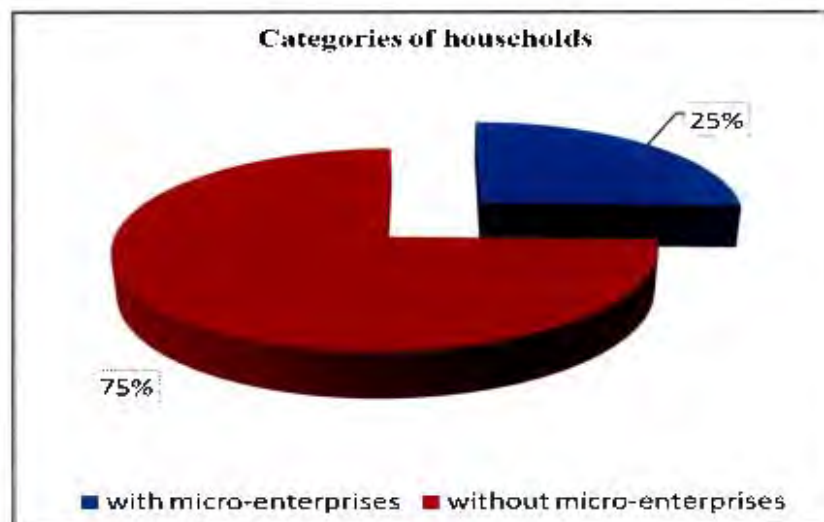


Figure 6.1 Categories of households

### 6.1.2 Household Income

Figure 6.2 shows the distribution of household income groups.

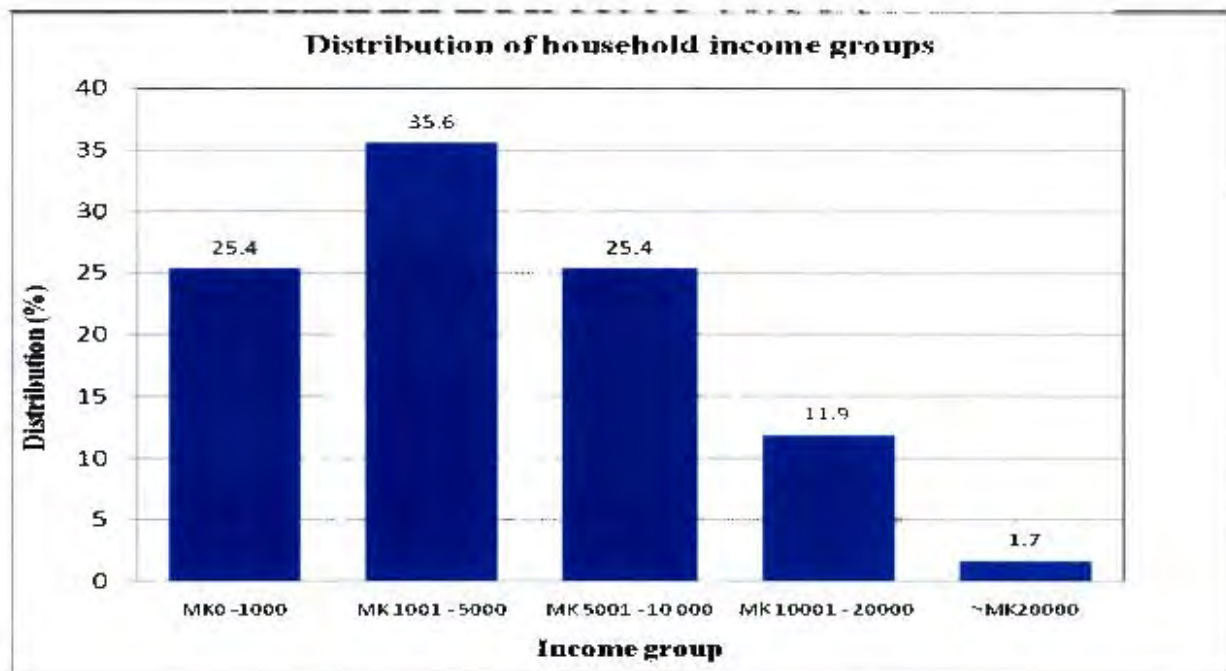


Figure 6.2 Distribution of household income groups

According to the survey results on income earned in May, 2007, five net monthly income groups were established. These include the very poor (< MWK1000), poor (MWK1001-5000), near poor (MWK5001-10000), middle (MWK10001-20000) and affluent (>MWK20000). About one quarter (25.4%) of the people in Nkolokosa village belongs to the poorest bracket and subsists on less than US\$7 in a month (or less than 1000 MWK); while 39% earn more than US\$43 (more than 6000 MWK). Nearly 11.9% of the households have income between US\$71 and US\$143 (or 10,001 - 20,000 MWK), in the middle class stratum. The income state shows that the higher income levels (more wealthy) constitute a mere 1.7% which is insignificant. The average disposable income per month for households with no business was US\$20.39 (2853.93MWK), business entities US\$38.92(5448.28 MK). The average monthly income for the village was US\$25 (or 3438.59 MK). Real household incomes were difficult to capture since the majority of rural households do not maintain book keeping.

### 6.1.3 Energy sources and end uses

Table E.1 shows the different types of fuel and end-uses in Nkolokosa. Firewood is the major source of energy of the households for cooking. Results show that all income groups (100%) rely on one type of fuel (firewood) to meet specific end-uses (i.e. cooking, heating and lighting). About 12.7% of the households use charcoal as a secondary source of energy. Paraffin as a domestic lighting fuel is used by 95.76% of the households. This is slightly higher than the national average of 93.1% (NSO, 1998; DoEA, 2003:17). 23% of households cook using paraffin. Other end-uses such as refrigeration are insignificant at the overall village level. Apart from these fuels, dry cell batteries, candles and car batteries are used by 2.5%, 8.5% and 15.3% of the households respectively.

### 6.1.4 Household energy expenditure

Table E.2 summarises the results of the analysis of monthly energy expenditure and expenditure share of all households by their monthly net income group. According to the survey results, households in Nkolokosa village spend about 15% of their net monthly income on energy, which is a very high proportion. The poorest group are earning less than US\$7 per month and spend between 18.5% and 43% of their income on energy. The more wealthy, who have an income of US\$143 (20,000MWK) per month, spend a maximum of 7.6% of their net monthly income on fuels which represents a lower share compared to the poor.

These findings do not agree with those obtained during the 1998 Integrated Household Survey<sup>10</sup>. This is so because of differences in the methods used to collect the data. It must be pointed out that results from one village may not give a true representative picture of the whole country. However, the results suggest that fuel use is not determined by income in itself. Whilst income is one of the deciding factors when choosing the type of fuel, clearly, it is the nature of activities such as cooking, lighting and entertainment that determined their fuel use and expenditure.

### 6.1.5 Household energy consumption

A summary of the estimated energy consumption by household income is provided in table E.3.

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<sup>10</sup> Source: Government of Malawi (2000), Profile of Poverty in Malawi: Poverty Analysis of the Integrated Household Survey, 1998, Table 36. According to this survey, at national level, the poor spend 4.3% on fuels. The non-poor spend about 3.4%. In rural areas, this translates to 3.5% (poor) and 3.4% (non-poor).

According to survey results, the average daily consumption of paraffin is 0.015 litres per person or a monthly consumption of 2.31 litres. The consumption of firewood is 110.27 kg/household/month. Annually, each person consumes 253.13 kg of firewood for cooking and heating. On average, a household uses 43 kg of charcoal per month. Given that households use more than one type of fuels, as well as different end-uses, it is likely that the calculated values are not accurate. It was observed that the amount of energy used depended on many factors such as the type of food cooked, the number of meals cooked, household size, combination of energy source and cooking equipment used.

### 6.1.5 Household willingness to pay for electricity

The household energy survey established the average quantities for fuels that were displaced by electricity. Using data from tables E.5 and E.6, the gross energy consumed has been calculated and the results are presented in table E.4. The results show that the total energy expenditure replaced by electricity is MWK 1,786.00 and the energy replaced is equivalent to 320 kWh of electricity. Therefore, the average willingness to pay is given by, (Davis and Horvei, 1995):

$$\text{Average willingness [MWK / kWh]} = \frac{\text{Expenditure on alternatives [MWK]}}{\text{Equivalent electricity consumption [kWh]}}$$

The average willingness to pay is calculated as MWK5.58/kWh of electricity.

Figures 6.3 and 6.4 respectively, show the distribution of people's willingness to pay for the maximum connection fee and in-house wiring costs and monthly electricity tariffs.

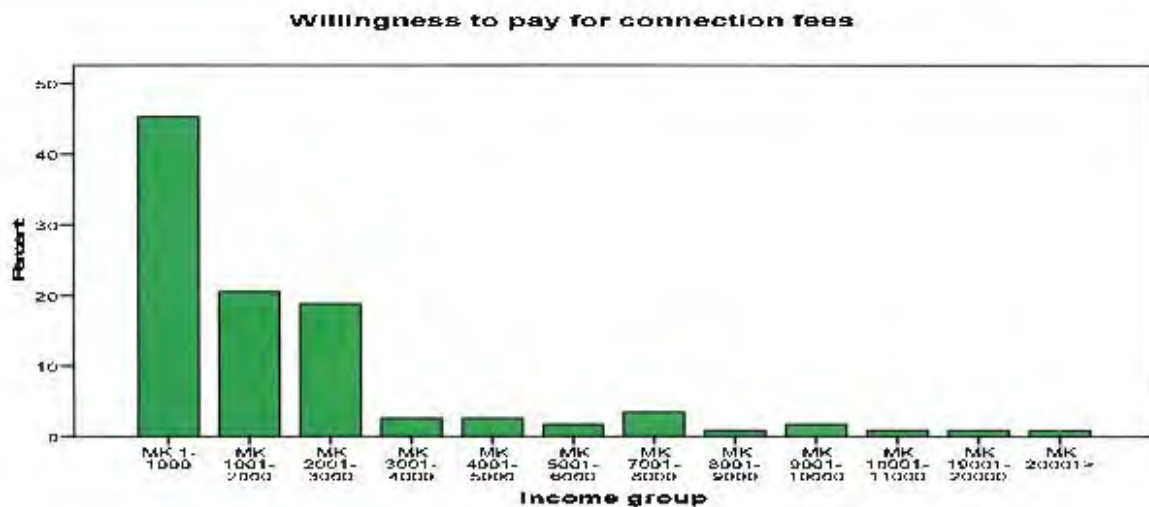


Figure 6.3 Maximum connection fees and in-house wiring costs

According to the survey results, both households with and without micro enterprises are willing to pay for the connection fees and in-house wiring costs and monthly electricity bills of MK2454.74 and MK551.11, respectively. About 45.3% are willing to pay less than MK1,000.00, 20.5% at MK1500.00 and 18.8% up to MK3,000.00 for connection fees and in-house wiring costs. The amounts are considerably less than the actual costs, MK12,000 (GoM, 2003) charged to ESCOM customers. This demonstrates the need for government provide subsidies for upfront costs of electrification as indicated in chapter 3.

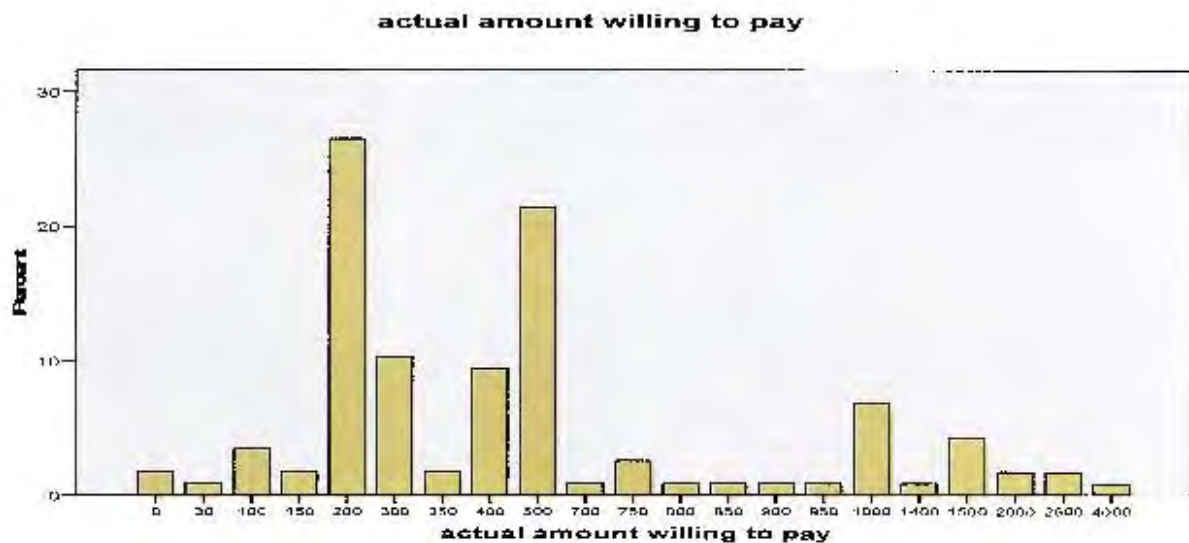


Figure 6.4 Amount willing to pay for monthly electricity consumption

As illustrated by figure 6.4, the very poor (26.5%) have expressed a willingness to pay up to MK200.00 per month, 10.3% at MK300 and 21.4% at MK500 per month for electricity bill. Micro-enterprises currently spending on average MK901.33 on energy sources are willing to spend up to MK4000.00. These figures are confirmed by results of similar studies undertaken by the DoEA (2003). The study found that on average, the monthly fuel cost for paraffin lighting was MK300. By contrast, the monthly electricity tariff of MK200 was for lighting. It was however, difficult to ascertain the results considering that household incomes may not have been accurately captured during the survey. Nevertheless, the results confirm that indeed, a significant portion of household income could be used to pay for the monthly electricity tariffs.

### 6.1.6 Appliances and end-uses of electricity

A number of appliances are expected to be purchased once electricity becomes available. Figure 6.5 indicates the distribution of the desired end-uses of electricity. The desired power usage differs according to the categories of households. Of the sample of 118 households, all households intend to use electricity for lighting, 86 (73%) for cooking, 91 (77%) for radio, and 48(41%) television. This confirms the proposition that lighting becomes the first use and entertainment follows. Fifteen (12.7%) expressed desire to buy refrigerators, 16 (13.6%) videos, and 5 (4.2%) electric heaters. For productive uses, the survey found that demand for maize mills and barber shops were considerable. Fourteen households (11.9%) desired to use electricity for maize milling and barber shops.

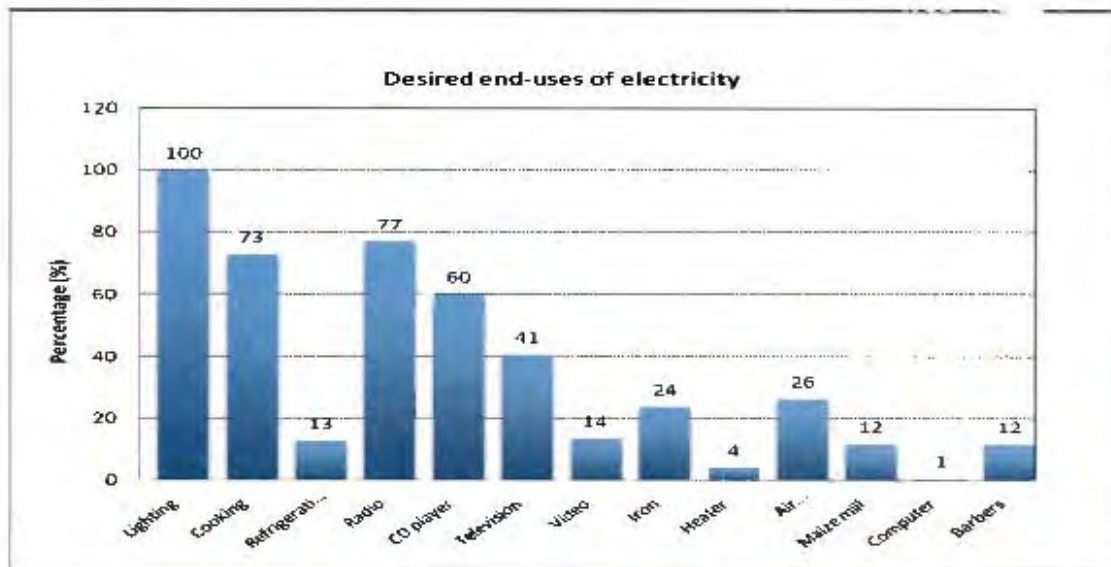


Figure 6.5 End-uses of electricity

### 6.1.7 Behavioural attitude towards electrification project

The survey attempted to establish household's perceptions about the benefits of introducing electricity to the village. Results of the expected effects of electricity are shown in figure 6.6. Most households perceive electricity as a catalyst that will improve security of their business premises and dwellings, increase business opening hours and entertainment. More importantly, households hope the cooking activities and other tasks performed at night will become easier. Those engaged in some form of income generating activities desire to diversify into other forms of businesses. About 11.9% will start hair dressing activities (barber shops), groceries (8.5%),

poultry keeping (4.2%), and battery charging (6.8%). Nearly half (48.3%) have no desire to start businesses.

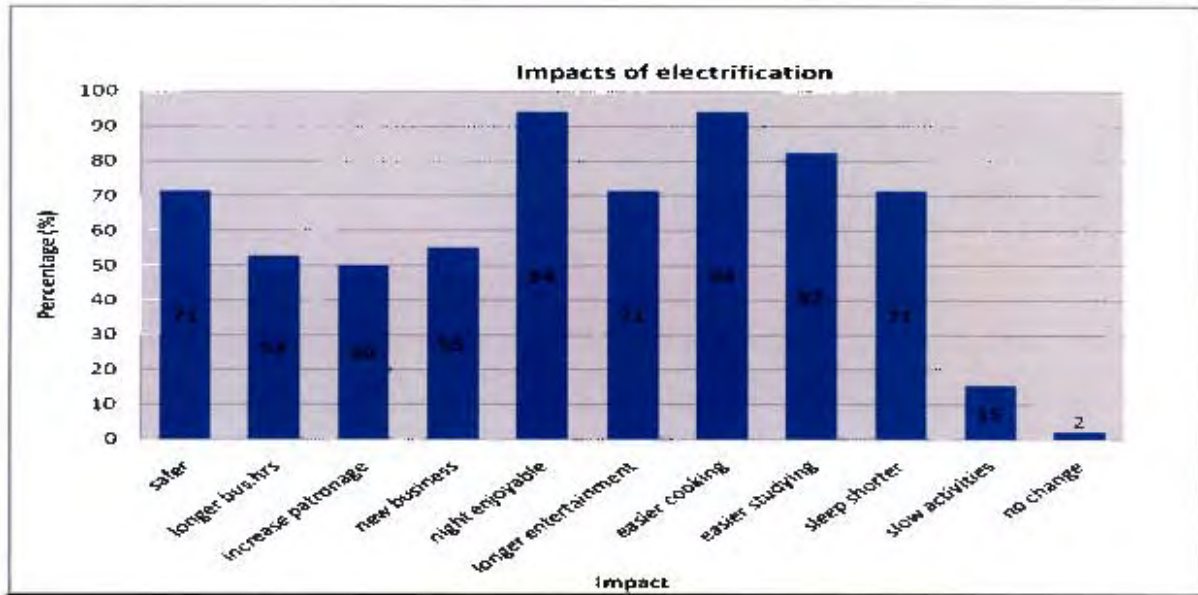


Figure 6.6 Behavioural attitudes towards electrification project

### 6.1.8 Community Participation

Survey results indicating willingness of the community to participate in the electrification project are presented in table 6.6. The results indicate that the majority of households in Nkolokosa village are willing to participate in the project. About 97% households are willing to provide labour, construction materials (81%) and work as plant operators (64%).

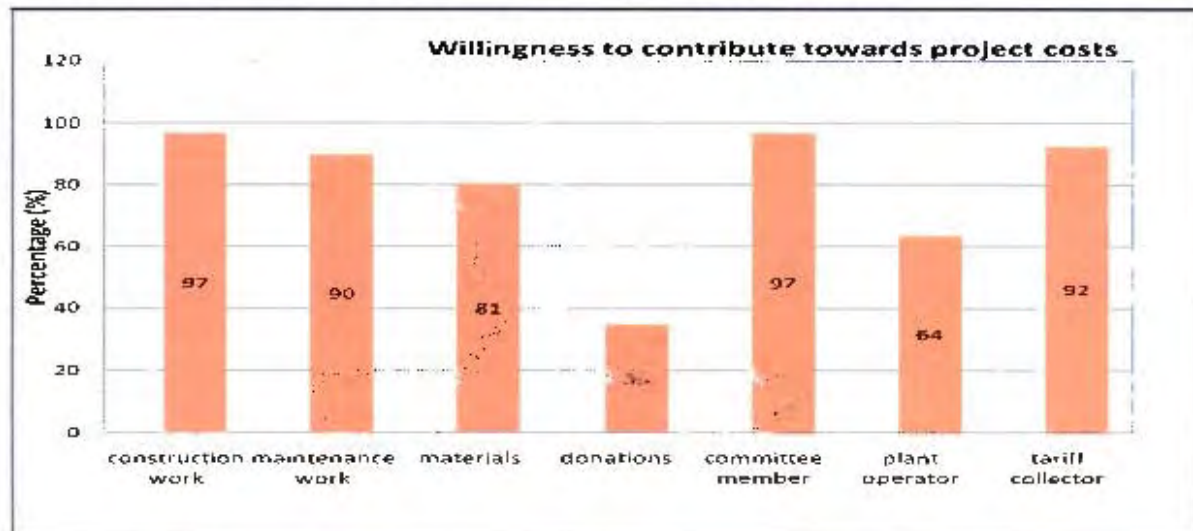


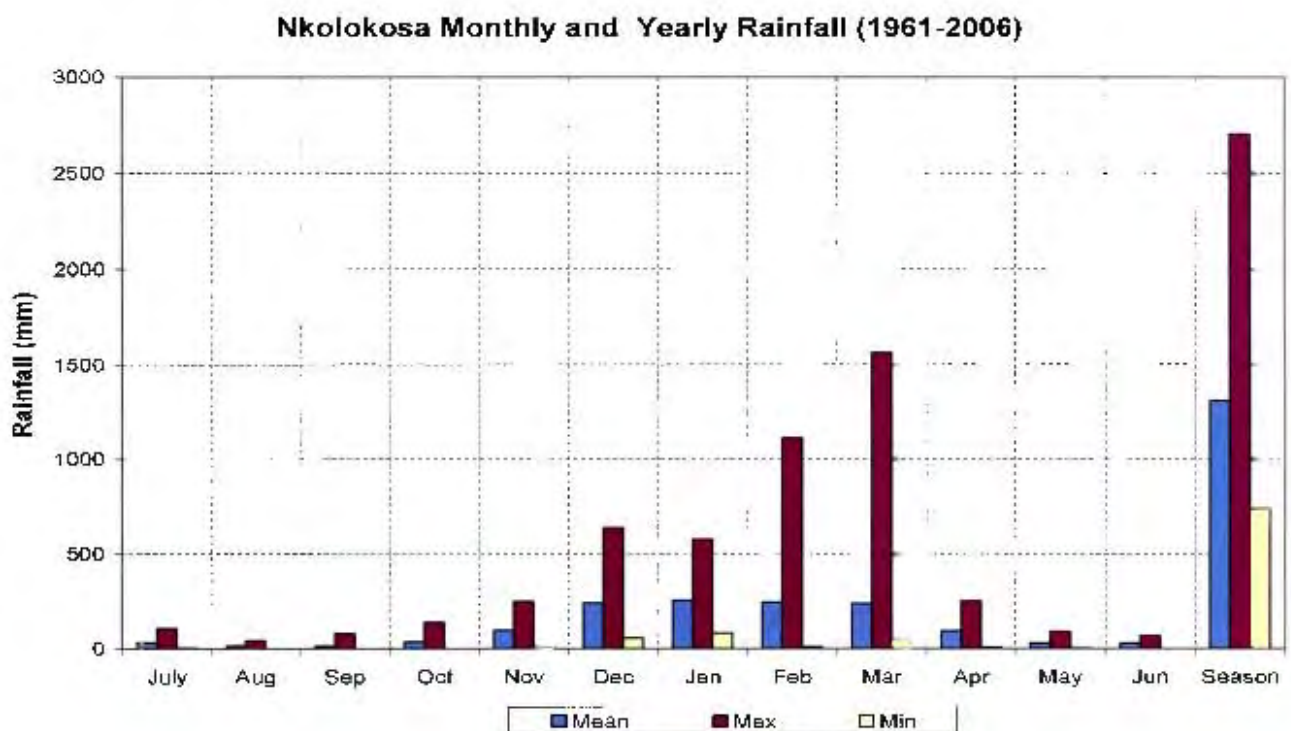
Figure 6.7 Willingness to contribute to project activities

## 6.2 Hydrological Study

This section presents results of the hydrological investigations. This study was necessary in order to know the characteristics of the flow of the river, which are essential for estimating the capacity and the energy which will be provided by the hydropower plant.

### 6.2.1 Meteorological data

Meteorological data such as precipitation, temperature, humidity, wind and sunshine data is recorded, processed and published by the Department of Meteorological Services. As stated in chapter 4, the average annual yield of a drainage area heavily depends on the average rainfall (Drayton et al., 1980:18). This suggests that average rainfall is a strong determinant of water flows in rivers and streams. Therefore, meteorological data was examined with a view to assessing the economic viability of the project. Figure 6.8 shows the monthly and yearly rainfall for Thyolo weather station. Rainfall values are given in the annex E.11.



Source: DMS, 2007

Fig 6.8 Thyolo Monthly and Yearly Rainfall (1962 to 2006)

The data collected covered a 44 year period from 1962 to 1997. The analysis shows that the mean precipitation is 1308.1 mm. The maximum and minimum precipitation is 2701.4 mm and 736.9 mm respectively. Results show that flows will be greatly affected between August and October, since the precipitation is almost zero. Precipitation values between November and March is adequate to give a significant amount of run off for hydropower generation.

### 6.2.2 River flow rate data

A number of indirect methods were used to determine the hydrological parameters such as the design flow, low flow and flood flow of the Nachipere River, currently not gauged. Records of daily water stage measurements for the Nswazi River at Kautuka, near Magombe Estate about 8 km upstream of Thyolo-Makwasa Bridge from the site was obtained from the Water Department. A rating curve modelled using Manning's equation (4.23) was developed for the gauging station. The stage-discharge relationship computed and used in this study is expressed as follows:

$$Q = 3.364 (H - 0.101)^{1.764}$$

where  $Q$  is the discharge and  $(H - 0.101)$  represents for the water depth at the cross section,  $a$  (= 3.364) and  $b$  (=1.764) are coefficients<sup>11</sup> specific to a channel cross section (Rantz et al, 1982:284). Computed daily discharges using preceding equation are provided in the CD accompanying this report. However, the monthly mean flow data was analysed for dependability. The statistical properties of the monthly mean flow data for the Nkolokosa River are given in annex E.9. Results show that the mean flow for the entire period under consideration is  $0.707\text{m}^3/\text{s}$ , which is quite considerable.

#### 6.2.2.1 Minimum Water Flows

The drainage-area ratio method proposed by Flynn (2003:7) was used to convert the daily data observed at Nswazi River into discharge data at the ungauged site on the Nachipere River. The drainage area at both the gauged and ungauged site were  $94.1\text{ km}^2$  and  $21\text{ km}^2$ , respectively giving an effective area ratio of 4.5. There were no significant differences in the annual average rainfall for the two drainage areas. As a result, the flow was not adjusted. Figure 6.9 shows the

<sup>11</sup>  $a$  is a scaling factor that encompasses the section width, the bottom slope and Manning coefficient,  $b$  includes the geometry of the river banks, in particular the departure from vertical banks and generally an indicator of the type of control acting on the stage-discharge relation (Rantz et al, 1982:284)

flow-duration curve for the Nkolokosa River, elaborated using equation (4.24), and on the basis of the monthly mean discharge data.

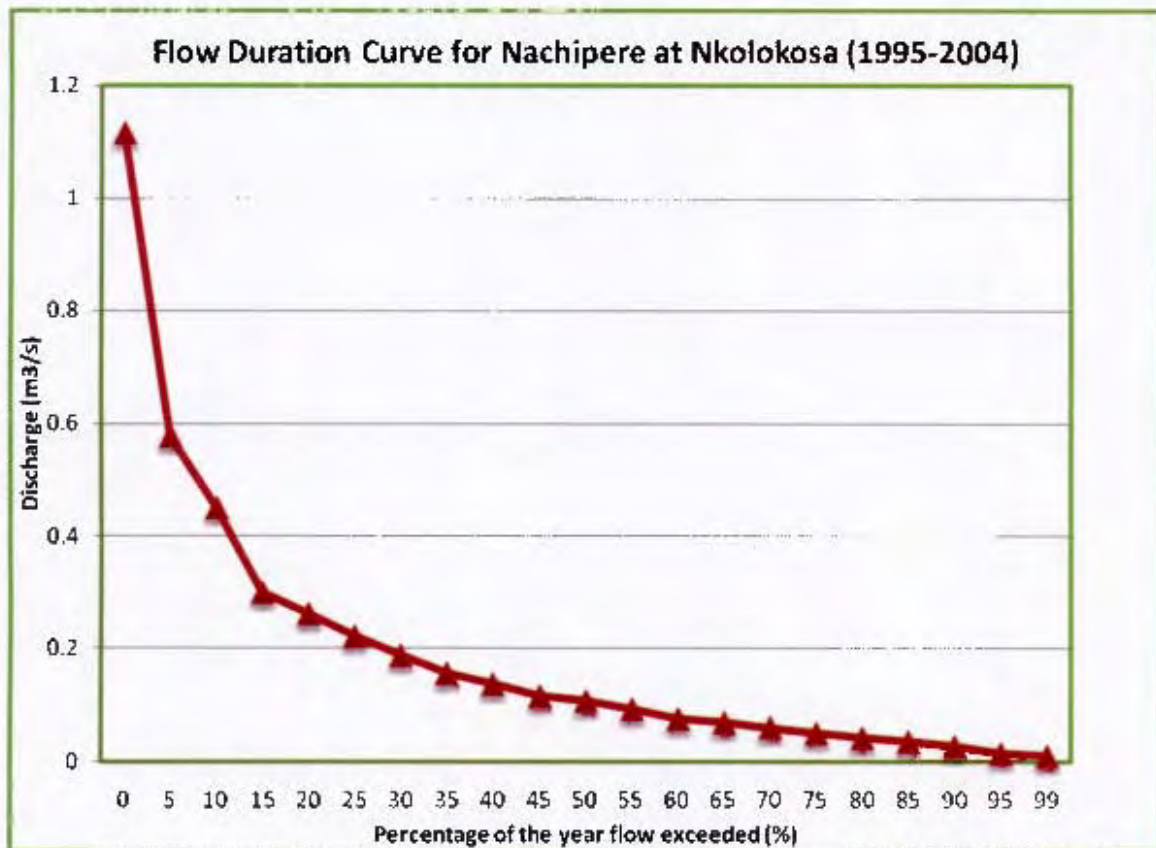


Figure 6.9 10-day flow duration curves for Nachipere River (1995-2004)

Drayton et al.(1980:26) suggest that the point on the flow duration curve to be used as a low-flow index is the 75 percentile 10 day discharge,  $Q_{75}(10)$ , expressed as a percentage of the annual daily flow (ADF)<sup>12</sup>. The minimum flow at the ungauged site is  $0.051\text{m}^3/\text{s}$  and was adopted for this study. However, it must be pointed out that the flow duration curve at the ungauged site was approximated and is valid only insofar as the assumptions hold for this particular situation. Thus a second approach was required to compare the consistency of the results.

<sup>12</sup> Average daily flow is the long term average rate of run off from the catchment and is expressed in cubic meters per second.

### 6.2.2.2 Average Daily Flow/Mean Annual Flow

A more accurate way to calculate the mean annual flow is to use the specific run-off method proposed by Inversin (1986). Using runoff data provided by the Department of Meteorological Services, the average daily flow was computed from the relationship between average annual yield (AAY)<sup>13</sup> and average annual rainfall, given by:  $ADF = \frac{AAY \times AREA}{31500}$  where AREA is the drainage area in km<sup>2</sup>. Analysis of precipitation data and average annual runoff<sup>14</sup> led to a simple linear regression model as follows:

$$AAY = 1.225AAR - 995 \quad (R^2 = 0.735)$$

A plot of the relationship between average annual yield and rainfall as well as average daily flow and rainfall are shown in figure 6.10.

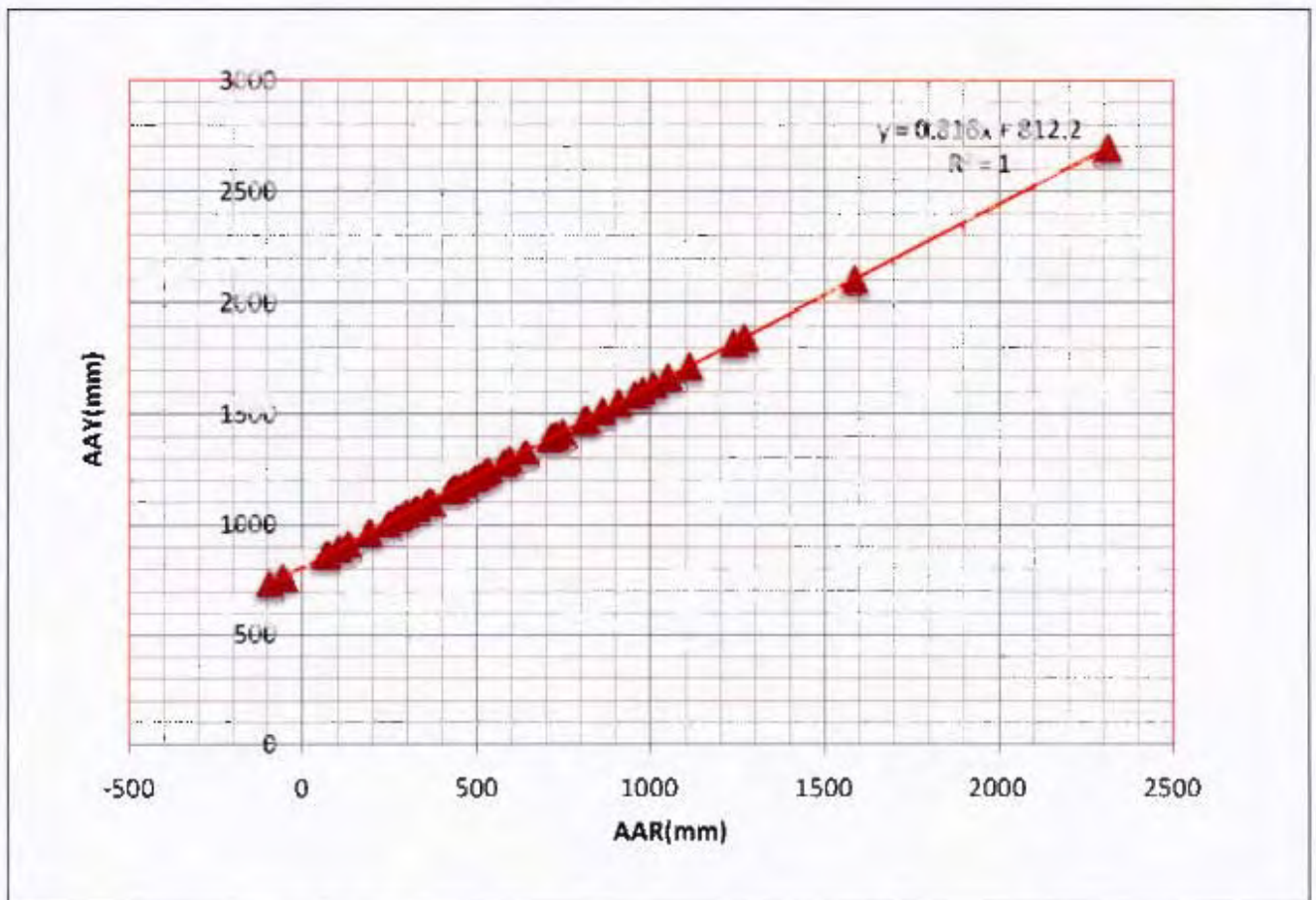


Figure 6.10 Relationship between average annual yield and rainfall

<sup>13</sup> Average annual yield is the average annual run off volume expressed as a depth in millimeters per year over the catchment

<sup>14</sup> Runoff is the rainfall that actually does enter the stream or river as either surface flow or subsurface flow.

Average annual rainfall (AAR) values are given in the appendix B and shown in figure 6.10. Substituting the value of 1308.1mm into the above equation resulted in an average daily flow of  $0.405\text{m}^3/\text{s}$ . The runoff coefficient was calculated to be 0.46. The flow-duration curve elaborated using the specific run-off method, is considered more accurate, and is shown in figure 6.11.

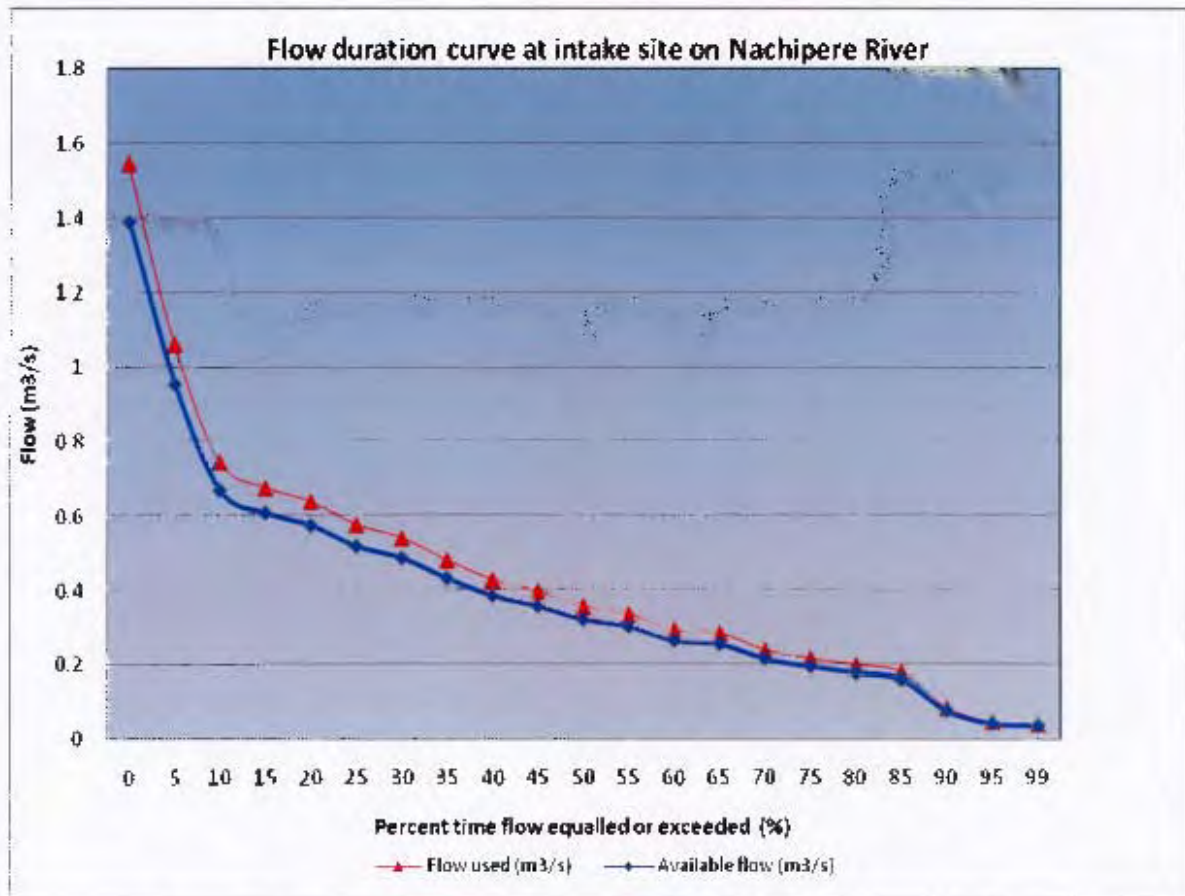


Figure 6.11 Flow duration curve at intake on Nachipere River

The curve reveals that  $0.05\text{m}^3/\text{s}$  of discharge is available at 95% of the period,  $0.217\text{m}^3/\text{s}$  for 75% of the overall period and  $0.357\text{m}^3/\text{s}$  for 50% of the overall period. The lean period flow reveals that a discharge of  $0.044\text{m}^3/\text{s}$  is available for 99% of the total duration of the lean period. This gives an indication that the flow at the proposed site is adequate for hydropower generation.

### 6.2.3 Flood Flow

Using annual maximum instantaneous flows given in annex J and applying the Log Pearson Type III Distribution method, the flood discharge at the ungauged site has been calculated and

presented in table E.10. Figure 6.12 shows the flood frequency analysis at Kautuka and Nkolokosa. The 100 years return period<sup>15</sup> flood at Nkolokosa was calculated to be 40m<sup>3</sup>/s and was used for this study to design intake structures to be constructed at the proposed project site.

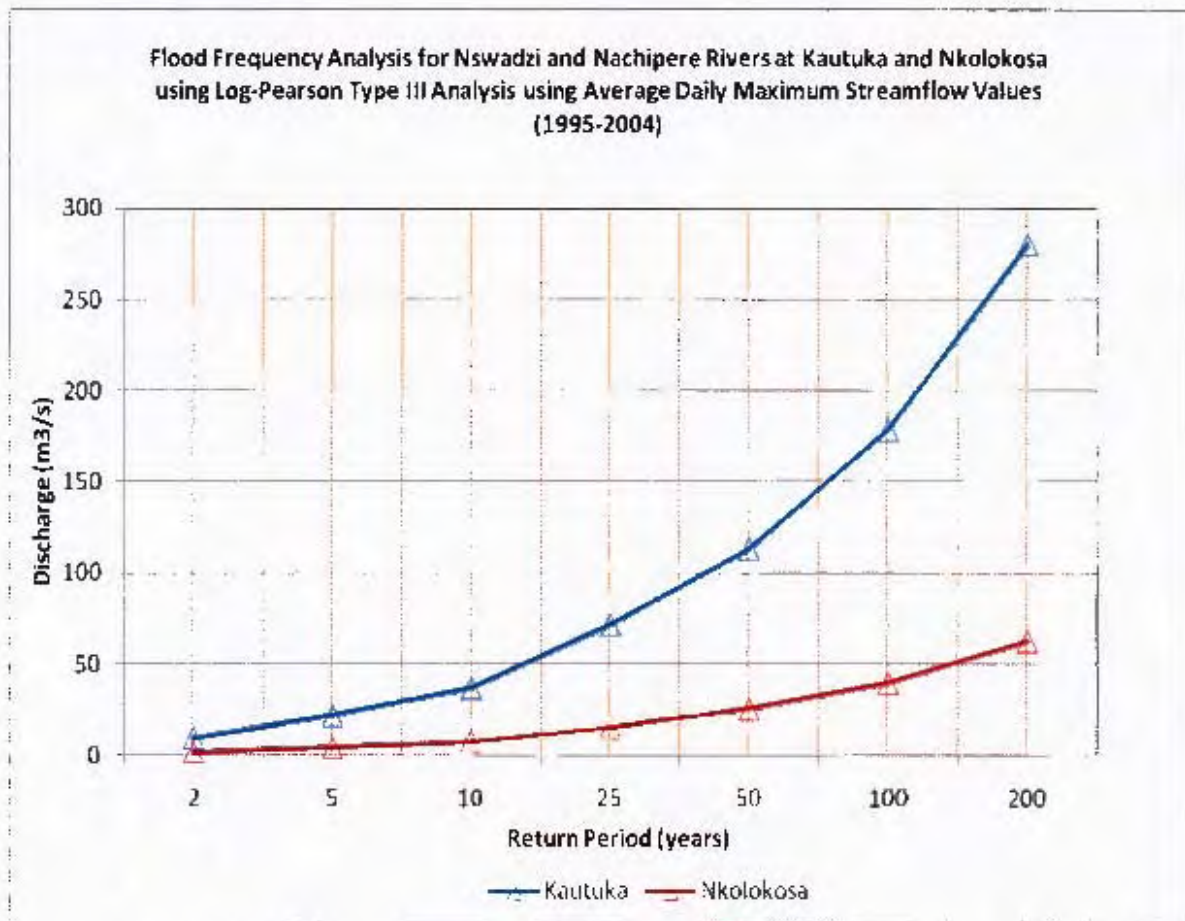


Figure 6.12 Flood frequency analyses for Nswazi and Nachipere at Kautuka and Nkolokosa

#### 6.2.4 Flow Correlations

Direct correlations of discharge at Nachipere River to Nswazi were not available due to time and financial limitations. Therefore, the two indirect methods (runoff and catchment-area) were applied for the hydrological computations. To ascertain the results, direct onsite river flow measurements were undertaken. The minimum water flow at the proposed site was calculated based on river section drawings obtained from the river section survey and flows measured using a flow current meter. Results of the flow measurement are presented in annex D.3 together with

<sup>15</sup> Return period is defined as the average interval (in years) between occurrences of a flood greater than or equal to a given value-it is also the reciprocal of the exceedance probability of a flood in any given year.

the record sheet utilized for the river flow measurement. The actual river flow recorded was  $0.387\text{m}^3/\text{s}$ . This compares well with the value of  $0.405\text{m}^3/\text{s}$  obtained using the runoff method. Flow duration curves derived using the drainage area and specific runoff methods gave low flow values of  $0.051\text{m}^3/\text{s}$  and  $0.217\text{m}^3/\text{s}$  respectively. These methods yielded substantially different results because of poor quality of flow data collected at the gauging station. Although the flow measured in May does not represent the minimum flow through the year, local residents reported that the river has not dried up in the past. The results however, show that river flow for power generation should be available in the dry season.

### 6.2.5 Water Availability

An investigation was made to assess water demand for the local industry, agricultural, and the local community. Consideration was given to the various possible purposes for this water, such as irrigation, power generation, and water supply for industrial and domestic use. The primary purpose of the assessment was to determine the power features of the designed hydro plant such as flow regulation, firm power, installed capacity and mean annual power output etc. These indexes reflect the power benefit of the hydro electric plant and the extent of utilisation of the water resources. Using the computed data of Nachipere River from 1995-2004, a hydrograph has been drawn and is shown in figure 6.13. Applying the flow duration curve presented in figure 6.11, the following results are obtained:

- Minimum discharge :  $0.217\text{m}^3/\text{s}$  (75% exceedance probability)
- Peak flood discharge :  $40\text{m}^3/\text{s}$  (estimated from flood marks)
- Irrigation discharge :  $0.02\text{m}^3/\text{s}$  (estimated from size of agricultural land available)<sup>16</sup>
- Residual flow :  $0.022\text{m}^3/\text{s}$  (10% of minimum discharge)

The discharge available for hydropower development thus becomes  $0.197\text{m}^3/\text{s}$ . Assuming flushing requirement of  $0.020\text{m}^3/\text{s}$ , the hydraulic structures are designed for a discharge of  $0.177\text{m}^3/\text{s}$ . Interview with the villagers showed that Nachipere River is at present used for domestic purposes by few households. However, one kilometre upstream of the proposed power

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<sup>16</sup> Department of Irrigation intends to establish an irrigation scheme and area to be irrigated is 5 hectares. This is equivalent to pumping 20 litres per second

station, there is a small irrigation group which uses water from the same stream. The installation of the small scale hydropower plant at the proposed site will not affect the demand for water.

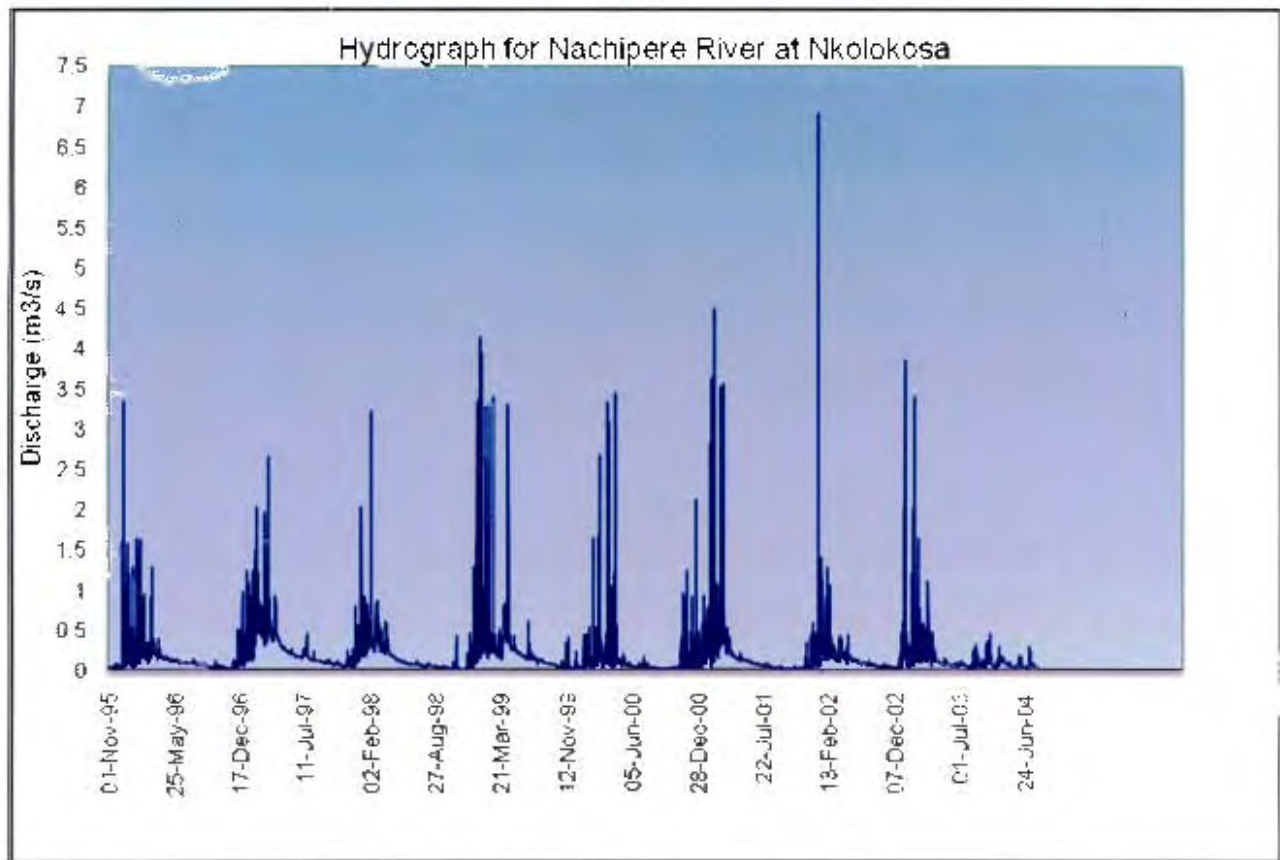


Fig 6.13 Hydrograph for Nachipere River at Nkolokosa

### 6.3 Energy Demand Study

#### 6.3.1 Maximum Power Demand

Energy requirements for Nkolokosa village were estimated based on the desire for electrification expressed during the socio-economic survey. A summary of the existing electric appliances, future purchase of appliances and desire for installation is presented in table F.1. An end-use analysis approach described in section 4.12.2 was used to estimate electricity consumption for different end-uses in the households. Using equation (4.39) and data from tables F.1 to F.2, the

a control factor. The results are depicted in tables F.5 to F.9. It is found that the peak demand was approximately 40.4kW in the daytime and 67.2kW in the night time. The demand for lighting constitutes 44% of the maximum power required. The maximum power demand of general consumers is 143.19 kW, public facilities (1.26kW), groceries and shops (0.68kW) and rural workshops (6.43kW). As shown in table F.10, the maximum power demand for the Nkolokosa village is presently at about 150 kW.

It was pointed out in section 4.12, that not all households can afford a connection once electricity is introduced into the rural community. Empirical evidence suggests that the official market penetration is around 10% per year during the first five years of operation and about 6 % thereafter (Feibel, 2003: 49). An initial connection rate of 10% which increases to 50% in 20 years, representing a linear increase of 2% per year, is adopted for this study. With this assumption, the maximum power demand in the village is at 23 kW (in 2007), but increases to about 65 kW by the year 2027. In view of the fact that the data on ownership of different household appliances and the effects of increases in appliance penetration on future electricity demand has not been studied, the results of this study should be taken with care. A more rigorous analysis could be conducted if data on appliance stock and elasticities were available.

### 6.3.2 Peak load

The peak load for different household sizes was calculated, with sizes ranging from 20 to 500 households. The average and minimum loads were assumed to be 55% and 30% of the peak load, respectively. Figure 6.14 shows a plot of energy demand under different household sizes. Given that the potential at Nkolokosa is about 40 kW, it is evident from this graph that between 100 and 115 households (22%) can access electricity. This is valid insofar as the above assumptions on peak values holds true.

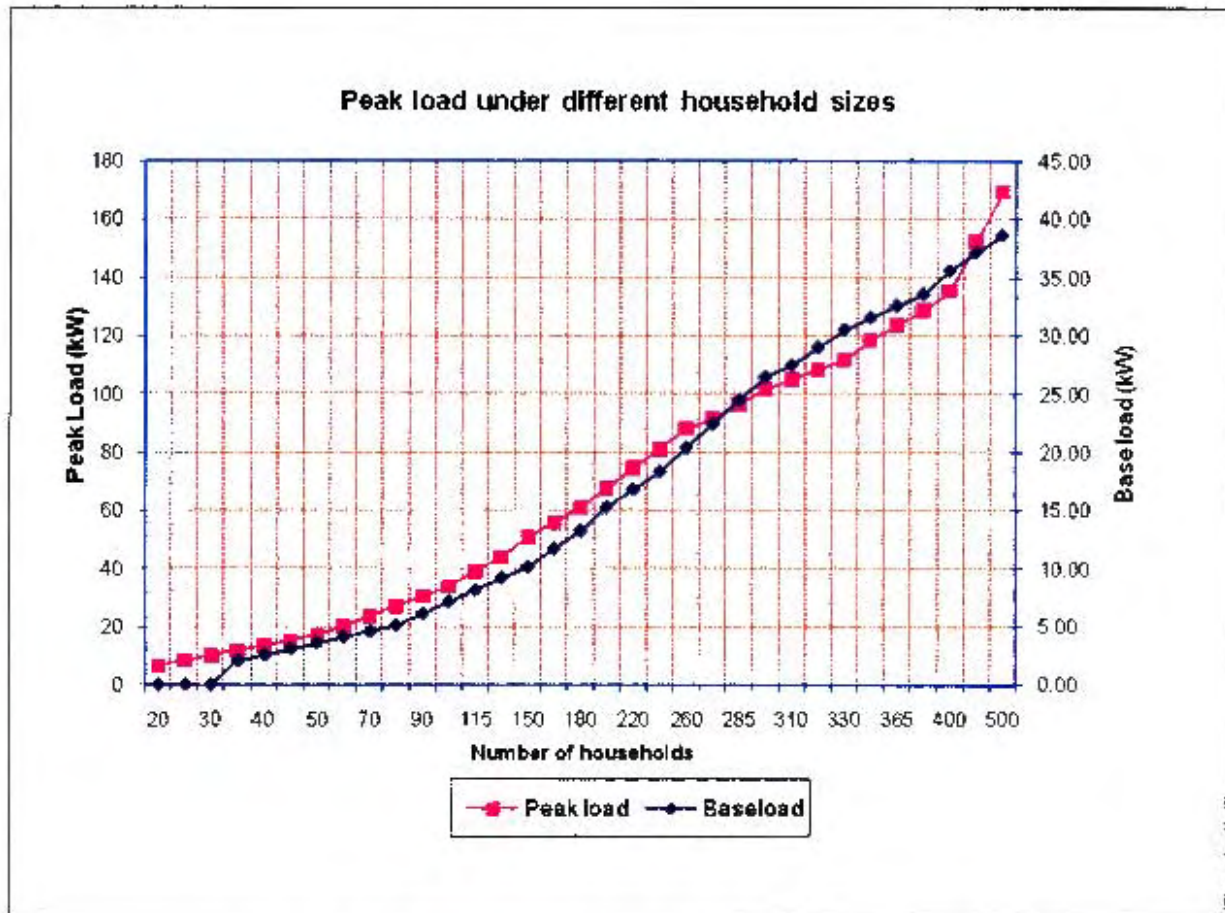


Figure 6.14 Power demands under different household sizes

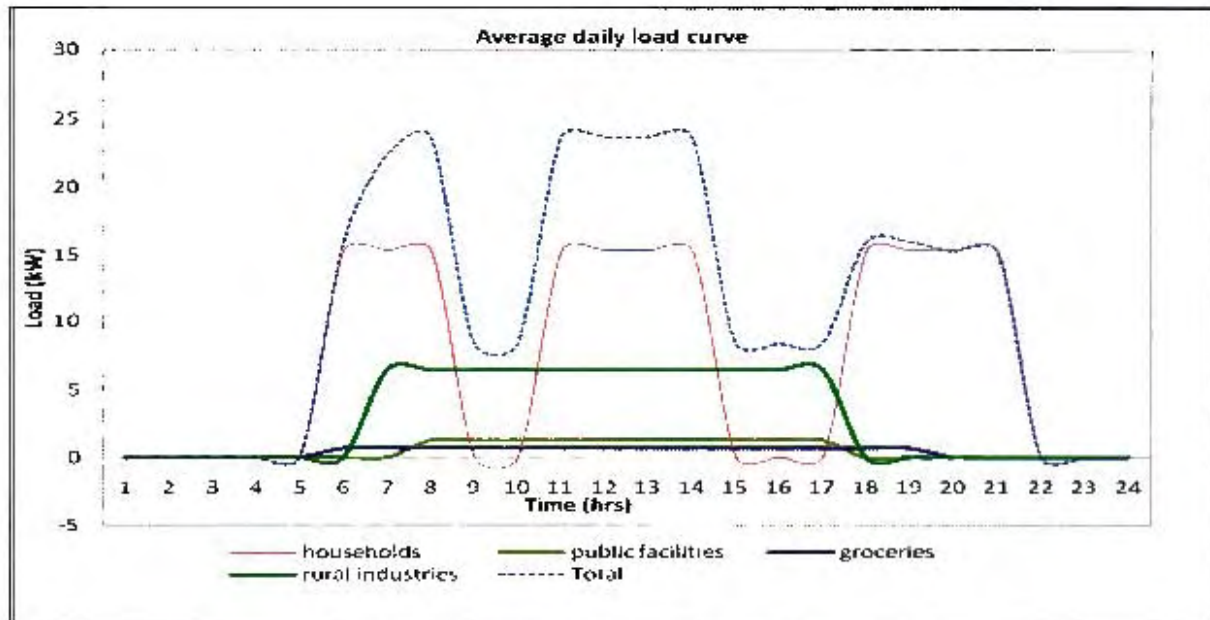


Figure 6.15 Average daily load curves for Nkolokosa Village

### 6.3.3 Required Output of Power Station

In order to meet the power demand of 65kW to the community in Nkolokosa, taking into consideration the distribution loss of 10%, the output of the power station should be set at 72 kW. A flow rate of 0.312m<sup>3</sup>/s would be required. The design flow which matches the site conditions clearly shows that demand is one and half times the potential. The flow rate of the river decreases in the dry season, and the power station output will drop to 20.33 kW when the discharge is 0.088m<sup>3</sup>/s (when the flow rate exceeds 90% of time [328 days] and to approximately 11.55 kW when the discharge is 0.050m<sup>3</sup>/s (when flow rate is 95% of the time [347 days]). Therefore an approximate load limitation is necessary during the dry season.

### 6.4 Estimation of future electricity consumption

Electricity consumption depends on appliances ownership, utilisation hours, and power ratings of each appliance. Household income plays a crucial role as it signifies the possibility of switching from traditional energy sources to commercial ones such as electricity. However, data on appliances ownership and utilisation were not available since the village is currently not electrified. As a consequence, this study carried out a regression analysis using data from the surveyed households. Household incomes, size and monthly energy expenditure have been analysed and the results are presented in annex J. The result of the analysis was a model that can be used to evaluate the daily peak demand, and is represented by the following equation:

$$Y = -0.0002B_1 + 1.744 B_2 - 2.376$$

where Y represents the daily peak demand ,B<sub>1</sub> is the household income, B<sub>2</sub> is the number of households in the village and B<sub>3</sub>(=0) is the household size. The result indicates a coefficient of determination (R<sup>2</sup>) value of 0.673, meaning that 67.3% of the variation in electricity consumption is explained by the number of appliances used. Thus only the number of appliances is significant at 95%, and that eliminating income and household size does not significantly improve the model fit.

Electricity consumption for shops, public facilities and maize mills were added to the regression equation. The known unitary capacity of a maize mill is 20 kW. A 50% diversity factor<sup>18</sup> was

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<sup>18</sup> Diversity factor is the ratio of the sum of the individual maximum demands of various parts of a power distribution system to the maximum demand of the whole system.

also introduced into the model to cater for situations where not all appliances are turned on. The following modified equation was obtained:  $Y = (1.7443B_2 - 2.376) \times D + 2.2B_4 + 20B_5$  where D: diversity factor ( $D = 0.5$ ),  $B_4$  is the number of business enterprises, and  $B_5$  is the number of maize mills installed in the village.

Forecasted number of households was calculated from the equations given below:

$$B_{2[2012]} = B_{2[2007]} \times (1 + 0.0127)^5$$

$$B_{2[2012+n]} = B_{2[2012]} \times (1 + 0.0127)^n = B_{2[2007]} \times (1 + 0.0127)^{n+5}$$

where  $B_{2[2007]}$ : number of households registered in a mid-year census

$B_{2[2012]}$ : number of households in the village in 2012

$B_{2[2012+n]}$ : number of households in the village in n years after 2007.

Forecast demand for all households in Nkolokosa village for every five years is given in table F.10.

## 6.5 Economic Analysis

This section aims at comparing the economic viability of small-scale hydropower, diesel and hybrid systems. The analysis was carried out using the life cycle costing approach. This approach allows systems to be compared on an equal basis by reducing all future costs, which occur at different intervals of the systems life, to one value referred to as life cycle cost (present value) of the system. Three cases were examined: construction of small-scale hydropower, installation of diesel power plant, and installation of diesel/hydro hybrid system. The basic assumptions made in this study were as shown in table G.1.

### 6.5.1 Capital costs

Capital costs for the small-scale hydropower plant were calculated and are shown in table G.2. They include the cost of construction, equipment and accessories, the cost of installation and transportation. All the construction costs assumptions were developed after reviewing the master plan for rural electrification in Malawi. Construction costs were estimated by the unit price method.<sup>19</sup> The quantity of each works was estimated using drawings prepared in the preliminary design.

<sup>19</sup> Cost = work quantity x unit price

The construction cost is MWK88, 679,714 (including transmission and distribution lines). Results of the calculations show that with the firm potential of 40kW the capital cost for small hydro is MWK2, 216, 992.86/kW (US\$15,835.66/kW). Table G.3 presents facility specifications and construction costs for diesel generators and diesel/hydro hybrid systems. For the hybrid system, the constructed costs calculated for the diesel generator were added to those for hydro.

### 6.5.2 Annual energy production

According to the results of the survey of power demand the daily load factor was found to be 30% during the day and 55% at night. To calculate the amount of energy generated, it was assumed that the daily load time in the planned site operates for 11 hours (7.00 am -18.00 pm) during the day and 6 hours (6.00 pm -12.00 am) at night. With the available capacity and using the above load factors, the energy delivered was calculated from equation (4.21). The results are given in table G.4. As seen from the table, the total electric energy generated throughout the year is 192,337 kWh. The total electricity generated energy in the day time is 124,453 kWh and that in the night time is 67,884 kWh. Diesel-generated electric energy amounts to 273,600 kWh in total when electricity that meets the demand shown is supplied throughout the year.

### 6.5.3 Fixed Annual Operating and Maintenance Costs

Operation and maintenance costs are estimated based on the percentage of investment and staff allocation. The yearly operation costs after starting operation of the power station were set at 1.5% of the annual capital cost for hydro, 5% for diesel, and 2% in case of the hybrid system. Given that costs increase with time as the system gets older, an initial value of 1.5% was used in this study. This was increased every five year interval up to 5.5%. The operating and maintenance costs are provided in annex J. The O&M costs for diesel power plant are expected to be higher than hydro due to high costs of imported fuel. The average annual O &M cost is MK257, 160 per annum and MK 478,750 for hydro and diesel plant, respectively.

### 6.5.4 Fuel cost

The unit fuel consumption was calculated using the formula given in the master plan as shown below (DoEA, 2003):

$$\text{Consumption (litre/hour)} = 0.1476 \times P_p$$

where  $P_p$  is the installed capacity of the diesel generator. The unit price of fuel (K250/l) was valid when the study was made.

### **6.5.5 Unit energy cost**

The unit energy cost reflects the cost of electricity and provides a measure for the cost at which a particular installation would be sold in order to recover the inclusive costs for providing the electricity service. Results of the life-cycle cost for the three options are presented below. Details of such calculations are appended in this report. For the hydro option the results are based on BWG cross flow turbine and generator set, both of which are not available in Malawi, but could be imported from South Africa. Similarly, for the diesel generator option, this study considers Cummins or Perkins Engine type also currently available on the Malawi market. Table G.7 provides a summary of the levelised cost of power for the three options.

It is observed that there is a wide variation in levelised cost of rated capacity in the three power supply options considered. The resulting electricity costs range from MWK7.72- 46.93/kWh for the hybrid, diesel and hydro. It is evident from the table that with the exception of investment costs, the hybrid system is cheaper than hydro and diesel supply options. The diesel supply option though has the lowest investment costs, is the most expensive in terms of unit energy cost. This is largely due to high fuel costs and relatively low capacity factor. However, the diesel option meets the demand imposed by all households in the village, whereas the hydro meets about one fifth.

## **6.6 Sensitivity Analyses**

Equipment prices, construction costs, market interest rate, fuel cost etc change with time and place of application. Their values directly affect economic viability. This implies that an economic study conducted for a certain location at a particular time may not be applicable for another location. To generalise results for different circumstances, the effects of these parameters were studied. Table G.8. shows the parameters that were varied by certain percentage from the base case. Results of the sensitivity analyses are presented in figures 6.16 to 6.20

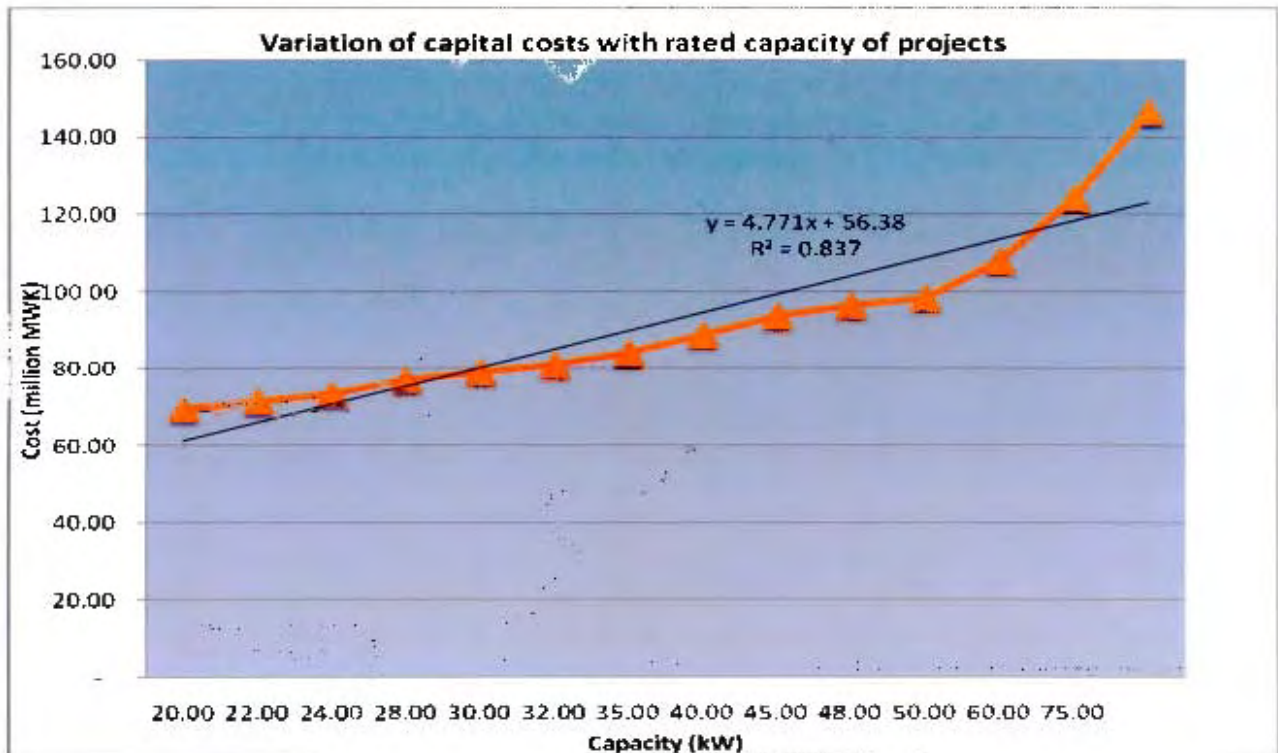


Figure 6.16 Variation of capital costs with rated capacity of projects

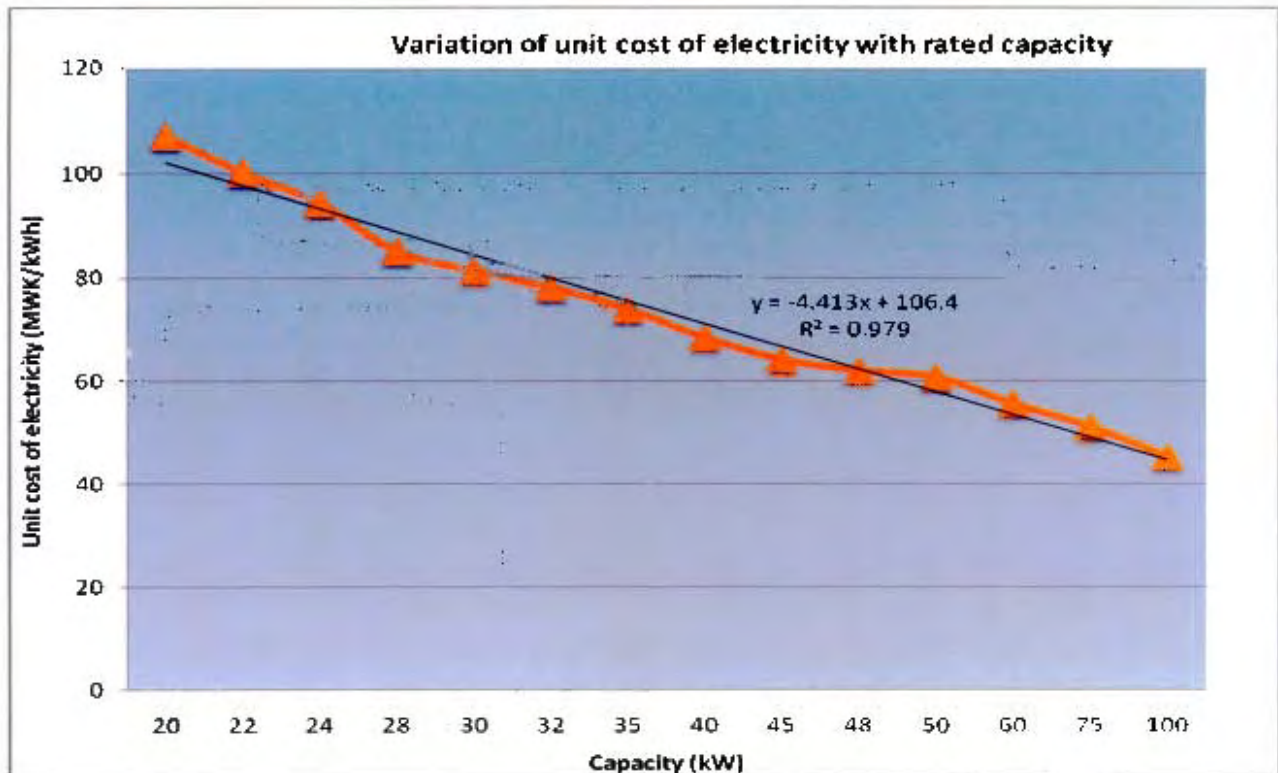


Figure 6.17 Variation of unit cost of electricity with rated capacity

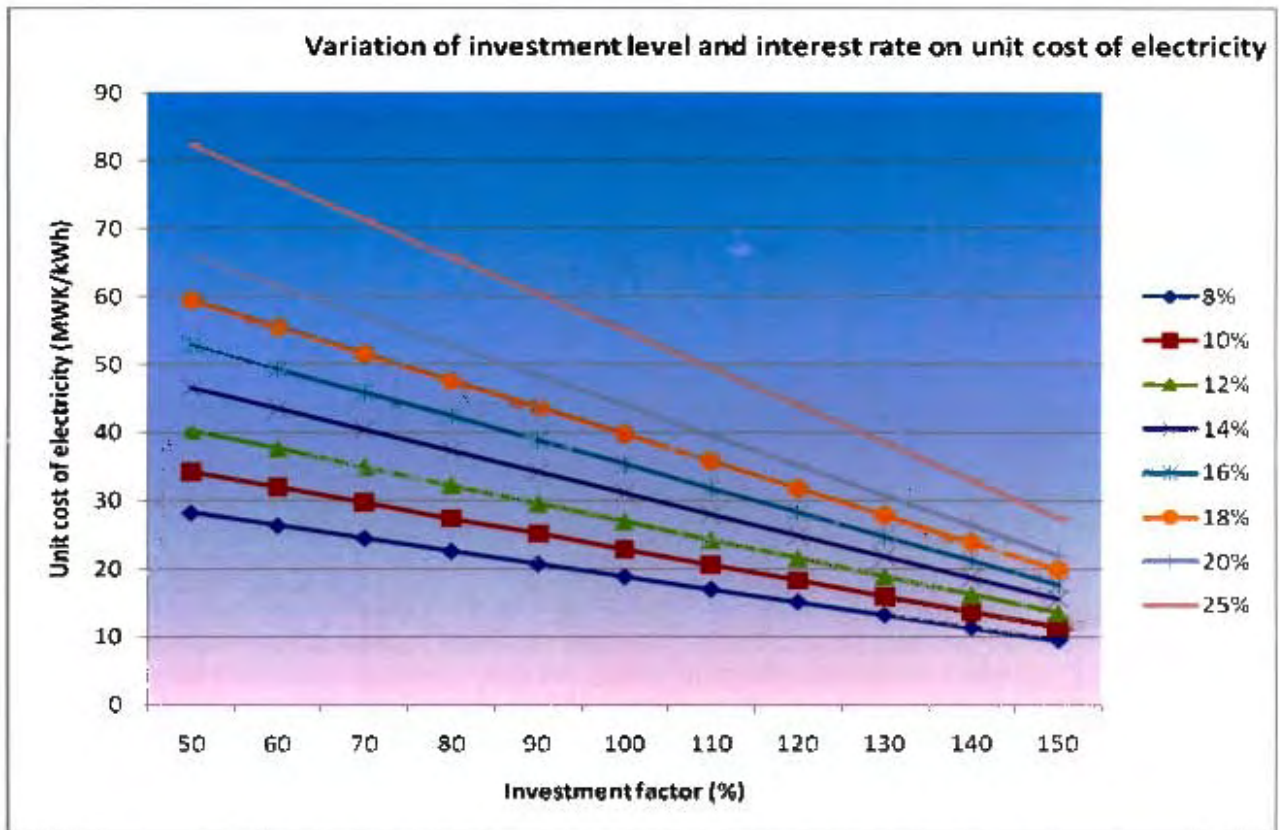


Figure 6.18 Variation of investment level and interest rate on unit cost of electricity

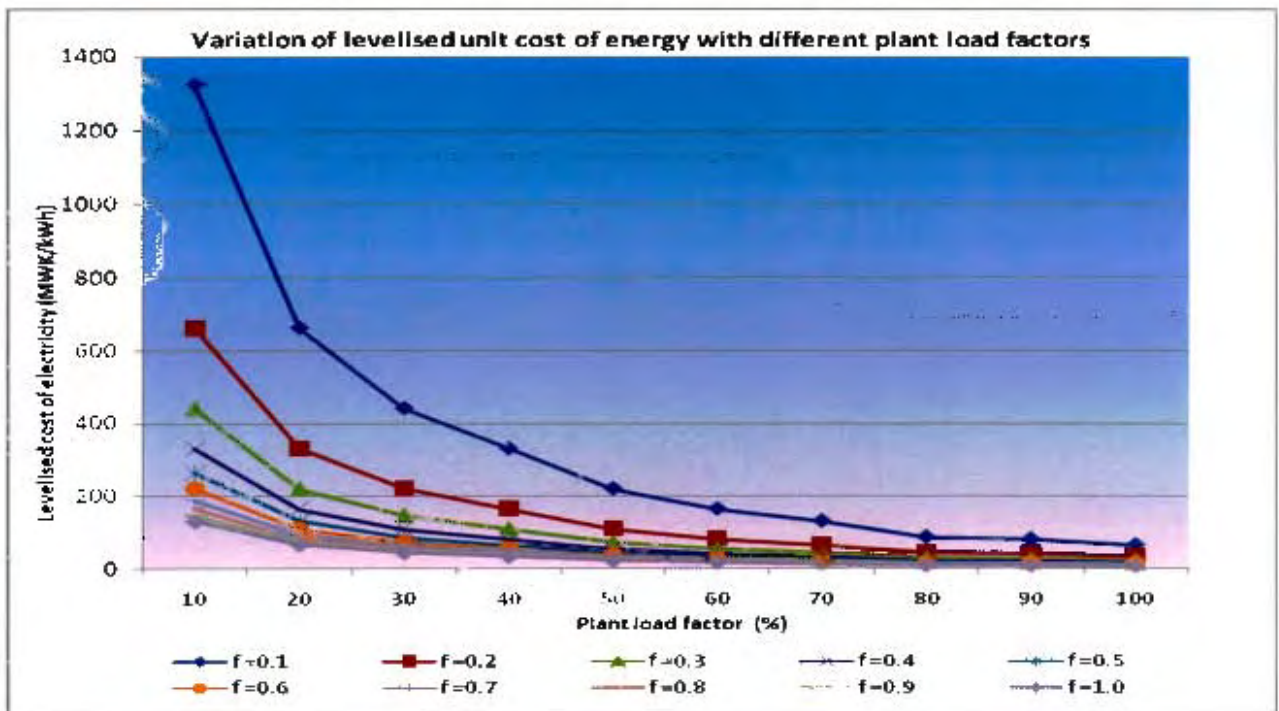


Figure 6.19 Variation of unit cost of electricity with different plant load factors

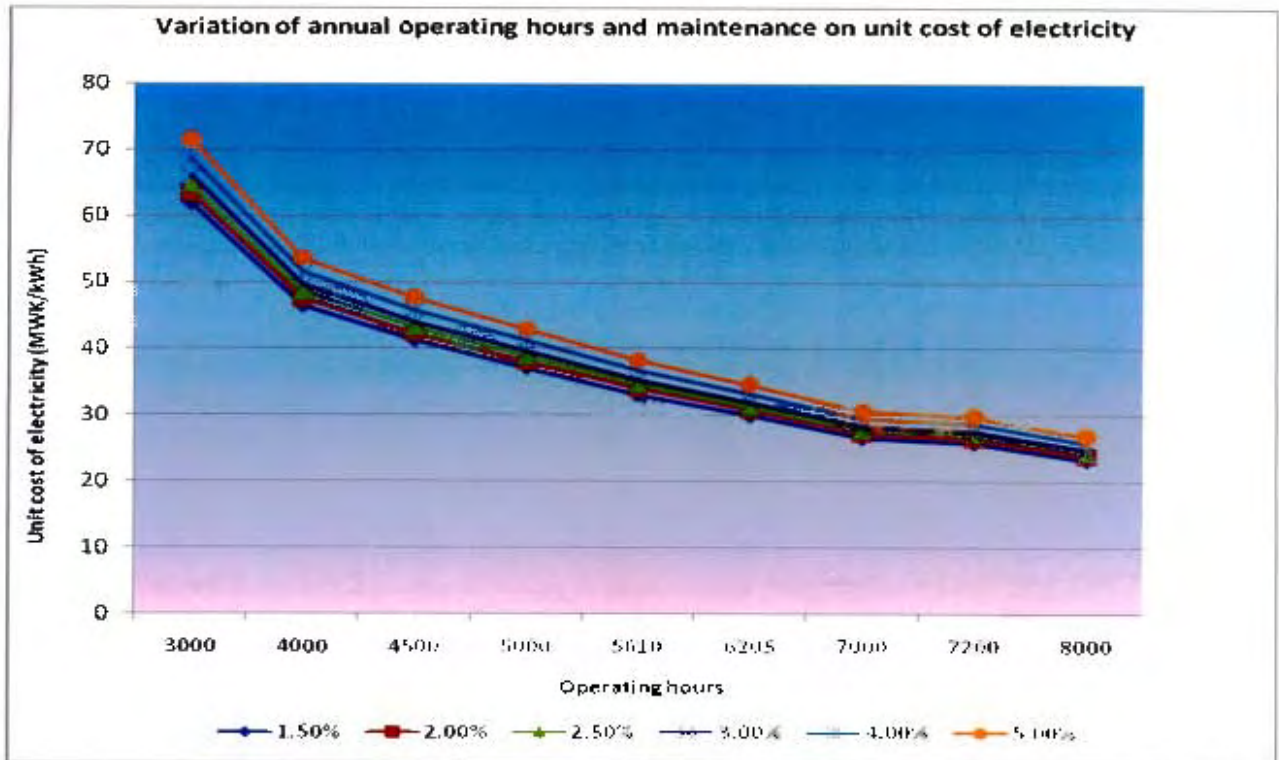


Figure 6.20 Variation of annual operating hours and maintenance on cost of electricity

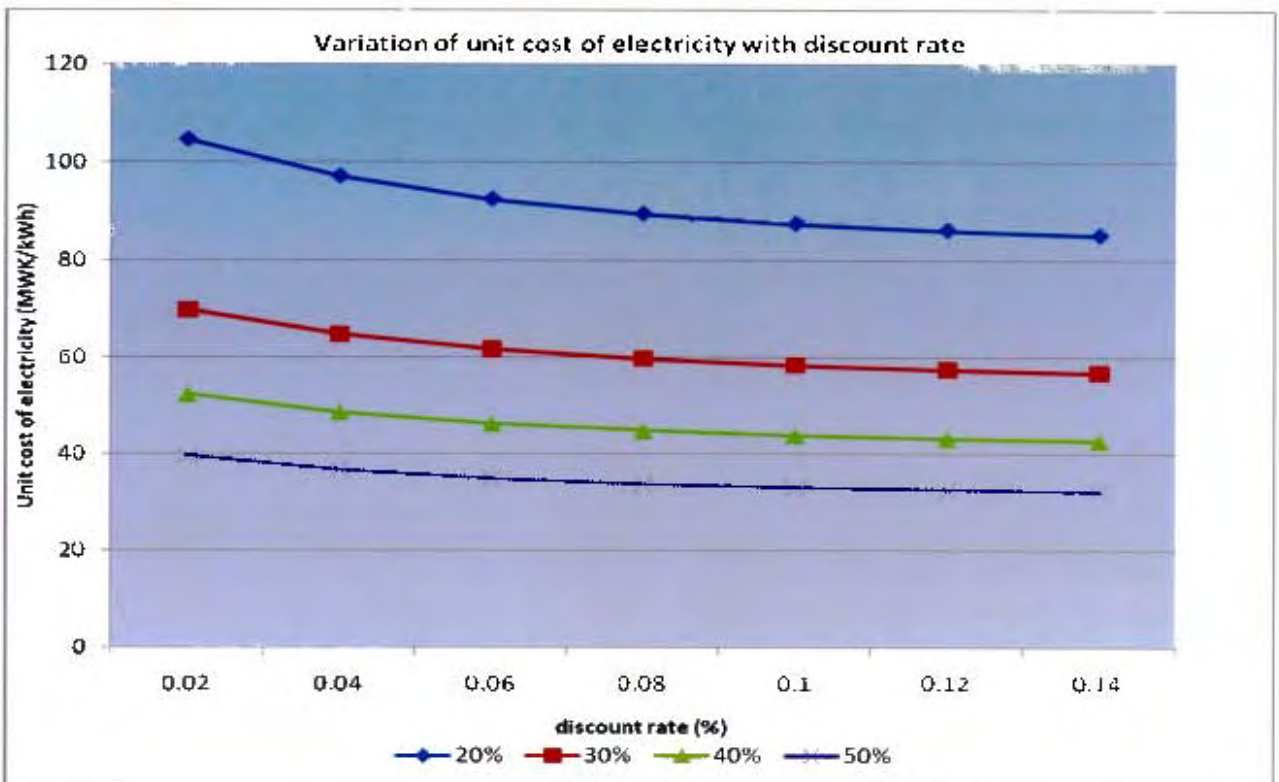


Figure 6.21 Variation of unit cost of electricity with discount rate for different load factors

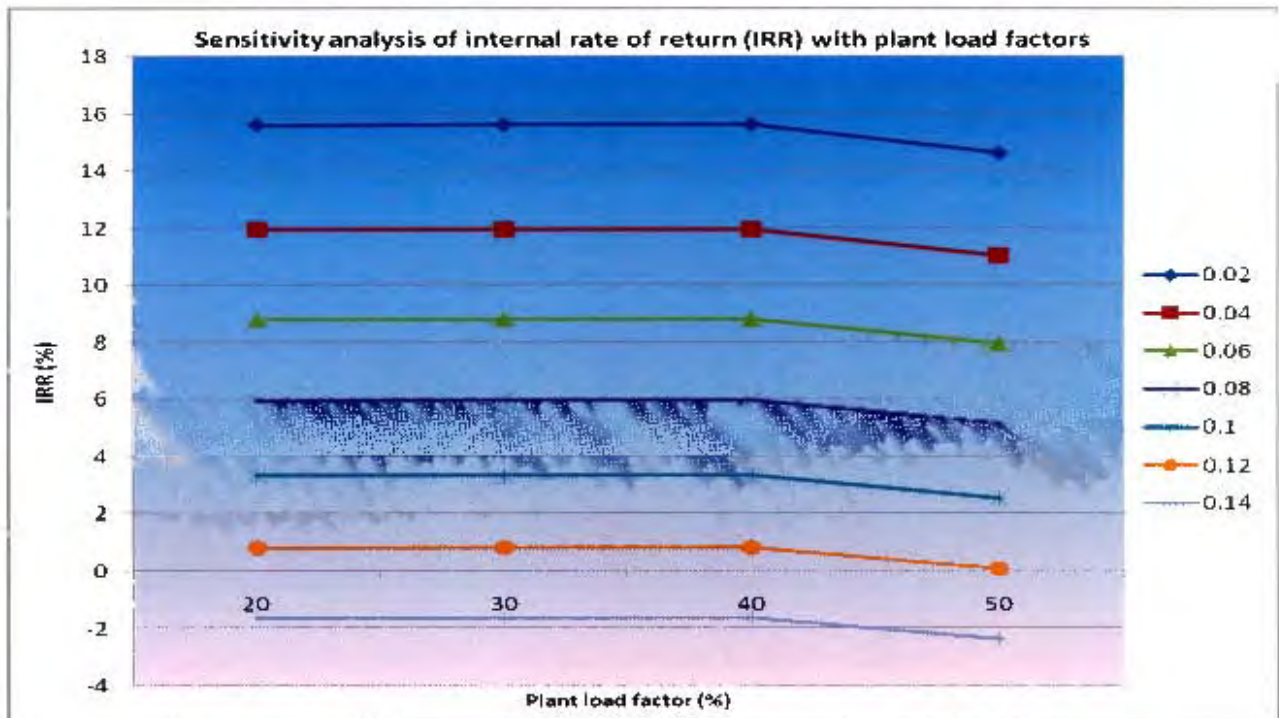


Figure 6.22 Sensitivity analysis of IRR with load factors for different discount rates

According to the calculation results shown in figure 6.16, a strong relation between capital investment and rated capacity of project is observed. As expected, an increase in capital cost increases significantly with the capacity. The capital costs are estimated to vary from MWK69.5million (US\$495,896) to MWK146 million (US\$1,046,020) for installed capacities of 20 kW and 100 kW, respectively. Based on the above capital cost, the specific costs per kW are estimated to range from MWK1.46 (US\$10,460) to MWK3.47 (US\$24,795). The values are relatively higher as compared to US\$1136 to US\$5630, reported by Khennas and Barnett (2000).The huge variation is attributed to differences in hydrological, geological and topographical conditions for sites chosen in this study. The investment is not viable if the investment costs decreases by the value of 50%.

Figure 6.17 shows the sensitivity of the unit cost of electricity to rated capacity of the hydropower plant. It can be seen that there is a strong correlation between these two factors resulting in a highly linear reduction of the unit cost with increasing capacity. This is can be attributed to higher capital costs (i.e. civil construction costs and transmission costs) which largely depend on the capacity of the hydro plant. These costs in turn, are affected by location

and nature of a site, as well as the construction methods and specifications. It is evident from figure 6.17 that construction costs play a significant part in determining the final economic viability of a small-scale hydropower plant.

A sensitivity analysis of plant load factor from 10% to 90% has been calculated and the results are shown in figure 6.19. The variations in the unit cost of electricity for projects rated between 5kW and 100 kW were calculated and shown in the same figure. The results show that for a given project, the unit cost of electricity is strongly influenced by the plant load factor. The cost per kWh for various load factors shows reduction in cost from MWK1326.07 (US\$9.47) to MWK6.63 (US\$0.05) for load factors between 10% and 90%. For a load factor of 30% the cost per kWh is estimated to be in the range of MWK22.10 (US\$0.16) to MWK 441.99 (US\$3.16) for capacities of 20 -100kWh. As is evident from figure 6.20, the unit cost of electricity is considerably higher for small size projects than large ones. The same is true for lower the plant load factors. This implies that high loading of small-scale hydropower plants would in significant terms, increase economic viability.

The effect of variation in the discount rates on the unit cost of electricity has also been examined and the results are shown in figure 6.21. As expected, the unit cost of electricity reduces significantly with increasing discount rates and plant load factors. For example, the unit cost of electricity for a 40 kW small-scale hydropower plant varies from MWK39.63/kWh to MWK104.73/kWh (mean value MWK66.64) for a discount rate of 2%. It ranges from MWK35.03/kWh to MWK92.58/kWh (mean value MWK58.91) and MWK32.63/kWh to MWK86.23/kWh (mean value MWK58.91) for discount rates of 6% and 12%, respectively. The results of this study show that the unit cost reduces from MWK39.63/kWh to MWK32.26/kWh for a plant load factor of 50%. Similarly, it decreases from MWK52.37/kWh to MWK42.62/kWh and MWK85.25/kWh to MWK1042.73/kWh for load factors of 40% and 20%, respectively. The sensitivity analysis provides clear evidence that discount rates and plant load factor are crucial parameters that could affect the viability of a small-scale hydropower scheme.

A sensitivity analysis of the internal rate of return (IRR) with plant load factors from 20% to 50% has been calculated and the results are shown in figure 6.22. As can be seen from this

figure, the IRR values decrease with increasing discount rates. For plant load factors (20% to 50%) and at a discount rate of 2%, the IRR ranges from 14.62% to 15.63%. Ranges of 5.16%-5.96% and 2.55% - 3.34% have been found for discount rates of 8% and 12%, respectively.

According to the results obtained, the selected discount rate is 8% which gives the IRR value of 5.98% and benefit-cost ratio of 6.25. The net present value was calculated to be MWK4,490,389.08 (US\$32,074) and corresponds to a payback period of 11 years. The analysis demonstrates that parameters such as IRR, plant load factors and discount rates are crucial to the financial viability of small-scale hydropower projects. Plant load factors and IRR values greater than 30% and 5% could bring positive returns on SHP investments.

## 6.7 Green house gas emissions (GHG)

Green house gases emitted through use of existing energy sources were calculated using the 1996 IPCC Guidelines for National Greenhouse Gas Inventory. The following formula was used for estimating the emissions:

$$E (tCO_2/year) = \sum Fuel\ consumption\ (TJ) \times Carbon\ Emission\ Factor - Carbon\ stored \times Fraction\ of\ Carbon\ Oxidized \times \frac{44}{12}. \quad (Equation\ 6.5)$$

### 6.7.1 CO<sub>2</sub> Emissions

Using equation (6.5) and data from tables E.3 and H.1, emissions generated from burning paraffin and biomass fuels have been calculated and presented in table H.2. The results show that the household sector in Nkolokosa emits 45 Gg of CO<sub>2</sub> per year. Use of paraffin accounts for 44.80 GgCO<sub>2</sub> emissions, firewood (876.26 GgCO<sub>2</sub>), and charcoal (683.41GgCO<sub>2</sub>). Apart from CO<sub>2</sub> emissions, the use of biomass as well as fossil fuel products like paraffin also produces significant amount of other green house gases. It has to be noted however, that the IPCC methodology assumes zero CO<sub>2</sub> emissions from biomass fuel since CO<sub>2</sub> is re-absorbed during plant growth. Thus the computations have been undertaken just for completeness.

### 6.7.2 Non- CO<sub>2</sub> Emissions

Figure 6.22 shows the estimated non-CO<sub>2</sub> emissions by source categories. As shown in the graph carbon monoxide (108 Gg) represents the largest non-CO<sub>2</sub> gases emitted by the sector. Estimated

quantities for other gases are as follows: methane (5.0 Gg), nitrous oxides (2 Gg) and non-methane volatile organic compounds (7Gg). Values for sulphur oxides (SO) and nitric oxides (N<sub>2</sub>O) are negligible and are registered as zero. These are significantly low since their emission invariably depends on the types of fuels and technologies, and perhaps existing pollution control policies.

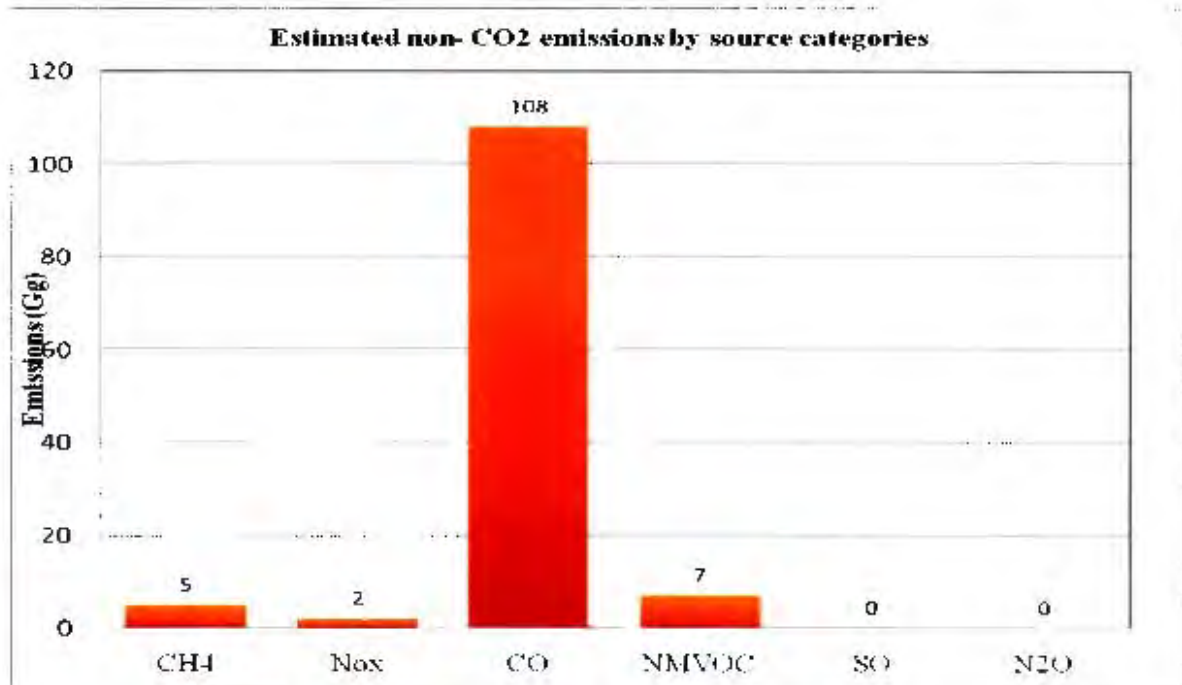


Figure 6.23 Estimated non-CO<sub>2</sub> emissions by source categories

### 6.7.3 Emission reductions

The substitution of paraffin and biomass fuels with small-scale hydropower would reduce air pollution and help mitigate global warming by CO<sub>2</sub> reduction. To estimate the potential reductions in CO<sub>2</sub> emissions, this study calculated baseline emissions using ESCOM's current generation mix data presented in table H.4. Rules specified in Type I (renewable energy projects) of the United Nations Framework Convention for Climate Change (UNFCCC) recommend application of one of the following options to calculate the emission coefficient (<http://unfccc.int/cdm/ssc.htm>):

- (a) The average of the approximate operating margin<sup>20</sup> and the build margin<sup>21</sup>;

<sup>20</sup> The average of the approximate operating margin is the weighted average (in kg CO<sub>2</sub> eq./kWh) of all generating sources serving the system, excluding hydro, geothermal, wind, low-cost biomass, nuclear, and solar generation.

(b) The weighted average emission (in kg CO<sub>2</sub>/kWh) of the current generation mix.

The average was calculated by dividing total CO<sub>2</sub> from every power generation source by the total generated output. The average GHG emissions were computed from using equation (6.5) and emission coefficients for each fuel given in table H.3. Based on results of this study, the installed capacity will be 40 kW and the plant operating capacity (load factor) is 50%. The project has an annual generation of 192,337 kWh per year, calculated using equation (4.20). The baseline emissions are computed as shown below.

$$[3.276 \text{ (TJ/yr)} \times 20.2 \text{ (tons C/TJ)} \times 0.99 \times 44/12] + [1.404 \text{ (TJ/yr)} \times 15.3 \text{ (tons C/TJ)} \times 0.995 \times 44/12] = 319 \text{ kt CO}_2/\text{year}$$

Dividing this figure by the total generated output of [(319 kt CO<sub>2</sub>/year)/1032.4 GWh/year] gives an emission rate of 0.31 tons CO<sub>2</sub>/MWh (or 0.31kgCO<sub>2</sub>/kWh). This shows that about 0.31 kg of CO<sub>2</sub> was produced per generated kilowatt-hour in 1999 in Malawi. Therefore; about 59.62 tons of CO<sub>2</sub> could be avoided annually. Projections of emission reductions in tons of CO<sub>2</sub> equivalent are summarized in table H.5. The cumulative emission reductions are expected to be about 12,520.20 tCO<sub>2</sub>eq. in 2027.

## 6.8 Scenario analysis

Scenario analysis was adopted in this study in order to assess energy-economic and environmental implications of utilising small-scale hydropower in the study area. Two scenarios for the household sector namely, a business as usual (BAU) and basic electricity for pro-poor (BEPP), covering the period from 2007 to 2027, were developed.

### 6.8.1 Business as Usual (BAU)

#### 6.8.1.1 Final energy demand

This scenario assumes that energy intensity for the current sources of energy remains the same for each end-use. The demand is largely driven by population, household size, population growth, and energy resource availability. Average population growth rate was taken to be 0.6%

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<sup>21</sup> The build margin is the weighted average emissions (in kg CO<sub>2</sub> eq. /kWh) of recent capacity additions to the system, which capacity additions are defined as the greater (in MWh) of the most 20% of the existing plants.

(NSO, 1998). The number of occupants per household was assumed constant through the forecast period. Using equation (6.4) and some input data from tables E.3 and E.4, the final energy demand has been estimated and presented in table H.7. The results are depicted in figure 6.23.

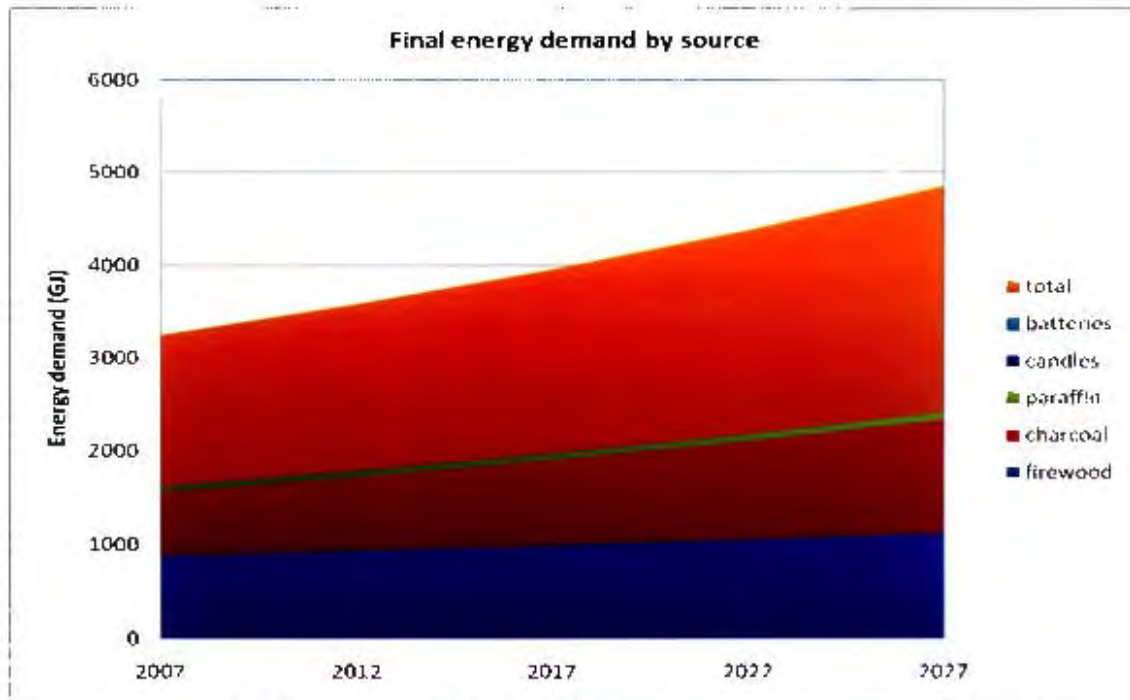


Figure 6.24 Final energy demand by source

It is found that the total energy demand increases from 1622.8 GJ in 2007 to 2423.4 GJ in 2027, corresponding to an annual increase of 1.96%. Firewood and charcoal consumption, which represents 97% of the total energy consumption in the village, is expected to increase to 1130.4 GJ (65 tons) and 1211.5 GJ (25 tons) respectively (table H.7). Paraffin use contributes 3% of the energy supply mix. Its consumption increases from 58 GJ in 2007 to 75.9GJ (1.4 tons). The contribution of candles and batteries is insignificant.

#### 6.8.1.2 Emissions

As shown in figure 6.23, an increase in emission levels is expected for the entire energy sector. CO<sub>2</sub> emissions caused by the use of paraffin for cooking and lighting are expected to increase from 45 Gg of CO<sub>2</sub> in 2007 and 50.7 Gg of CO<sub>2</sub> in 2027. The cumulative emissions for the study period are estimated to about 1004 Gg of CO<sub>2</sub>.

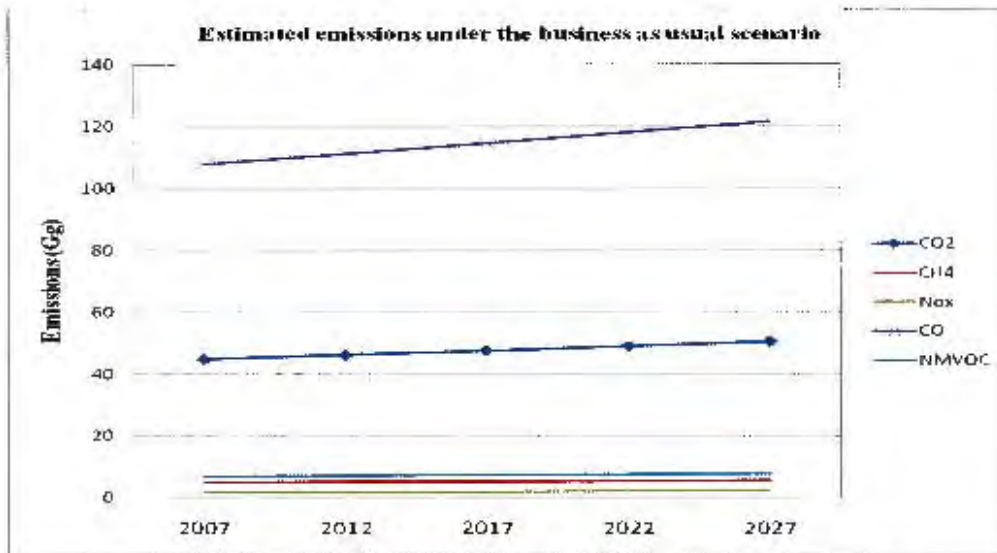


Figure 6.25 Estimated emissions under the business as usual scenario

### 6.8.2 Basic Electricity for Pro-poor (BEPP)

This scenario assumes a deliberate policy that aims at supplying basic electricity for rural areas. Electricity consumption for the village depends on population, household size and population growth (Feibel, 2003:46-47). The main parameters used are market penetration, average base consumption, average growth rates, or peak factor. These are given in table H.6. Average population growth rate was taken to be 0.6% (NSO, 1998). The number of occupants per household was assumed constant throughout the forecast period. It was further assumed that the initial connection rate would be 10% and this increases to 50% in 20 years, representing a linear increase of 2% per year. Using Nepal micro hydro utilities as the model (Feibel, 2003) three levels of connections hereinafter taken as scenario options were applied. BEPP1 limits loads up to 14 W CFL for lighting (50kWh/year), BEPP2 includes the use of 14 W CFL bulb and radio (80kWh/year). BEPP3 caters for 100 W loads (200kWh/year) and this connection will be equipped with load control time switches to disconnect power during peak times.

#### 6.8.2.1 Final electricity demand

Applying equation (6.6) and using data from table H.6, the total electricity consumption has been calculated and shown in figure 6.25. The results show that implementing BEPP1 and BEPP2 scenarios, would lead to significant increase in the final electricity demand from 3.6 GJ in 2007

to 28.3 GJ in 2027. In the BEPP3 scenario, electricity demand increases from 5.8GJ to 43.8 GJ during the forecast period. It is found that electricity meets between 1.2% and 1.8% of the final energy demand (for BEPP1 and BEPP3 respectively). One possible explanation of the scenario results is the limitation in the size of the load connected. Electricity is largely used for lighting purposes and its impact on consumption levels is however, significant.

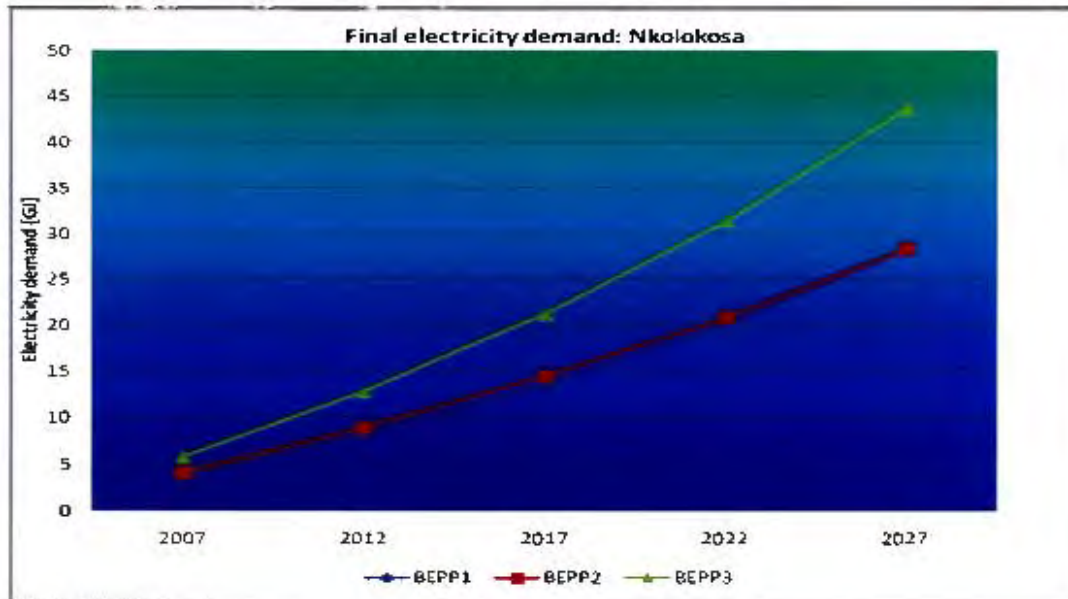


Figure 6.26 Final electricity demand for Nkolokosa

The policy measures are likely to reduce the consumption of paraffin. In the case of the BEPP1 scenario, paraffin consumption decreases from 93.79% in 2007 to 62.71% in 2007. In the BEPP2 scenario, electricity substitutes about 7.07% of paraffin consumption in 2007 and this grows to 37.42% at the end of the period. Similarly in the BEPP3 scenario, paraffin consumption decreases from 90% in 2007 to 42.29% in 2027. It was difficult to estimate the useful energy demand for productive purposes since the study could not establish the kind of business enterprises to be established with such kind of load limitations and how fast these will penetrate. Nevertheless, the results suggest that the higher the numbers connected, the higher the fuel substitution will be.

### 6.8.2.2 Reduction of GHG and other pollutants

Figure 6.25 gives a very useful comparison of emission reductions in Nkolokosa over a period of over 20 years. Details are presented in table II.9. As the forecast shows, the largest impacts on emission levels due to the proposed scenarios are expected to occur for CO<sub>2</sub> and CO emissions.

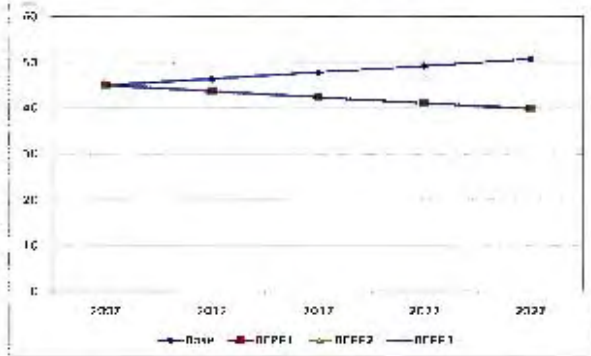
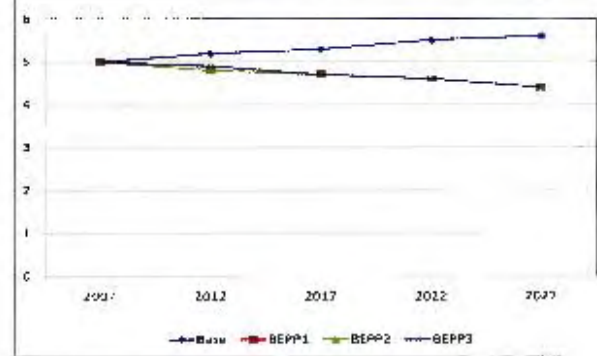
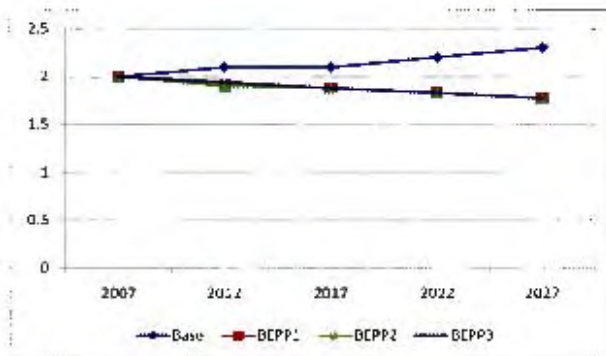
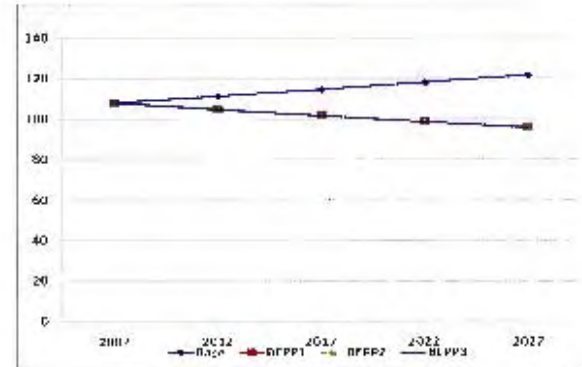
Figure 6.27a CO<sub>2</sub> emissions(Gg)Figure 6.27b CH<sub>4</sub> emissions(Gg)Figure 6.27c NO<sub>x</sub> emissions (Gg)

Figure 6.27d CO emissions (Gg)

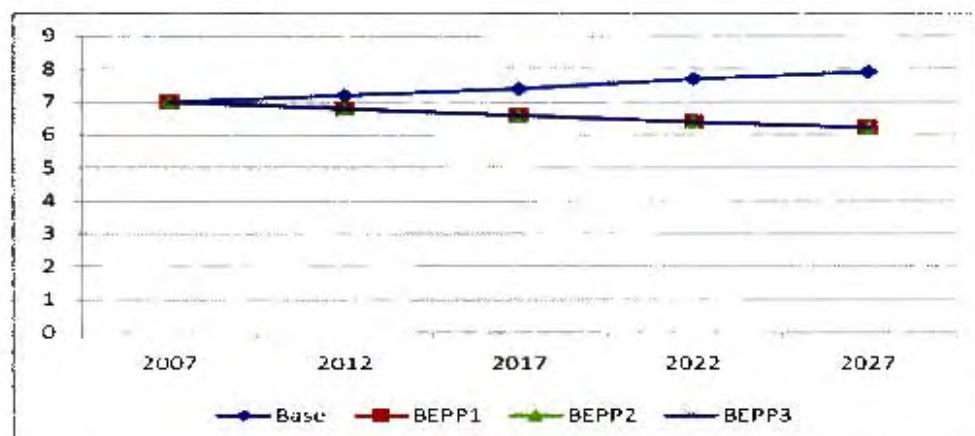


Figure 6.27e NMVOC emissions (Gg)

Based on the calculation, CO<sub>2</sub> emissions will be reduced from 45 Gg in 2007 to 39.9 Gg in 2027. Similarly, CO emissions will be reduced from 108 Gg to 95.8 Gg. Total green house gas emissions are expected to decrease by around 11.3% for the BEPP scenarios, in comparison to the base case. This value is considerably low given that the reductions occur over 20 years. This is because the calculations were based on carbon emission rate of 0.31 kg CO<sub>2</sub>eq/kWh against the default IPCC value of 0.9 kg CO<sub>2</sub> eq/kWh derived from diesel generation (UNFCCC, 2003). Although emission reductions is relatively low, this should be viewed as a positive impact since the policy demonstrates significant potential to contribute to the emission reductions of green house gases and other pollutants.

### **6.9 Installed capacity and number of households**

Figure 6.26 shows the relationship between the installed capacity and the number of households connected under different scenarios. As can be seen from figure 6.26, about 276 people (52 households) are expected to receive electric connection in 2007 and 1555 people (294 households) in 2027. In the BEPP1 scenario, a 5 kW system is required in 2007 and this grows to 39 kW at the end of the period. With 10% reserve margin, an estimated 1074 people will be connected. Similar results are expected in the BEPP2 scenario. For BEPP3, an 8 kW system is required at the beginning but requires an installed capacity of 60 kW if the same number of people as BEPP1 and BEPP2 are to be connected.

Analysis of the results shows that 1kW would supply electricity to 8 households. Increasing the subscription rate to 100 W per household would require 216kWh/year. For cooking, at least at the rate of 2 hours per day with one 1000 W cooking appliance, about 720 kWh/year is needed. For Nkolokosa village with a site potential of 40 kW, either BEPP 1 or BEPP 2 can meet the electricity demand.

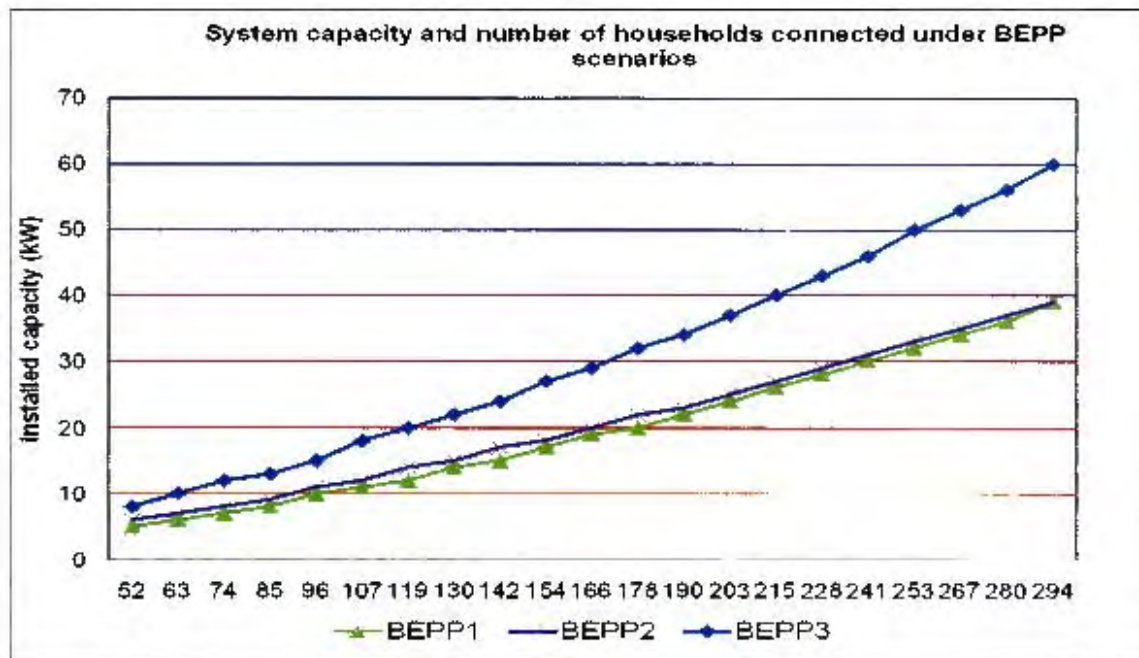


Figure 6.28 System capacity and number of households connected under BEPP scenarios

### 6.10 Electrification rates

Using the available data, as shown in table A.6 and applying (equation 6.6), the potential to increase the electrification level in Malawi has been determined and the results are presented in table H.10. The results show that with an average subscription rate of 60 W per household (85kWh/year), about 43,385 households will be connected. This represents about 1.9% of total households in Malawi. Taking an average household size of 5.3, about 230,000 people (2.3%) could be served with electricity. According to the results of this study access to electricity in rural areas would increase from 0.8% (DoEA, 2003) to 2.7%. It has to be noted that the installation of small-scale hydropower schemes is envisaged to utilize electricity for lighting, entertainment and communication equipment like televisions and radios.

It is found that schemes with installed capacity of up to 100 kW would generate 1.2 GWh, serving about 3283 households (0.13%) or 15,831 people (0.16%) which at national level are insignificant. However, for villagers surrounding the hydropower plants and considering the benefits expected from such basic electricity, this potential cannot be casually dismissed.

## CHAPTER 7

### CONCLUSIONS AND RECOMMENDATIONS

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#### 7.1 Summary of principle findings

This study has investigated the potential for utilizing small-scale hydropower for rural electrification schemes in Malawi. It has examined three case studies to test the first hypothesis that “*small-scale hydropower schemes in areas with potential could play a significant role in meeting the energy needs of rural areas.*” Small-scale hydropower is found to be suitable for enhancing the quality of life for rural people in numerous ways. Firstly, it provides a wide range of services such as improved lighting, more entertainment and communication options and operation of a range of appliances. Secondly, small-scale hydropower reduces environmental pollution through replacement of paraffin lamps and other cooking fuels. Thirdly, it supports rural enterprises, workshops, schools, clinics and production centres. These services are of great importance to the people in need of such services, and should therefore be given due consideration in energy planning.

Small-scale hydropower could play a key role in lowering wood fuel consumption, and consequently reducing deforestation. However, the impact of electricity on wood fuel consumption will depend largely on household incomes and relative fuel prices. The findings of this study confirm that electricity would be used mainly for lighting and entertainment. It is found that households with higher incomes are likely to shift from using traditional fuels to electricity. A key conclusion from this is that household income drives the transition from the use of traditional fuels to electricity. Therefore, supplying small-scale hydroelectricity to rural areas will not replace wood fuel for cooking. It should be seen as a necessary but not sufficient condition for reducing deforestation.

The study has identified critical issues for successful rural electrification programmes. Key elements include strong government support in terms of policies, regulation and subsidies. The removal of the affordability barrier on upfront costs (on connection fees), policies on monthly

tariffs and targeted subsidies are important strategies to ensure that poor households have access to electricity. Government has a major role to play in mobilizing resources and encouraging private sector investment in small-scale hydropower development.

The case studies have shown that a decentralized approach and local participation in all stages of projects is central to achieving success. Involving the community with formation of community committees and cooperatives who are pro-active in all stages can help reduce costs as well as provide better services. The study concludes that effective policies and measures lead to successful rural electrification. Validation studies are necessary before adopting these policies to suit Malawi's economic conditions and where necessary adjustments made.

A survey of 118 households in Nkolokosa village has shown that all households use firewood for cooking and water heating. The average consumption per household per month for cooking varies from 95.424 to 133.33kg (mean value 110.27 kg). Analysis of other sources of energy shows that paraffin is used for lighting (95.76%) and cooking (23%). Paraffin consumption per household per month for cooking varies from 1.232 to 3.585 litres (mean value 2.3litres) and for lighting varies from 0.69 to 0.998 litres (mean value 0.93litres). Similarly, 12.7% of the households use charcoal for cooking and the average consumption per household per month varies from 31.667 to 66.667 kg (mean value 43.14 kg). This is equivalent to 320kWh/month (3840kWh/year) of electricity. Based on the calculations of fuel consumption, the total firewood required in the village works out to be 605 tonnes/year. Charcoal demand for cooking is about 236.6 tonnes/year and paraffin demand for cooking and lighting is about 17.8 kilolitres per year.

A testable hypothesis posed at the beginning of this chapter is that *"small- scale hydro schemes can contribute to reduction in environmental degradation."* In testing this hypothesis, the energy consumption for the village and emission of greenhouse gases and their reduction have been estimated for a period of 20 years. Results of the study have shown that the household sector consumes 1622.8GJ per annum. This increases to 2423.6 GJ in 2027 corresponding to a 1.96% annual growth rate. Paraffin use accounts for 3% of total energy supply. Currently, the village emits 45 Gg of CO<sub>2</sub> per year. It further releases about 108 Gg of carbon monoxide into the environment, 5 Gg methane, 2 Gg nitrous oxides and 7 Gg non-methane volatile organic

compounds. CO<sub>2</sub> emissions will grow to 50.7 Gg in 2027. The study has found that a policy measure such as “basic electricity for the pro-poor” could reduce the emission of various pollutants. For example, supplying the community would reduce CO<sub>2</sub> emissions from 45 Gg in 2007 to 39.9 Gg in 2027. Compared to the base case, the proposed policy measure could reduce the total green house gas emissions by 11.3% over a period of 20 years. Although the reduction is relatively low, this should still be viewed as positive, considering the low carbon emission rate used for this study. To that extent, the results of this study should be taken with care. A more rigorous analysis of greenhouse gas emissions could produce accurate figures if a detailed energy survey were conducted.

More importantly, the study has found that installing a 40 kW small-scale hydropower plant in the village would result in an annual reduction of 59.62 tons CO<sub>2</sub>, using an emission factor of 0.31 ton CO<sub>2</sub> eq/MWh derived from ESCOM’s current generation mix in 1999. Total cumulative emission reductions for the period 2007 to 2027 are expected to be 12,520 tons CO<sub>2</sub> equivalent. At national level, the results indicate that about 97,931.1 tons CO<sub>2</sub> eq/year could be avoided entering into the local atmosphere. It can thus be concluded that small scale hydropower has potential to reduce fuel demand in the household sector, and consequently green house gases.

Analysis of the household energy demand indicated that electricity would be used mainly for lighting. All surveyed households expressed the desire to use electricity for lighting and entertainment. Approximately 24.6% of the households, mainly from the middle to affluent income groups might use it for cooking, and 11.9% for maize mills. However, this depends on the power output of the scheme. And the Nkolokosa scheme is not large enough to supply electricity for cooking.

Results of the study have shown that developing a firm potential of 5.9 MW and pursuing the basic electricity for pro-poor scenario (85kWh/year) would enable 43,385 households (1.9%) to receive an electricity connection. About 230,000 people (2.3%) would have access to electricity. However, the study has found that if schemes with an installed capacity of less than 100 kW are considered, only 3283 (0.13%) or 15,831 people would benefit. But based on one of study

hypotheses, small-scale hydropower would increase the national electrification coverage by 2.3%.

However, investing in small-scale hydropower presents commercial and technical risks. Commercial risks such as lack of appropriate collateral to secure bank loans, competition from cheap biomass fuels as well as grid electricity are obstacles to be considered. Additionally, importation of spare parts for generators and turbine parts is a barrier that might increase costs. Increase in the rate of deforestation in river basins might affect the hydrology of the rivers considered for small-scale power generation. Nevertheless, the potential rewards such as green house gas mitigation, and empowerment of rural people, necessitates investment in small-scale hydropower.

This study has calculated the total capital costs for different capacities ranging from 20 to 100 kW. The range of capital costs to develop a small-scale hydropower fall within MWK1.46million/kW (US\$10460/kW) to MWK3.47million/kW (US\$24795/kW). The median is MWK2.4million/kW (US\$16975/kW) and this value represents the average capital cost per kW installed. The variability in specific site requirements leads to the differences in costs. These values are prohibitively higher as compared to US\$1000-US\$3000/kW reported in Paish (2002). This makes the technology to be uncompetitive if compared with conventional energy sources, and necessitates the use of government subsidies.

A key observation made from the sensitivity analysis is that the cost per unit of rated capacity decreases with increasing capacity. Based on the capital costs of US\$16975/kW, for small-scale hydropower, the installation of a 40 kW scheme in Nkolokosa necessitates US\$679,000 (MWK95million). The break-even unit electricity cost has been determined using cash flow projections, with an 8% discount rate and zero NPV. It has been found that to achieve an internal rate of return of 5.98%, considering an interest rate value of 15% (assuming inflation stabilises at 7%), the unit cost of electricity should be sold at an average of MWK44.80/kWh (US\$0.32/kWh). Reported costs for produced electricity vary as low as US\$0.025/kWh (Inversin, 1986) to US\$0.12/kWh (Jiandong, 2003).

For a plant load factor of 30% and useful life of 20 years, the break even unit cost of electricity has been estimated at MWK59.73/kWh (US\$0.43/kWh). The analysis indicates that projects with plant load factors below 30% would not be viable. The study demonstrates that rated capacity, investment level, interest rate, discount rates, plant load factors, annual operating hours as well as maintenance have a major effect on the unit cost of electricity. Increasing any of these parameters decreases the unit cost of electricity.

A preliminary economic analysis of the cost of supplying power to the village has been presented. The study results indicate that small-scale hydropower would be a favourable option. The specific construction cost per kW is MWK 2,216,992.86 (US\$15,835.66). The net present value was found to be MWK 4,490,389.08 with an 8% discount rate, and the economic rate of return (EIRR) was 5.98%. The benefit cost ratio was 6.25. The break- even tariff is MWK 44.80 per kWh. The average willingness to pay is MWK 5.58/kWh. In order to make this project viable, a subsidy of MWK39.22/kWh would be required. Despite this analysis, this study clearly indicates that the project is economically viable and should be implemented. However, there appear little evidence to support the hypothesis that small-scale hydropower is going to have a huge impact on meeting the energy needs of rural people or rather, increasing the electrification levels in Malawi, but it has a part to play in contributing to renewable energy targets and for this reason should not be ignored.

### **7.2 Recommendations**

This study has highlighted the need for Malawi to adopt rural electrification as a key policy of government as it can improve the living standards of the people and reduce poverty by the creation of new income sources in rural areas. It is clear that the utilization of small-scale hydropower can provide a viable source of energy to increase the electrification levels in Malawi. However, small-scale hydropower will only be able to fulfill this role if certain policy and other issues are addressed before implementation of projects. As a result, this study has made a number of recommendations, a summary of which is provided below:

- (a) There is need to review the existing policy, legislation and regulatory framework in the energy sector. It is suggested that the government should create a separate and

comprehensive pro-poor energy policy. This policy should focus on providing small-scale hydroelectricity to rural households;

- (b) It is proposed to launch the national energy programme for small-scale hydropower development. However, there is need to constitute a separate rural electrification agency whose mandate will be to facilitate small-scale hydropower development as well as systematic investigation of its potential. The agency should be empowered to manage pro-poor funds, use district development funds or constituency funds, where necessary. Furthermore, this agency should be given the task of mobilizing resources from both local and international donors for the development of small-scale hydropower.
  
- (c) There is clearly a need for government to organize measurement of hydro-meteorological parameters as well as the development of pre-project documents which will form a basis for potential investors to make informed decisions on construction of small-scale hydropower schemes on specific locations.
  
- (d) The study has made it clear that the capital investment for smaller size projects are prohibitively high for investors, low-interest would be significant incentives for private investors. This could be achieved through tax and subsidies on interest rates for companies that initiate projects. At household level, there is need for subsidies on connection fees as well as monthly electricity tariffs;
  
- (e) There is need to develop standards and guidelines for planning, design and construction supervision of small-scale hydropower projects. This will ensure quality of construction at low cost. There is also need to promote public private partnerships as well as encourage private sector participation, non governmental organizations, financing institutions in small-scale pro-poor electrification.

Areas of further research and development work have been identified which requires funding to address the following areas:

- (a) Carry out a more exhaustive feasibility studies to re-evaluate the previous studies and establish the available potential and cost to develop these sites;
- (b) Assess the potential of building small-scale hydropower plants at the existing canals and irrigation schemes;
- (c) Design and manufacture of low –cost turbines.

Finally, readers are reminded that the results of this study are merely indicative, and therefore should be taken with caution. The study has reported results based on data available and used in the preparation of the master plan study for rural electrification in Malawi. The data reported is more conservative as the criteria used in the selection of sites rejected those with stream flows less than  $0.05 \text{ m}^3/\text{s}$  and 5 kW installed capacity (even where an on site demand existed), and 5 km from the existing grid connections. There is need to do more detailed hydrological, topographical and geological studies at each candidate site. A more rigorous analysis of energy consumption and future demand would be useful.

The spreadsheets model used in this study could give a better graphic interface if coded in Visual Basic or Matlab. Further work is required to improve the interface. The hydrological data analysis could be linked to the economic so that the complete site assessment can be made in one program.

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**ANNEXES**


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**Annex A**
**Energy resources, imports statistics and consumption**
**Table A.1: Malawi Coal Reserves and Quality<sup>22</sup>**

| Coal fields            | Ash content | Calorific value |       | Estimated reserves<br>(million tonnes) |
|------------------------|-------------|-----------------|-------|--|
|                        | (%, wb)     | kcal/kg         | MJ/kg |  |
| Ngana                  | 21          | 4,799           | 20.1  | 16                                     |
| North Rukuru-Nthalire  | 28          | 5,410           | 22.6  | -                                      |
| Livingstonia (Mchenga) | 14          | 7,226           | 30.2  | 2                                      |
| Lengwe                 | 50          | 4,250           | 17.8  | -                                      |
| Mwabvi                 | 40          | 5,030           | 21.1  | 4                                      |

Source: Venendaal (1996:64)

**Table A.2: Annual Fuel Import Statistics (in Megalitres)**

| Year | Petrol | Diesel  | Jet A-1 | Paraffin | Avgas | Total   |
|------|--------|---------|---------|----------|-------|---------|
| 2000 | 84.896 | 124.905 | 7.238   | 31.397   | 0.107 | 248.545 |
| 2001 | 81.039 | 125.106 | 8.800   | 18.921   | 0.357 | 234.225 |
| 2002 | 88.329 | 127.157 | 6.417   | 20.955   | 0.202 | 243.062 |
| 2003 | 92.976 | 136.408 | -       | 23.652   | -     | 253.038 |
| 2004 | 94.186 | 147.922 | -       | 24.762   | -     | 266.870 |
| 2005 | 84.023 | 152.664 | -       | 21.838   | -     | 258.527 |

Source: Annual Economic Report 2006, Ministry of Economic Planning and Development

<sup>22</sup> All coal in Malawi has a sulphur content of less than 8%

**Table A.3: Costs of fuel import as a percentage of total external imports (in million Kwacha)**

| Year | Petrol   | Paraffin | Diesel and other | Total value of fuel imports | Total value of imports | Percentage of total value of imports (%) |
|------|----------|----------|------------------|-----------------------------|------------------------|--|
| 2001 | 1,701.60 | 462      | 3,160.60         | 5,324.20                    | 39,480.10              | 13                                       |
| 2002 | 1,827.70 | 1,254.50 | 2,573.70         | 5,655.90                    | 53,657                 | 11                                       |
| 2003 | 2,760.60 | 664.2    | 4,210.40         | 7,635.20                    | 76,650                 | 10                                       |
| 2004 | 3,500.40 | 859.2    | 5,954.10         | 10,313.70                   | 101,553.70             | 10                                       |
| 2005 | 3,252.10 | 1,074.70 | 6,684.50         | 11,011.30                   | 129,856.10             | 8  |

Source: NSO, Quarterly Statistical Bulletin, March 2006

**Table A.4: Consumption per Fuel group in Malawi**

| Fuel group                            | Year              |                   |                   |                   |                   |                   |                   |
|---------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                                       | 1997              | 1998              | 1999              | 2000              | 2001              | 2002              | 2003              |
| Hard coal                             | 1,022.25          | 1,412.68          | 1,337.28          | 1,353.86          | 1,438.25          | 984.98            | 468.30            |
| Electricity                           | 2,912.20          | 3,038.40          | 3,085.20          | 3,232.80          | 3,243.60          | 3,159.29          | 3,350.16          |
| Petroleum                             | 7,282.44          | 8,351.47          | 8,254.97          | 8,230.09          | 7,790.35          | 8,438.98          | 9,111.15          |
| Renewables <sup>23</sup><br>and waste | 166,006.88        | 169,414.51        | 172,889.19        | 176,251.01        | 179,899.25        | 188,532.16        | 193,866.77        |
| Geothermal<br>and solar               | n/a               | n/a               | n/a               | n/a               | n/a               | 0.59              | 1.37              |
| <b>Total energy (TJ)</b>              | <b>177,223.97</b> | <b>182,217.06</b> | <b>185,566.65</b> | <b>189,067.75</b> | <b>192,371.45</b> | <b>201,215.96</b> | <b>206,797.76</b> |

Source: Energy Statistics 2007, Department of Energy Affairs

<sup>23</sup> Renewables in this context refers to firewood, charcoal, crop residues etc. DoEA has no proper data collection system. They face human and financial challenges to collect, analyse and adjust figures. Unfortunately, it appears these figures are mere extrapolations therefore, do not reflect actual situation on the ground

Table A.5: Large- hydropower Potential

| Site (River)                                     | Estimated Parameter |                               |                 | Firm power (MW) | Firm Energy output (GWh/a) | Exploitable potential |                       |
|--|---------------------|-------------------------------|-----------------|-----------------|----------------------------|-----------------------|-----------------------|
|  | Net head (m)        | Firm flow (m <sup>3</sup> /s) | Load factor (%) |                 |                            | Capacity (MW)         | Energy Output (GWh/a) |
| Kapichira (Shire)                                | 58.5                | 170                           | 50              | 120             | 525                        | 300                   | 1470                  |
| Mpatamanga (Shire)                               | 59.2                | 170                           | 50              | 120             | 525                        | 300                   | 1470                  |
| Tedzani III (Shire)                              | 35.1                | 91                            | 50              | 40              | 175                        | 100                   | 250                   |
| Kholombidzo (Shire)                              | 68                  | 170                           | 50              | 140             | 613                        | 280                   | 1795                  |
| Low Fufu with flow regulated (South Rukuru)      | 347                 | 24                            | 45              | 102             | 402                        | 180                   | 835                   |
| Low Fufu(South Rukuru)                           | -                   | -                             | 45              | 56              | 244                        | 140                   | 610                   |
| High Fufu falls with no regulation(South Rukuru) | 408                 | 15                            | 45              | 75              | 295                        | 175                   | 800                   |
| HengaValley(South Rukuru)                        | -                   | -                             | 45              | 16              | 70                         | 40                    | 185                   |
| Rumphhi(South Rukuru)                            | -                   | -                             | 45              | 5               | 24                         | 13                    | 60                    |
| Chizuma(Bua)                                     | 106                 | 18.5                          | 45              | 24              | 95                         | 50                    | 170                   |
| Chasombo(Bua)                                    | 87                  | 17                            | 45              | 18              | 70                         | 50                    | 215                   |
| Malenga(Bua)                                     | 117                 | 16.6                          | 45              | 24              | 95                         | 60                    | 240                   |
| Mbongozi(Bua)                                    | 101                 | 16.3                          | 35              | 21              | 82                         | 50                    | 240                   |
| Manolo   | -                   | -                             | 35              | 52              | 236                        | 130                   | 590                   |
| Chingonda  |                     |                               | 35              | 20              | 112                        | 50                    | 280                   |
| Zoa Falls(Ruo)                                   |                     |                               | 35              | 18              | 80                         | 45                    | 200                   |
| Nkula Falls (Shire)                              |                     |                               | 60              | 124             | 540                        | 310                   | 1350                  |
| Others   |                     |                               | 30              | 7               | 28                         | 20                    | 150                   |
| <b>Total estimated large-hydro potential</b>     |                     |                               |                 | <b>982</b>      | <b>4,211</b>               | <b>2293</b>           | <b>10,910</b>         |

Source: UNIDO/GoM, 1986; [www.iea-shp.org](http://www.iea-shp.org)

**Table A.6: Small-scale hydropower potential**

| Name of hydropower scheme                                  | Estimated Parameters |                               |                 |                                   | Firm power (kW) | Energy output (MWh/a) |
|--|----------------------|-------------------------------|-----------------|-----------------------------------|-----------------|-----------------------|
|  | Net head (m)         | Mean flow (m <sup>3</sup> /s) | Load factor (%) | Catchment area (km <sup>2</sup> ) |                 |                       |
| Kaseye   | 28                   | 1.29                          | 30              | 560                               | 150             | 394                   |
| Kalenje1   | 122                  | 1.08                          | 30              | 80                                | 230             | 604                   |
| Chambo   | 100                  | 0.6                           | 30              | 117                               | 6               | 16                    |
| Mbalizi  | 187                  | 0.98                          | 30              | 270                               | 30              | 79                    |
| Kalenje2   | 63                   | 1.08                          | 30              | 80                                | 120             | 315                   |
| Upstream Lufira  | 67                   | 3.2                           | 30              | 806                               | 130             | 340                   |
| Lufira   | 135                  | 10.6                          | 30              | 1380                              | 940             | 2470                  |
| North Rukuru   | 132                  | 11.9                          | 30              | 1610                              | 2250            | 5913                  |
| North Rukuru 2   | 75                   | 11.0                          | 30              | 1310                              | 1070            | 2810                  |
| North Rukuru 3   | 83                   | 6.35                          | 30              | 698                               | 670             | 1760                  |
| Wovwe  | 194                  | 3.01                          | 30              | 140                               | 1400            | 3680                  |
| Chisenga   | 15-20                | 0.1                           | 30              | 4                                 | 15              | 39                    |
| Kakasu   | 10-30                | 0.1                           | 30              | 8                                 | 15              | 39                    |
| Hewe   | 25-30                | 0.2                           | 30              | 37                                | 45              | 118                   |
| Ntchenachena   | 10-30                | 0.2                           | 30              | 18                                | 30              | 78                    |
| Murwerzi   | 10-15                | 0.05                          | 30              | 7                                 | 5               | 13                    |
| Luzinkhuni   | 50-60                | 0.15                          | 30              | 80                                | 50              | 131                   |
| Sasasa   | 20-30                | 0.1                           | 30              | 85                                | 20              | 52                    |
| Ngapani  | 5-15                 | 0.05                          | 30              | 48                                | 5               | 13                    |
| Mtemankhokwe   | 20-30                | 0.1                           | 30              | 24                                | 25              | 65                    |
| Nswazi   | 5-15                 | 1                             | 30              | 380                               | 75              | 197                   |
| Choyoti  | 30-40                | 0.2                           | 30              | 13                                | 60              | 157                   |
| <b>Total estimated small-scale hydroelectric potential</b> |                      |                               |                 |                                   | <b>7,345</b>    | <b>19,283</b>         |

Source: National Energy Plan, 1988-1997; DOE/JICA (2003)

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## Annex B

### Table B.1: Typical Examples of Rural Electrification Benefits

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Quantifiable Benefits: Cost Savings and Increased productivity

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#### 1. *Industrial Uses of Electricity*

- 1.1 Motive power-replacing liquid fuel or gas;
- 1.2 Lighting-replacing liquid fuel;
- 1.3 Space heating, cooling and refrigeration- replacing liquid fuel, coal, gas, biomass or animal waste
- 1.4 Processing food-replacing liquid fuel, coal, gas, biomass, or animal waste
- 1.5 Transport-replacing liquid fuel

#### 2. *Household Uses of Electricity*

- 2.1 Lighting- replacing liquid fuel, gas, biomass, or animal waste;
- 2.2 Preparing meals- replacing biomass, animal waste, liquid fuel, coal, or gas
- 2.3 Space heating, cooling and refrigeration- replacing biomass, animal wastes, Liquid fuel, coal or gas
- 2.4 Home appliances (fan, iron, radio, TV, etc.) – replacing batteries, biomass, or
- 2.5 Drinking water-replacing liquid fuel (for pumping)

#### 3. *Agricultural Uses of Electricity*

- 3.3 Water pumping-replacing liquid fuel, coal, gas, or muscle power;
- 3.4 Parboiling, heating and drying-replacing biomass, coal, or liquid fuel;
- 3.5 Milling, chaff cutting, threshing, etc.-replacing liquid fuel, hydro and muscle power, coal or biomass.

#### 4. *Commercial Uses of Electricity*

- 4.1 Lighting
- 4.2 Air-conditioning
- 4.3 Improved audio and video opportunities
- 4.4 More attractive atmosphere
- 4.5 Longer opening times

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#### Benefits That are Difficult or Impossible to Quantify

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1. Modernisation, dynamism, and attitude changes-catalytic effects;
  2. Quality of life, community services, and participation;
  3. Income redistribution and social equity;
  4. Employment creation;
  5. Other socio-political effects.
- 

Source: Adapted from Munasinghe (1987:85); and Zomers (2001: 50)

## Annex C

### Calculation of shape number, runner speed and diameter

#### 4.5.2 Shape number

The power output  $P_o$  from a turbine depends on head  $H$ , the angular velocity  $\omega$ , the diameter of the turbine, and the density of water  $\rho$ . Two useful dimensionless parameters that can be formed from these physical quantities, are the power coefficient,

$$K_p = \frac{P}{(\omega^3 D^5 \rho)} \text{ and the head coefficient, } K_h = \frac{gH}{(\omega^2 D^2)}. \text{ When the turbine is}$$

operating at maximum efficiency,  $K_p$  and  $K_h$  can be used to predict the power and head in terms of diameter and the angular velocity. Eliminating the dependence on diameter, a dimensionless ratio shown in equation 4.4 is obtained.

$$k_n = \frac{k_p^{1/2}}{k_h^{5/4}} = \frac{\omega P^{1/2}}{\rho^{1/2} (gH)^{5/4}}. \text{ Substituting } P = \rho g H Q \eta \text{ from equation 4.1 and assuming}$$

$$\eta = 1,$$

The equation for shape number becomes:

$$\text{Shape number, } k_n = \frac{n \sqrt{P_o / \rho}}{(gH)^{1.25}} \quad (\text{Equation 4.3})$$

where  $n$  is the rotational speed of the turbine (in rpm). The formula above can be written in a simple form:

$$k_n = 5 \left( \frac{r}{R} \right) \frac{v_B}{v_\omega} \quad (\text{Equation 4.4})$$

where  $\frac{r}{R}$  is the ratio of diameter of the incoming flow or jet of the water to the total

diameter of the turbine.  $\frac{v_B}{v_\omega}$  is the ratio of the blade speed to the speed of the water.

### 4.5.3 Runner Speed

A synchronous speed of the generator is used to determine the runner speed. For turbine speed,  $n$ , to be synchronous, the following equation is applied:

$$n = \frac{120(f)}{N_p} \quad (\text{Equation 4.5})$$

where  $n$  is the rotational speed (rpm) ,  $f$  is electrical frequency (Hz) and,  $N_p$  is the number of poles for the generator.

### 4.5.4 Runner diameter

Sadrul et al (2002:216-219) provide an equation for approximating the runner diameter for the cross flow turbine as follows:

$$D = 40 \frac{\sqrt{H}}{n} \quad (\text{Equation 4.6})$$

The jet thickness  $t_j$  is generally between one fifth and one tenth of the diameter. The approximate runner length, in metres, is therefore given by:

$$L = \frac{0.23 Q}{t_j \sqrt{H}} \quad (\text{Equation 4.7})$$

### Determination of power output, design flow and penstock diameter

The maximum amount of power available in theory from the flow is related to the speed of flow, and the head. The power output  $P$  is the product of the efficiency  $\eta$ , the potential energy per unit volume,  $\rho gh$ , and the volume of water flowing per second  $Q$ . This relationship is expressed by the formula (Harvey et al, 1993:4-5; Inversin, 1986:48-49; ESHA, 1998: 75-77).

$$P = \rho g H Q \eta \quad (\text{Equation 4.8})$$

where  $P$  , is net power output (kW);  $Q$  , is the flow through the turbine ( $\text{m}^3/\text{s}$ );  $H$  , is the net head of water (m);  $\rho$  = density of water ( $\text{kg}/\text{m}^3$ );  $g$  = acceleration due to gravity ( $= 9.81 \text{ m}/\text{s}^2$ ); and  $\eta$  = overall efficiency of the system.

Giesecke and Mosonyi (2003), cited in Maskey, (2004: 56), give the following modified formula in order to determine the amount of electricity produced by a hydropower plant

$$\text{from water to wire: } P = \frac{\eta_{Tot} \cdot \rho \cdot g \cdot Q_d \cdot H \cdot (1 - l_{pel})}{1000} \quad (\text{Equation 4.9})$$

with  $\eta_{Tot} = \eta_T \cdot \eta_{gen} \cdot \eta_{tr}$ , is overall system efficiency;  $\eta_T$  is turbine efficiency,  $\eta_{gen}$  = generator efficiency,  $\eta_{tr}$  = transmission efficiency,  $Q_d$  being the design discharge and  $l_{pel}$  parasitic electrical losses. The overall efficiency comprises efficiencies of penstock, turbine, gearing, generator, transformers and losses in the transmission and distribution lines (Harvey et al, 1993:4-5).

Inversin (1986:96-102) presents an equation for head loss due to pipe friction derived from Manning's equation:

$$h_f = \frac{10.3n^2 Q^2}{D^{5.333} L} \quad (\text{Equation 4.10})$$

where  $h_f$  is the head loss due to friction (in metres),  $n$  is the roughness coefficient,  $Q$  is the flow (in cubic metres per second),  $D$  is the pipe diameter (in metres), and  $L$  is the pipe length (in metres). The gross head is the difference in elevation between the penstock inlet and the turbine. The net or usable head is the gross head minus head lost due to friction, and is expressed as follows:

$$H = H_{gross} - h_f \quad (\text{Equation 4.11})$$

The head lost comprise the following partial losses: (1) intake losses, including trash rack loss; (2) friction losses along the entire water way (canal, tunnel, penstock); and (3) local losses along the water way (bends, valves etc). Substituting equations (4.4) and (4.5) into (4.2) gives power as a function of  $Q, D, n, L, H_{gross}$ , and  $h_f$

$$P = 9.81 n Q \left( H_{gross} - \frac{10 n^2 Q^2}{D^{5.333} L} \right) \quad (\text{Equation 4.12})$$

There are two conditions of interest for which to solve this equation. The first is to limit flow so that head loss due to friction is minimum. Second, is to find  $Q$  for which  $P$  is a maximum, bearing in mind that head decreases with increasing flow: Maximising  $P$  as a function of  $Q$ :

$$\frac{dP}{dQ} = 9.81 n H_{gross} - 9.81 n \frac{30 n^2 Q^2}{D^{5.333} L} = 0 \quad (\text{Equation 4.13})$$

Solving for  $Q$ , yields equation (4.7) below.

$$Q = \sqrt{\frac{D^{5.333} H_{gross}}{30 n^2 L}} \quad (\text{Equation 4.14})$$

It follows that:

$$D = \left( \frac{10.3 n^2 Q^2 L}{h_f} \right)^{0.1875} \quad (\text{Equation 4.15}).$$

By limiting  $h_f$  at  $4H/100$  (so that power losses do not exceed 4%),  $D$  is computed using the following formula:

$$D = 2.69 \left( \frac{10.3 n^2 Q^2 L}{H_{gross}} \right)^{0.1875} \quad (\text{Equation 4.16}).$$

### 4.9.3 Regression Equation Approach

Regression equations that relate stream flow statistics at gauged stream-gauging stations to basin and climatic characteristics are used to estimate stream flow statistics for ungauged sites. The basic equation for the multiple non-linear regressions is:

$$y = a_0 \cdot x_1^{a_1} \cdot x_2^{a_2} \cdot x_3^{a_3} \cdots x_n^{a_n}$$

where  $y$  is a dependent variable,  $x_i$  = independent variables, and  $a_i$  are regression coefficients. The dependent variables are  $Q$  (90, daily),  $Q$  (70, daily) and  $Q$  (50 daily) whereas the independent variables are the different catchment characteristics such as rainfall, area.

Ries and Friesz (2000:26) described the stream flow and catchments characteristics used in a hydrologic regression typically to be log-normally distributed which necessitates transformation of the variables to logarithms. Therefore, using logarithms of the independent and dependent variables in equation (4.23) the model takes the following form:

$$\log y = \log a_0 + a_1 \cdot \log x_1 + a_2 \cdot \log x_2 + a_3 \cdot \log x_3 \dots a_n \cdot \log x_n$$

Substituting  $\log y$  with  $u$ ,  $\log x_i = u_{x_i}$ , and  $\log a_0 = b_0$ , a simple linear regression equation is obtained as :

$$u = b_0 + a_1.u_{x_1} + a_2.u_{x_2} + a_3.u_{x_3} + \dots + a_n.u_{x_n}$$

Using  $\Delta u_{x_i}$  instead of  $(u_{x_i} - \bar{u}_x)$ , the regression coefficients are calculated by means of equation system:

$$a_1.\sum \Delta u_{x_1}^2 + a_2.\sum (\Delta u_{x_1}\Delta u_{x_2}) + \dots + a_n.\sum (\Delta u_{x_1}\Delta u_{x_n}) = \sum (\Delta u_y\Delta u_{x_1})$$

$$a_1.\sum (\Delta u_{x_1}\Delta u_{x_2}) + a_2.\sum \Delta u_{x_2}^2 + \dots + a_n.\sum (\Delta u_{x_2}\Delta u_{x_n}) = \sum (\Delta u_y\Delta u_{x_2})$$

⋮

$$a_1.\sum (\Delta u_{x_1}\Delta u_{x_n}) + a_2.\sum (\Delta u_{x_2}\Delta u_{x_n}) + \dots + a_n.\sum \Delta u_{x_n}^2 = \sum (\Delta u_y\Delta u_{x_n})$$

in matrix form, equation (4.19) becomes:

$$\underline{U}_x.\vec{A} = \vec{U}_y$$

where  $\underline{U}_x$  is a  $nxn$  matrix made up of  $n$  observations on each of the  $n$  independent variables,

$\vec{A}$  is a  $nx1$  vector of unknown regression coefficients and  $\vec{U}_y$  is a  $nx1$  vector observations.

With this system of equations  $a_1, a_2, \dots, a_n$  can be calculated. To determine  $b_0$  the calculated coefficients  $a_i$  together with the arithmetic means of  $u_y, u_{x_1}, u_{x_2}, \dots, u_{x_n}$  are filled in equation (4.25).

The squares of the errors between the observed and predicted observations are used to evaluate how well a regression model fits the sample data. To express the quality of fit between a regression model and the sample data, a statistical index commonly referred to as *coefficient of multiple determination* ( $R^2$ ) is typically used. The coefficient of multiple determination is defined as:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \quad (\text{Equation 4.28})$$

where  $\left[ SST = \sum (y_i - \bar{y})^2 \right]$  are the observed responses,  $\left[ SSE = \sum (y_i - \hat{y}_i)^2 \right]$  is the model error, and  $\left[ SSR = \sum (\hat{y}_i - \bar{y})^2 \right]$  is the regression model.

The total variability in the observed responses (SSE) is equal to the random variability not explained by the model or model error (SSE) plus the systematic variability that is explained by the regression model. Put simply,  $R^2$  explains how much of the variability in the  $y$ 's can be explained by the fact that they are related to  $x$ , i.e. how close the points are to the regression function. Values of  $R^2$  range from 0 to 1. Higher values of  $R^2$  indicate a better fit of the model to the sample observations.

#### 4.10.1 Economic concepts

Economic analysis of small hydropower project represents the cost and benefit to the rural communities in terms of opportunity cost. All cost streams are changed to represent economic value. The costs and benefits streams considered include capital costs, operation and maintenance in cost streams and revenue from electricity supply and capacity benefit in benefit streams.

#### Present Value

Present value is the value today of a benefit or cost that occurs in the future. It is measured using the discount rate. In mathematical terms, the present value of a sum of money received or spent in some future period is calculated using the formula below:

$$PV = FV(1+r)^{-n} \quad (\text{Equation 4.25})$$

where  $PV$  is the present value,  $FV$  = future value,  $r$  is the discount rate, and  $n$  is number of years. The equation below is often referred to as the present worth factor and is used to calculate the present value:

$$\frac{1}{(1+r)^n} \quad (\text{Equation 4.26})$$

### Net Present Cost/ Life Cycle Cost

The net present cost is the sum of the present values of all associated costs over the period of the project. Costs in any future year are discounted back to the base period using equation 4.25. In calculating the net present cost, the following assumptions are made:

- Initial investment costs are lump sum (all occur at once) in period 0;
- All recurrent costs begin to accumulate in period 1;
- Costs in any period are lumped together and assumed to occur at the end of that period; and
- Salvage values are considered as negative costs.

### Net Present Value

The Net Present Value of the project is the sum of the present values of all benefits associated with the project, less the sum of the present values of all associated costs. It is calculated using the formula below:

$$NPV = \sum \frac{(TB - TC)}{(1 + r)^n} \quad (\text{Equation 4.27})$$

where  $NPV$  = net present value,  $TC$  = total costs,  $TB$  are total benefits,  $r$  is discount rate, and  $n$  = number of years.

### Internal Rate of Return

The internal rate of return (IRR) is the discount rate at which the cumulative net present value of the project is equal to zero. At this discount rate, the cumulative net present value of all projects costs is exactly equal to the cumulative net present value of project benefits. As a general rule, if the being evaluated has an internal rate of return lower than the discount rate, the project should not be undertaken. The IRR is found by solving the formula below through iteration to find the discount rate ( $r$ ) at which the NPV equals zero.

$$\sum PV = 0, \text{ thus } \sum \frac{FV}{(1 + r)^n} = 0 \quad (\text{Equation 4.28})$$

**Benefit-to-Cost Ratio (BCR)**

The benefit to cost ratio is equal to the NPV of associated benefits divided by the NPV of associated costs (net present cost).

$$BCR = \frac{NPV_{benefits}}{NPV_{costs}} \quad (\text{Equation 4.29})$$

**Cost of Generation (CoG)**

The cost of generation is equal to the net present cost of the energy system divided by the total kWh generated over the life of the system.

$$CoG = \frac{NPC}{Total\ kWh} \quad (\text{Equation 4.30})$$

**Annex D****Annex D1: Household Demand Survey Questionnaire****1.0 General Information**

Name of respondent .....

Address .....

Sex                      Male       Female

Status of respondent    Household       Business owner

Number of occupants (specify)

Village .....

Traditional Authority .....

District .....

**2.0 Income**

How much income did you receive monthly or yearly in average?

*(Select a code [0 – 21] from table shown below. If code#21 is selected, please specify the amount in MK)*

Monthly:

Yearly

| Code |              | Code |               |
|------|--------------|------|---------------|
| 0    | MK 0         |      |               |
| 1    | MK 1-1,000   | 11   | MK10001-11000 |
| 2    | MK1001-2000  | 12   | MK11001-12000 |
| 3    | MK2001-3000  | 13   | MK12001-13000 |
| 4    | MK3001-4000  | 14   | MK13001-14000 |
| 5    | MK4001-5000  | 15   | MK14001-15000 |
| 6    | MK5001-6000  | 16   | MK15001-16000 |
| 7    | MK6001-7000  | 17   | MK16001-17000 |
| 8    | MK7001-8000  | 18   | MK17001-18000 |
| 9    | MK8001-9000  | 19   | MK18001-19000 |
| 10   | MK9001-10000 | 20   | MK19001-20000 |
|      |              | 21   | MK 20001<     |

### 3.0 Household Expenditure

- 3.1 How much is the maximum expendable monthly amount? (Select a code [0 – 21] from table shown below. If code#21 is selected, please specify the amount in MK

| Code |              | Code |               |
|------|--------------|------|---------------|
| 0    | MK 0         |      |               |
| 1    | MK 1-1,000   | 11   | MK10001-11000 |
| 2    | MK1001-2000  | 12   | MK11001-12000 |
| 3    | MK2001-3000  | 13   | MK12001-13000 |
| 4    | MK3001-4000  | 14   | MK13001-14000 |
| 5    | MK4001-5000  | 15   | MK14001-15000 |
| 6    | MK5001-6000  | 16   | MK15001-16000 |
| 7    | MK6001-7000  | 17   | MK16001-17000 |
| 8    | MK7001-8000  | 18   | MK17001-18000 |
| 9    | MK8001-9000  | 19   | MK18001-19000 |
| 10   | MK9001-10000 | 20   | MK19001-20000 |
|      |              | 21   | MK 20001<     |

- 3.2. On average, how much per month was spent on each of the energy sources for the dwelling unit or business unit?

| Energy Sources             | Average Expenses (MK/month) |
|----------------------------|-----------------------------|
| 1) Paraffin – lighting     |                             |
| 2) Paraffin – cooking      |                             |
| 3) Paraffin – refrigerator |                             |
| 4) Firewood                |                             |

|                                 |  |
|---------------------------------|--|
| 5) Charcoal                     |  |
| 6) Gas                          |  |
| 7) Candles                      |  |
| 8) Torch cells                  |  |
| 9) Batteries (charging fee etc) |  |
| 10) Others (specify )           |  |
| Total Amount                    |  |

#### 4.0 End Uses

How do you want to use electricity? Please check on (1 = Want to use, 0 = Do not want to use) the following table. If you select "14) other", please specify how/what you want to use.

| <i>1</i><br>= Yes<br>0 = No |                           | <i>1 = Yes</i><br><i>0 = No</i> |                               | <i>1 = Yes</i><br><i>0 = No</i> |                        |
|-----------------------------|---------------------------|---------------------------------|-------------------------------|---------------------------------|------------------------|
|                             | 1) Lighting               |                                 | 6) Television                 |                                 | 11) Air<br>Conditioner |
|                             | 2) Cooking                |                                 | 7) video Cassette<br>Recorder |                                 | 12) Maize Mill         |
|                             | 3) Refrigerator           |                                 | 8) Electric iron              |                                 | 13) Computer           |
|                             | 4) Radio                  |                                 | 9) Electric Heater            |                                 | 14)<br>Other(specify)  |
|                             | 5) Cassette/<br>CD Player |                                 | 10) Electric Fan              |                                 |                        |

#### 5.0 What are the expected benefits /impacts of electrification?

|  | Yes                      | No                       |
|--|--------------------------|--------------------------|
| 1) Nothing will change   | <input type="checkbox"/> | <input type="checkbox"/> |
| 2) The business unit or dwelling unit will become safer                  | <input type="checkbox"/> | <input type="checkbox"/> |
| 3) Opening business will be longer hours per day                         | <input type="checkbox"/> | <input type="checkbox"/> |
| 4) Customer patronage to the business will increase                      | <input type="checkbox"/> | <input type="checkbox"/> |
| 5) Start new business (specify:-----<br>Night time become more enjoyable | <input type="checkbox"/> | <input type="checkbox"/> |
| 6) Entertainment time become longer                                      | <input type="checkbox"/> | <input type="checkbox"/> |
| 7) Cooking/domestic work at night become easier                          | <input type="checkbox"/> | <input type="checkbox"/> |
| 8) Studying or reading at night become easier                            | <input type="checkbox"/> | <input type="checkbox"/> |
| 9) Sleeping hours become shorter   | <input type="checkbox"/> | <input type="checkbox"/> |
| 10) Activities of family members slows down                              | <input type="checkbox"/> | <input type="checkbox"/> |
| 11) Other (specify:-----   | <input type="checkbox"/> | <input type="checkbox"/> |

- 6.0. What is the maximum amount of money you are willing to pay for connection fee and in-house wiring cost for electricity? (select a code number [0 – 21] from the table shown below. If code #21 is selected, please specify the amount in MK )

| Code |              | Code |               |
|------|--------------|------|---------------|
| 0    | MK 0         |      |               |
| 1    | MK 1-1,000   | 11   | MK10001-11000 |
| 2    | MK1001-2000  | 12   | MK11001-12000 |
| 3    | MK2001-3000  | 13   | MK12001-13000 |
| 4    | MK3001-4000  | 14   | MK13001-14000 |
| 5    | MK4001-5000  | 15   | MK14001-15000 |
| 6    | MK5001-6000  | 16   | MK15001-16000 |
| 7    | MK6001-7000  | 17   | MK16001-17000 |
| 8    | MK7001-8000  | 18   | MK17001-18000 |
| 9    | MK8001-9000  | 19   | MK18001-19000 |
| 10   | MK9001-10000 | 20   | MK19001-20000 |
|      |              | 21   | MK 20001<     |

- 7.0. What is the maximum amount of money you are willing to pay for monthly electricity consumption? (Select a code number [0 – 21] from the table shown below. If code #21 is selected, please specify the amount in MK )

| Code |             | Code |             |
|------|-------------|------|-------------|
| 0    | MK 0        |      |             |
| 1    | MK1-200     | 11   | MK2001-2200 |
| 2    | MK201-400   | 12   | MK2201-2400 |
| 3    | MK401-600   | 13   | MK2401-2600 |
| 4    | MK601-800   | 14   | MK2601-2800 |
| 5    | MK801-1000  | 15   | MK2801-3000 |
| 6    | MK1001-1200 | 16   | MK3001-3200 |
| 7    | MK1201-1400 | 17   | MK3201-3400 |
| 8    | MK1401-1600 | 18   | MK3401-3600 |
| 9    | MK1601-1800 | 19   | MK3601-3800 |
| 10   | MK1801-2000 | 20   | MK3801-4000 |
|      |             | 21   | >MK4001     |

- 8.0 Can you provide any contribution for electrification project?

|  | Yes                      | No                       |
|--|--------------------------|--------------------------|
| 1) Do not contribute anything                                    | <input type="checkbox"/> | <input type="checkbox"/> |
| 2) Attend construction work voluntarily                          | <input type="checkbox"/> | <input type="checkbox"/> |
| 3) Participate maintenance/repair work voluntarily               | <input type="checkbox"/> | <input type="checkbox"/> |
| 4) Provide construction materials from private properties        | <input type="checkbox"/> | <input type="checkbox"/> |
| 5) Provide donation to the project (bear a part of project cost) | <input type="checkbox"/> | <input type="checkbox"/> |

- 6) Can manage as a member of electrification project committee
- 7) Possible to work as power plant operator
- 8) Possible to work as an electricity tariff collector

**Table D.1: Level surveying from intake to fore bay tank**

| Levelling BS | IS    | F.S   | HPC     | RL      | Distance | Remarks                                    |
|--------------|-------|-------|---------|---------|----------|--|
| 0.844        |       |       | 100.844 | 100.000 |          | TBM A                                      |
| 1.475        |       | 0.475 | 101.844 | 100.369 |          | GL,Cpt 1                                   |
|              | 1.065 |       |         | 100.779 | 0        | Peg A                                      |
|              | 1.670 |       |         | 100.174 | 5        | Peg B                                      |
|              | 1.864 |       |         | 99.980  | 10       | Peg C                                      |
|              | 2.268 |       |         | 99.576  |          | Stream channel                             |
|              | 2.443 |       |         | 99.401  | 22       | Waters edge R/B                            |
|              | 2.414 |       |         | 99.430  |          | Waters edge mid left bank                  |
|              | 1.846 |       |         | 99.998  |          | Top of rock                                |
|              | 2.537 |       |         | 99.307  |          | Waters edge L/B                            |
| 3.418        |       | 1.179 |         | 100.665 |          | G,L Cpt 2                                  |
| 0.625        |       | 1.478 |         | 102.605 | 33       | Peg D, L/bank                              |
|              | 3.904 |       |         | 99.326  |          | Water level R/bank                         |
|              | 1.629 |       |         | 101.601 |          | GL.Cpt 3                                   |
| 0.885        |       | 3.904 | 100.211 | 99.326  | 66       | Peg F (level transferred from waters edge) |
|              | 0.885 |       |         | 99.326  | 87       | Peg G                                      |
| 0.585        |       | 0.885 | 99.911  | 99.326  | 106      | Peg H                                      |
| 1.050        |       | 0.585 | 100.376 | 99.326  | 126      | Peg I                                      |
|              | 1.050 |       |         | 99.326  | 146      | Peg J                                      |
| 1.037        |       | 1.050 | 100.363 | 99.326  | 167      | Peg K                                      |
|              | 1.037 |       |         | 99.326  | 193      | Peg L                                      |
| 1.391        |       | 1.037 |         | 99.326  | 207      | Peg M                                      |
|              | 1.391 |       |         | 99.326  | 253      | Peg N                                      |
| 3.180        |       | 1.391 |         | 99.326  | 269      | Peg O                                      |
|              | 1.180 |       |         | 99.326  | 294      | Peg P                                      |
|              |       | 1.342 |         | 99.111  |          | TBM A closing                              |

**Notes**

1. Distance from proposed intake site to the fore bay tank is 294m.
2. Reduced level on proposed power canal is 99.326 m.

**Table D.2: Level surveying from fore bay tank to power house**

| Levelling<br>BS | IS    | F.S   | HPC     | RL      | Distance | Remarks                |
|-----------------|-------|-------|---------|---------|----------|------------------------|
| 0.665           |       |       | 100.665 | 100.000 | 0        | TBM B                  |
| 0.475           |       | 3.970 | 97.005  | 96.530  |          | Ground level,<br>Cpt 1 |
| 1.295           |       | 3.668 | 94.632  | 93.337  |          | GL Cpt 2               |
| 1.615           |       | 3.680 | 92.567  | 90.952  |          | GL Cpt 3               |
| 0.268           |       | 3.081 | 89.754  | 89.486  | 20       | Peg A                  |
| 2.210           |       | 3.665 | 88.299  | 86.089  |          | GL Cpt 4               |
| 1.607           |       | 3.805 | 86.101  | 84.494  |          | GL Cpt 5               |
| 0.634           |       | 3.222 | 83.513  | 82.879  |          | GL Cpt 6               |
| 0.354           |       | 3.695 | 80.172  | 79.818  | 40       | Peg B                  |
| 0.751           |       | 3.599 | 77.324  | 76.573  |          | GL Cpt 7               |
| 0.523           |       | 3.926 | 73.921  | 73.398  |          | GL Cpt 8               |
| 0.455           |       | 3.705 | 70.681  | 70.216  | 62.7     | GL Cpt 9               |
|                 | 3.947 |       |         | 66.734  | 74.0     | Lag peg                |
|                 |       | 3.610 |         | 67.071  |          | TBM C                  |
|                 |       |       |         |         |          |                        |
|                 |       |       |         |         |          |                        |

## Notes

3. Linear distance from proposed fore bay tank to power house 74 m.
4. Vertical distance from the proposed fore bay tank to power house is 33 m.

Table D.3: Stream flow measurement

| Distance from initial point | Depth | Depth of Observation from water surface | Time (secs) | Revolution | Velocity |                  |                 | Area (m <sup>2</sup> ) | Mean depth | Width | Discharge (m <sup>3</sup> /s) | Remarks |
|-----------------------------|-------|---|-------------|------------|----------|------------------|-----------------|------------------------|------------|-------|-------------------------------|---------|
|                             |       |   |             |            | At point | Mean in vertical | Mean in section |                        |            |       |                               |         |
| 1.0                         | 0     |   |             |            |          |                  |                 |                        | 0.100      |       |                               | WLRB    |
| 1.2                         | 0.14  |   | 43          | 80         |          | 0.606            |                 | 0.035                  | 0.250      | 0.021 |                               |         |
| 1.5                         | 0.14  |   | 46          | 90         |          | 0.636            |                 | 0.070                  | 0.400      | 0.045 |                               |         |
| 2.0                         | 0.13  |   | 43          | 100        |          | 0.818            |                 | 0.065                  | 0.500      | 0.053 |                               |         |
| 2.5                         | 0.15  |   | 55          | 120        |          | 0.704            |                 | 0.075                  | 0.500      | 0.053 |                               |         |
| 3.0                         | 0.13  |   | 55          | 110        |          | 0.649            |                 | 0.065                  | 0.500      | 0.042 |                               |         |
| 3.5                         | 0.12  |   | 64          | 90         |          | 0.459            |                 | 0.060                  | 0.500      | 0.028 |                               |         |
| 4.0                         | 0.14  |   | 59          | 90         |          | 0.505            |                 | 0.070                  | 0.500      | 0.035 |                               |         |
| 4.5                         | 0.12  |   | 49          | 90         |          | 0.599            |                 | 0.060                  | 0.500      | 0.036 |                               |         |
| 5.0                         | 0.11  |   | 64          | 90         |          | 0.459            |                 | 0.055                  | 0.500      | 0.025 |                               |         |
| 5.5                         | 0.14  |   | 49          | 110        |          | 0.723            |                 | 0.049                  | 0.036      | 0.035 |                               |         |
| 5.7                         | 0.14  |   | 49          | 70         |          | 0.494            |                 | 0.028                  | 0.020      | 0.014 |                               |         |
| 5.9                         | 0     |   |             |            |          |                  |                 |                        | 0.010      |       |                               | WELB    |
| TOTALS                      |       |   |             |            |          |                  |                 | 0.632                  | 4.90       | 0.387 |                               |         |

## Annex E

## Results of socioeconomic and hydrological study

Table E.1: Energy sources and end-uses in Nkolokosa village

| Fuel     | End-uses (% respondents) |          |
|----------|--------------------------|----------|
|          | Cooking                  | Lighting |
| Paraffin | 23                       | 95.76    |
| Charcoal | 12.7                     | -        |
| Firewood | 100                      | -        |
| Candles  | -                        | 8.5      |

Table E.2: Monthly energy expenditure and expenditure share by net income group

| <i>Household expenditure in MK/month</i> |            |                          |                 |             |              |                  |        |
|--|------------|--------------------------|-----------------|-------------|--------------|------------------|--------|
|  |            | Weighted energy averages | Less than 1,000 | 1,000-5,000 | 5,001-10,000 | More than 20,000 | Mean   |
| Firewood                                 | MK/kg      | 4.50                     | 429.41          | 549.06      | 406.25       | 600.00           | 496.18 |
| Paraffin                                 | MK/l       | 150.00                   | 184.74          | 357.10      | 535.77       | 275.00           | 338.15 |
| Charcoal <sup>24</sup>                   | MK/kg      | 15.00                    | 475.00          | 613.64      | 1000.00      | 500.00           | 647.16 |
| Candles                                  | MK/unit    | 10.00                    | -               | 100.71      | 150          | n/a              | 125.36 |
| Dry cells                                | MK/unit    | 30.00                    | 60.00           | 210.00      | 200.00       | n/a              | 156.67 |
| Car batteries                            | MK/service | 0                        | 70.00           | 154.63      | 214.50       | 140.00           | 144.78 |
| Energy share in household budget         |            |                          |                 |             |              |                  |        |
|  | Minimum    |                          | 18.5%           | 12.2%       | 13%          | 5.1%             |        |
|  | Maximum    |                          | 43%             | 40%         | 25%          | 7.6%             |        |

<sup>24</sup> Household may report more than one type of fuel used. About 12.7% use both charcoal and firewood. Share of firewood which is purchased only.

**Table E.3: Estimated energy consumption by household income**

|                       | Very poor<br>N = 32 | poor<br>N = 71 | Near poor<br>N = 13 | Better off<br>N = 2 |
|-----------------------|---------------------|----------------|---------------------|---------------------|
| <b>Paraffin</b>       |                     |                |                     |                     |
| Litre/person/day      | 0.008               | 0.015          | 0.023               | 0.012               |
| Litre/household/month | 1.232               | 2.381          | 3.585               | 1.833               |
| Litre/ household/year | 14.784              | 28.572         | 43.02               | 21.996              |
| All households        | 473.088             | 2028.612       | 559.26              | 43.992              |
| <b>Charcoal</b>       |                     |                |                     |                     |
| kg/person/day         | 0.199               | 0.257          | 0.419               | 0.210               |
| kg/ household/month   | 31.667              | 40.909         | 66.667              | 33.333              |
| kg/ household/year    | 380.000             | 490.908        | 800.000             | 399.996             |
| All households        | 12,160              | 34,854.468     | 10,400              | 800                 |
| <b>Firewood</b>       |                     |                |                     |                     |
| kg/person/day         | 0.600               | 0.767          | 0.568               | 0.839               |
| kg/ household/month   | 95.424              | 122.013        | 90.278              | 133.333             |
| kg/ household/year    | 1,145.088           | 1,464.156      | 1,083.336           | 1,599.996           |
| All households        | 36,642.816          | 103,955.076    | 14,083.368          | 3,199.992           |

**Table E.4: Energy consumption and expenditure displaced by electricity**

|                        | Wood       | Paraffin<br>(cooking) | Paraffin<br>(lighting) | Charcoal  | Candles   | Batteries |
|------------------------|------------|-----------------------|------------------------|-----------|-----------|-----------|
| Consumption            | 110 kg     | 2.311                 | 0.93 l                 | 43 kg     | 0.4 pkt   | 4 batts   |
| Energy content         | 15.5 MJ/kg | 35.0 MJ/kg            | 35.0 MJ/kg             | 30. MJ/kg | 21 MJ/pkt | 0.02 MJ   |
| Gross energy consumed  | 473.61kWh  | 22.46 kWh             | 9.04 kWh               | 358.3kWh  | 2.33 kWh  | 0.022 kWh |
| Conversion             | 0.308      | 0.615                 | 0.109                  | 0.444     | 0.018     | 1.000     |
| Electricity equivalent | 145.87kWh  | 13.81 kWh             | 0.98 kWh               | 159.1 kWh | 0.04 kWh  | 0.022 kWh |
| Expenditure            | K495.00    | K346.50               | K139.50                | K645.00   | K40.00    | K120.00   |
| Price                  | K4.50/kg   | K150/litre            | K150/litre             | K15/kg    | K100/pkt  | K30/batt  |

Table E.5: Typical Appliance Efficiencies/Efficacies

| Application   | Fuel        | Appliance         | Min             | Max | Average            | Conversion          |
|---------------|-------------|-------------------|-----------------|-----|--------------------|---------------------|
|               |             |                   | (%)             | (%) | (%)                |                     |
| Cooking       | Electricity | Hot plate         | 55              | 75  | 65                 | n/a                 |
|               |             | Stove             | 55              | 75  | 65                 |                     |
|               | Paraffin    | Wick              | 20              | 35  | 30                 | 0.462 <sup>25</sup> |
|               |             | Primus            | 30              | 55  | 40                 | 0.615 <sup>1</sup>  |
|               | Gas         | Ring              | 40              | 60  | 45                 | 0.692 <sup>1</sup>  |
|               |             | Stove             | 40              | 60  | 45                 | 0.692 <sup>1</sup>  |
|               | Wood        | 3-stone           | 13              | 15  | 15                 | 0.231 <sup>1</sup>  |
|               |             | Stove             | 20              | 30  | 25                 | 0.385 <sup>1</sup>  |
|               | Coal        | Stove             | 20              | 30  | 25                 | 0.385 <sup>1</sup>  |
| Brazier       |             | 6                 | 10              | 8   | 0.123 <sup>1</sup> |                     |
| Water heating | Electricity | Geyser            | 48              | 92  | 58                 | n/a                 |
|               |             | On-line           | 96              | 96  | 96                 |                     |
|               | Paraffin    | Wick/pot          | 20              | 35  | 30                 | 0.517 <sup>26</sup> |
|               |             | Primus/pot        | 30              | 55  | 40                 | 0.692 <sup>2</sup>  |
|               | Gas         | Ring/pot          | 40              | 60  | 45                 | 0.776 <sup>2</sup>  |
|               |             | Geyser            | 75              | 92  | 80                 | 1.38 <sup>2</sup>   |
|               | Wood        | File/pot          | 13              | 15  | 14                 | 0.241 <sup>2</sup>  |
|               |             | Stove/pot         | 20              | 30  | 25                 | 0.431 <sup>2</sup>  |
|               | Coal        | Stove             | 20              | 46  | 30                 | 0.517 <sup>2</sup>  |
| Lighting      | Electricity | 60W incandescent  | 11 lumens/Watt  |     |                    | n/a                 |
|               |             | 100W incandescent | 18 lumens/Watt  |     |                    |                     |
|               |             | 20W fluorescent   | 62 lumens/Watt  |     |                    |                     |
|               |             | 40W fluorescent   | 75 lumens/Watt  |     |                    |                     |
|               | Candle      |                   | 0.2 lumens/Watt |     |                    | 0.018 <sup>27</sup> |
|               | Paraffin    | Wick lamp         | 0.3 lumens/Watt |     |                    | 0.027 <sup>3</sup>  |
|               |             | Pressure lamp     | 1.2 lumens/Watt |     |                    | 0.109 <sup>3</sup>  |
|               | Gas         | Gas lamp          | 1 lumens/Watt   |     |                    | 0.091 <sup>3</sup>  |

Source: Davis, M &amp; Horvei, T. (1992)

## Notes:

Efficiencies are defined as the ratio of useful energy to gross energy when using a particular appliance. Efficacies are generally used for lighting where it is difficult to define the useful energy output. Here, the ratio of the lumen output to the power consumption of the lamp is defined as the efficacy of the lamp.

<sup>25</sup> Taking the average efficiency of an electric hot plate as the alternative;

<sup>26</sup> Taking the average efficiency of an electric geyser as the alternative;

<sup>27</sup> Taking a 60W incandescent globe as the alternative

**Table E.6: Calorific values of a range of fuels**

| Fuel                         | Calorific value |                  |
|------------------------------|-----------------|------------------|
|                              | MJ              | kWh <sup>2</sup> |
| Gas [kg]                     | 49.8            | 13.8             |
| Paraffin [litre]             | 38.0            | 10.6             |
| Candles [each]               | 3.45            | 0.96             |
| Wood (20%) <sup>1</sup> [kg] | 15.5            | 4.3              |
| Wood (40%) <sup>1</sup> [kg] | 10.9            | 3                |
| Coal[kg]                     | 27              | 7.5              |
| Petrol [litre]               | 62.8            | 17.4             |
| Diesel [litre]               | 48.4            | 13.5             |
| PM-9 battery [each]          | 0.081           | 0.02             |
| PM-10 battery [each]         | 0.020           | 0.006            |
| Torch battery [each]         | 0.029           | 0.006            |
| Car battery [per charge]     | 1.3             | 0.36             |

Source: Davis, M & Horvei, T.(1992)

1 20% and 40% refer to the moisture content of the wood

2 the conversion factor from MJ to kWh is 0.278, i.e. 3.6 MJ = 1 kWh

**Table E.7: Dependability for Nachipere and Nswazi Rivers based on 1-day and 10-day duration curves**

| Dependability                | Flow (m <sup>3</sup> /s) |           |              |           |
|------------------------------|--------------------------|-----------|--------------|-----------|
|                              | 1-day curve              |           | 10-day curve |           |
|                              | Nswazi                   | Nachipere | Nswazi       | Nachipere |
| 50% (equivalent to 183 days) | 0.400                    | 0.089     | 0.482        | 0.107     |
| 75% (equivalent to 274 days) | 0.204                    | 0.046     | 0.231        | 0.051     |
| 90% (equivalent to 328 days) | 0.104                    | 0.023     | 0.119        | 0.026     |
| 95% (equivalent to 347 days) | 0.063                    | 0.014     | 0.069        | 0.015     |
| 99%(equivalent to 361 days)  | 0.023                    | 0.005     | 0.046        | 0.010     |

**Table E.8: Flood Frequency Calculations using Log-Pearson Type III Distribution (1995-2004)**

| Return Period (years) | Skew Coefficient K(-2) | Discharge at Kautuka Q (m <sup>3</sup> /s) | Discharge at Nkolokosa Q (m <sup>3</sup> /s) |
|-----------------------|------------------------|--|--|
| 2                     | -0.317                 | 9.56                                       | 2.133  |
| 5                     | 0.788                  | 21.377                                     | 4.771  |
| 10                    | 1.526                  | 36.57                                      | 8.161  |
| 25                    | 2.441                  | 71.253                                     | 15.901                                       |
| 50                    | 3.077                  | 113.181                                    | 25.258                                       |
| 100                   | 3.701                  | 178.292                                    | 39.789                                       |
| 200                   | 4.323                  | 280.364                                    | 62.568                                       |

**Table E.9: Dependability for Nachipere River using the runoff method**

| Dependability                | Flow (m <sup>3</sup> /s) |
|------------------------------|--------------------------|
| 50% (equivalent to 183 days) | 0.357                    |
| 75% (equivalent to 274 days) | 0.217                    |
| 90% (equivalent to 328 days) | 0.088                    |
| 95% (equivalent to 347 days) | 0.050                    |
| 99%(equivalent to 361 days)  | 0.044                    |

**Table E.9: Monthly Mean flows for Nachipere River at Nkolokosa (1995-2004)**

| Nachipere at Nkolokosa |       |       | Catchment area: 21 km <sup>2</sup> |       |       |       | Station : 14 /14B9 |       |       |       |       |       |       |
|------------------------|-------|-------|------------------------------------|-------|-------|-------|--------------------|-------|-------|-------|-------|-------|-------|
|                        | Jan   | Feb   | Mar                                | Apr   | May   | Jun   | Jul                | Aug   | Sep   | Oct   | Nov   | Dec   | Mean  |
| 1995                   |       |       |                                    |       |       |       |                    |       |       |       | 0.183 | 1.397 | 0.79  |
| 1996                   | 1.173 | 1.181 | 1.351                              | 0.781 | 0.547 | 0.425 | 0.395              | 0.324 | 0.182 | 0.173 | 0.077 | 0.734 | 0.612 |
| 1997                   | 1.411 | 3.168 | 2.568                              | 1.914 | 1.067 | 0.768 | 0.853              | 0.54  | 0.422 | 0.306 | 0.289 | 0.733 | 1.17  |
| 1998                   | 1.826 | 2.1   | 1.232                              | 0.735 | 0.418 | 0.308 | 0.242              | 0.218 | 0.136 | 0.14  | 0.048 | 0.631 | 0.67  |
| 1999                   | 3.542 | 2.487 | 1.259                              | 2.123 | 0.925 | 0.797 | 0.543              | 0.341 | 0.235 |       | 0.26  | 0.179 | 1.154 |
| 2000                   | 0.414 | 1.511 | 1.187                              | 1.143 | 0.366 | 0.192 | 0.222              | 0.109 | 0.057 | 0.091 | 0.762 | 0.569 | 0.552 |
| 2001                   | 0.892 | 2.434 | 2.407                              | 1.004 | 0.587 | 0.394 | 0.267              | 0.179 | 0.102 | 0.059 | 0.052 | 0.438 | 0.735 |
| 2002                   | 1.827 | 1.254 | 0.865                              | 0.726 | 0.471 | 0.331 | 0.228              | 0.185 |       |       |       | 0.193 | 0.676 |
| 2003                   | 1.295 | 1.588 | 1.174                              | 0.778 | 0.379 | 0.259 | 0.288              |       |       |       |       |       | 0.823 |
| 2004                   | 0.346 | 0.419 | 0.427                              | 0.456 | 0.236 | 0.286 | 0.344              |       |       |       |       |       | 0.359 |
| Qmean                  | 1.414 | 1.794 | 1.386                              | 1.073 | 0.555 | 0.418 | 0.376              | 0.271 | 0.189 | 0.154 | 0.239 | 0.609 | 0.707 |
| Qmax                   | 3.542 | 3.168 | 2.568                              | 2.123 | 1.067 | 0.797 | 0.853              | 0.54  | 0.422 | 0.306 | 0.762 | 1.397 | 1.17  |
| Qmin                   | 0.346 | 0.419 | 0.427                              | 0.456 | 0.236 | 0.192 | 0.222              | 0.109 | 0.057 | 0.059 | 0.048 | 0.179 | 0.359 |
| Qmed                   | 1.295 | 1.588 | 1.232                              | 0.781 | 0.471 | 0.331 | 0.288              | 0.218 | 0.159 | 0.14  | 0.183 | 0.6   | 0.706 |
| St.Dev                 | 0.959 | 0.833 | 0.685                              | 0.571 | 0.273 | 0.218 | 0.206              | 0.144 | 0.13  | 0.096 | 0.251 | 0.386 | 0.252 |
| N.of years             | 9     | 9     | 9                                  | 9     | 9     | 9     | 9                  | 7     | 6     | 5     | 7     | 8     | 10    |

Table E.10: Flood Frequency Analysis for Nswazi and Nachipere Rivers using Log-Pearson Type III Analysis

| Water Year | Max Stream Flow (m <sup>3</sup> /s) | Rank | Water Year | Ranked Max Stream Flow | logQ                | (logQ-avg(logQ))^2 | (logQ-avg(logQ))^3 | Return Period<br>Tr = [(N+1)/M] | Exceedence Probability (1/Tr) |                      |
|------------|-------------------------------------|------|------------|------------------------|---------------------|--------------------|--------------------|---------------------------------|-------------------------------|----------------------|
|            |                                     |      |            | Q(m <sup>3</sup> /s)   | (m <sup>3</sup> /s) |                    |                    |                                 |                               |                      |
| 1996       | 14.947                              | 1    | 2002       | 30.956                 | 1.491               | 0.128              | 0.045984604        | 10                              | 0.1                           |                      |
| 1997       | 11.821                              | 2    | 2001       | 20.024                 | 1.302               | 0.029              | 0.004832878        | 5                               | 0.2                           |                      |
| 1998       | 14.385                              | 3    | 1999       | 18.508                 | 1.267               | 0.018              | 0.00245379         | 3.333                           | 0.3                           |                      |
| 1999       | 18.508                              | 4    | 2003       | 17.164                 | 1.235               | 0.010              | 0.001065536        | 2.5                             | 0.4                           |                      |
| 2000       | 15.402                              | 5    | 2000       | 15.402                 | 1.188               | 0.003              | 0.000167258        | 2                               | 0.5                           |                      |
| 2001       | 20.024                              | 6    | 1996       | 14.947                 | 1.175               | 0.002              | 7.44803E-05        | 1.666                           | 0.6                           |                      |
| 2002       | 30.956                              | 7    | 1998       | 14.385                 | 1.158               | 0.0006             | 1.64449E-05        | 1.428                           | 0.7                           |                      |
| 2003       | 17.164                              | 8    | 1997       | 11.821                 | 1.073               | 0.004              | -0.000214124       | 1.25                            | 0.8                           |                      |
| 2004       | 2.02                                | 9    | 2004       | 2.02                   | 0.305               | 0.684              | -0.56587331        | 1.111                           | 0.9                           |                      |
|            |                                     |      |            | Average                | Average             | Sum                | Sum                |                                 |                               |                      |
|            |                                     |      |            | 16.136                 | 1.132               | 0.879              | -0.511492443       |                                 |                               |                      |
|            |                                     |      |            |                        |                     |                    |                    |                                 |                               |                      |
|            |                                     |      |            |                        |                     | variance           | 0.109842111        |                                 |                               |                      |
|            |                                     |      |            |                        |                     | standard deviation | 0.331424366        |                                 |                               |                      |
|            |                                     |      |            |                        |                     | skew coefficient   | -2.258085598       |                                 |                               |                      |
|            |                                     |      |            |                        |                     |                    |                    |                                 |                               |                      |
|            |                                     |      |            |                        | Tr                  | K(-0.2)            | K(-0.3)            | slope                           | K(-2.2581)                    | Q(m <sup>3</sup> /s) |
|            |                                     |      |            |                        | 2                   | 0.033              | 0.05               | 0.17                            | -0.319                        | 9.55974              |
|            |                                     |      |            |                        | 5                   | 0.85               | 0.853              | 0.03                            | 0.788                         | 21.37737             |
|            |                                     |      |            |                        | 10                  | 1.258              | 1.245              | -0.13                           | 1.526                         | 36.57044             |
|            |                                     |      |            |                        | 25                  | 1.68               | 1.643              | -0.37                           | 2.441                         | 71.25328             |
|            |                                     |      |            |                        | 50                  | 1.945              | 1.89               | -0.55                           | 3.077                         | 113.181              |
|            |                                     |      |            |                        | 100                 | 2.178              | 2.104              | -0.74                           | 3.701                         | 178.2915             |
|            |                                     |      |            |                        | 200                 | 2.388              | 2.294              | -0.94                           | 4.323                         | 280.3644             |

**Table E.11: Thyolo monthly and seasonal rainfall totals in millimeters (1961-2006)**

|         | JUL.  | AUG. | SEP. | OCT.  | NOV.  | DEC.  | JAN.  | FEB.   | MAR.   | APR.  | MAY  | JUN. | SEASONAL |
|---------|-------|------|------|-------|-------|-------|-------|--------|--------|-------|------|------|----------|
| 1961/62 | 37.1  | 41.0 | 21.4 | 18.7  | 54.2  | 118.2 | 372.0 | 55.4   | 295.1  | 249.6 | 73.0 | 0.3  | 1336.0   |
| 1962/63 | 41.5  | 0.6  | 7.7  | 6.9   | 77.2  | 374.2 | 272.2 | 353.4  | 315.2  | 104.4 | 21.0 | 18.0 | 1592.3   |
| 1963/64 | 25.2  | 2.5  | 0.0  | 37.3  | 52.1  | 170.2 | 262.1 | 238.4  | 70.1   | 26.8  | 18.5 | 16.3 | 919.5    |
| 1964/65 | 71.3  | 29.2 | 1.8  | 1.3   | 50.4  | 358.1 | 278.0 | 136.9  | 375.4  | 55.9  | 42.4 | 21.5 | 1422.2   |
| 1965/66 | 2.3   | 8.0  | 14.4 | 55.7  | 70.1  | 222.9 | 97.2  | 332.8  | 123.3  | 84.8  | 13.8 | 52.5 | 1077.8   |
| 1966/67 | 23.6  | 6.4  | 12.5 | 15.8  | 45.0  | 172.9 | 204.7 | 110.7  | 301.4  | 111.7 | 28.4 | 23.7 | 1056.8   |
| 1967/68 | 58.8  | 21.2 | 17.9 | 17.0  | 77.6  | 166.6 | 162.7 | 205.5  | 133.3  | 138.6 | 13.8 | 21.1 | 1034.1   |
| 1968/69 | 6.6   | 18.0 | 1.6  | 12.0  | 105.6 | 343.5 | 270.5 | 150.4  | 168.5  | 201.7 | 25.1 | 32.9 | 1336.4   |
| 1969/70 | 22.2  | 25.7 | 4.1  | 12.9  | 28.0  | 636.3 | 124.6 | 103.6  | 99.5   | 76.4  | 7.4  | 19.6 | 1160.3   |
| 1970/71 | 20.8  | 2.0  | 0.0  | 76.9  | 195.8 | 300.4 | 327.5 | 99.0   | 102.7  | 8.6   | 68.8 | 20.6 | 1223.1   |
| 1971/72 | 21.3  | 0.0  | 2.8  | 8.2   | 225.3 | 182.6 | 316.6 | 194.3  | 132.0  | 72.5  | 20.4 | 36.9 | 1212.9   |
| 1972/73 | 13.3  | 18.1 | 4.4  | 10.3  | 100.5 | 111.7 | 242.6 | 1111.4 | 241.4  | 174.8 | 12.5 | 67.1 | 2108.1   |
| 1973/74 | 26.2  | 25.6 | 6.1  | 11.4  | 125.1 | 207.0 | 221.9 | 494.5  | 335.1  | 95.7  | 35.6 | 27.0 | 1611.2   |
| 1974/75 | 78.5  | 15.0 | 6.9  | 7.6   | 99.1  | 312.2 | 135.9 | 197.6  | 76.2   | 84.3  | 22.9 | 42.2 | 1078.4   |
| 1975/76 | 20.3  | 15.2 | 0.5  | 46.7  | 125.0 | 98.8  | 97.1  | 309.1  | 305.3  | 118.1 | 59.4 | 42.7 | 1238.2   |
| 1976/77 | 35.1  | 3.8  | 7.9  | 100.8 | 112.3 | 338.1 | 222.8 | 64.5   | 228.6  | 37.6  | 5.8  | 15.5 | 1172.8   |
| 1977/78 | 13.7  | 19.6 | 30.5 | 48.3  | 85.6  | 243.1 | 250.6 | 137.7  | 444.8  | 171.5 | 8.6  | 25.1 | 1479.1   |
| 1978/79 | 40.4  | 0.0  | 4.6  | 67.1  | 77.2  | 316.2 | 141.7 | 144.8  | 351.3  | 37.3  | 6.6  | 62.7 | 1249.9   |
| 1979/80 | 70.9  | 6.9  | 16.5 | 14.5  | 116.3 | 170.7 | 80.6  | 82.3   | 121.2  | 115.1 | 40.1 | 38.1 | 873.2    |
| 1980/81 | 25.9  | 15.7 | 18.7 | 65.7  | 25.2  | 289.9 | 209.0 | 343.8  | 1563.8 | 94.6  | 32.3 | 16.8 | 2701.4   |
| 1981/82 | 38.1  | 3.6  | 16.9 | 73.5  | 108.2 | 186.5 | 222.7 | 185.5  | 103.5  | 58.9  | 28.8 | 14.5 | 1040.7   |
| 1982/83 | 104.9 | 25.1 | 30.0 | 137.3 | 54.9  | 150.1 | 107.9 | 224.7  | 105.0  | 6.4   | 50.5 | 16.4 | 1013.2   |
| 1983/84 | 53.4  | 11.0 | 0.0  | 27.3  | 72.9  | 173.2 | 83.8  | 294.8  | 428.9  | 96.1  | 36.5 | 20.7 | 1298.6   |
| 1984/85 | 1.7   | 13.7 | 5.6  | 42.3  | 201.6 | 324.6 | 346.8 | 264.2  | 300.1  | 192.7 | 10.1 | 17.3 | 1720.7   |
| 1985/86 | 10.9  | 21.5 | 13.7 | 36.7  | 127.3 | 296.2 | 366.8 | 331.0  | 149.2  | 136.1 | 10.9 | 54.1 | 1554.4   |

|         |       |      |      |       |       |       |       |        |        |       |      |      |        |
|---------|-------|------|------|-------|-------|-------|-------|--------|--------|-------|------|------|--------|
| 1986/87 | 21.3  | 0.0  | 11.0 | 104.3 | 246.8 | 231.4 | 285.7 | 83.2   | 47.2   | 29.7  | 15.9 | 36.2 | 1112.7 |
| 1987/88 | 2.9   | 0.0  | 6.8  | 76.1  | 36.9  | 355.9 | 228.4 | 332.7  | 103.9  | 133.6 | 64.8 | 52.1 | 1394.1 |
| 1988/89 | 13.7  | 20.4 | 0.0  | 72.6  | 115.1 | 77.6  | 241.9 | 528.2  | 481.5  | 55.4  | 9.9  | 21.3 | 1637.6 |
| 1989/90 | 13.2  | 25.1 | 13.4 | 76.4  | 80.6  | 172.3 | 214.7 | 120.3  | 177.7  | 77.4  | 76.7 | 32.4 | 1080.2 |
| 1990/91 | 17.7  | 23.1 | 78.3 | 1.0   | 56.7  | 95.3  | 150.2 | 120.3  | 279.8  | 52.1  | 7.6  | 15.3 | 897.4  |
| 1991/92 | 35.6  | 21.6 | 12.6 | 23.2  | 162.1 | 155.2 | 139.2 | 9.4    | 103.4  | 28.2  | 11.9 | 34.5 | 736.9  |
| 1992/93 | 20.9  | 28.4 | 0.0  | 0.0   | 95.2  | 150.7 | 466.3 | 334.0  | 80.6   | 57.0  | 11.6 | 40.3 | 1285.0 |
| 1993/94 | 27.8  | 19.2 | 1.6  | 19.8  | 68.2  | 54.4  | 341.7 | 68.0   | 111.7  | 27.8  | 7.7  | 18.9 | 766.8  |
| 1994/95 | 23.7  | 7.7  | 12.4 | 82.8  | 14.9  | 118.2 | 323.3 | 234.0  | 46.5   | 34.4  | 42.2 | 29.1 | 969.2  |
| 1995/96 | 17.4  | 1.1  | 0.0  | 4.2   | 48.5  | 401.4 | 300.7 | 250.5  | 286.0  | 83.0  | 88.0 | 35.9 | 1516.7 |
| 1996/97 | 43.6  | 6.2  | 28.2 | 8.6   | 93.6  | 264.0 | 382.9 | 372.5  | 281.9  | 177.8 | 7.3  | 3.0  | 1669.6 |
| 1997/98 | 88.5  | 17.2 | 18.9 | 24.9  | 108.6 | 284.7 | 337.4 | 233.7  | 228.0  | 39.8  | 1.4  | 16.5 | 1399.6 |
| 1998/99 | 15.7  | 17.0 | 2.6  | 15.7  | 64.4  | 304.3 | 575.1 | 311.8  | 332.2  | 169.4 | 14.3 | 27.2 | 1849.7 |
| 1999/00 | 40.1  | 3.4  | 70.7 | 9.3   | 86.9  | 156.1 | 284.4 | 297.9  | 88.1   | 85.2  | 29.0 | 15.9 | 1167.0 |
| 2000/01 | 33.0  | 15.2 | 0.0  | 7.3   | 205.7 | 134.4 | 226.3 | 510.2  | 241.4  | 54.5  | 33.2 | 12.1 | 1473.3 |
| 2001/02 | 28.9  | 26.2 | 17.1 | 5.1   | 58.9  | 614.1 | 382.9 | 286.2  | 167.6  | 169.8 | 35.4 | 33.0 | 1825.2 |
| 2002/03 | 22.7  | 18.4 | 4.6  | 37.3  | 53.3  | 103.7 | 463.7 | 167.9  | 233.7  | 26.8  | 22.8 | 36.5 | 1191.4 |
| 2003/04 | 49.3  | 15.1 | 7.6  | 6.0   | 80.2  | 66.6  | 127.8 | 165.1  | 111.9  | 138.2 | 59.2 | 39.6 | 866.6  |
| 2004/05 | 27.1  | 23.1 | 6.5  | 37.0  | 177.1 | 469.3 | 160.6 | 71.5   | 66.8   | 29.7  | 29.0 | 7.9  | 1105.6 |
| 2005/06 | 32.9  | 0.0  | 25.0 | 20.8  | 57.6  | 275.7 | 351.2 | 208.7  | 314.6  | 96.5  | 11.1 | 13.1 | 1407.2 |
|         |       |      |      |       |       |       |       |        |        |       |      |      |        |
| Mean    | 32.0  | 14.2 | 12.5 | 35.2  | 96.1  | 238.9 | 253.4 | 241.6  | 236.8  | 91.5  | 28.3 | 27.7 | 1308.1 |
| Max     | 104.9 | 41.0 | 78.3 | 137.3 | 246.8 | 636.3 | 575.1 | 1111.4 | 1563.8 | 249.6 | 88.0 | 67.1 | 2701.4 |
| Min     | 1.7   | 0.0  | 0.0  | 0.0   | 14.9  | 54.4  | 80.6  | 9.4    | 46.5   | 6.4   | 1.4  | 0.3  | 736.9  |

Source: Meteorological Services Department, 2007

## Annex F

## Results of the energy demand study

Table F.1: Demand for Electricity in Nkolokosa Village

| Electrical Appliance | Category |            | Power Consumption (W) | Nos. | Control Factor | Demand Factor | Peak Demand (kW) |             |
|----------------------|----------|------------|-----------------------|------|----------------|---------------|------------------|-------------|
|                      | Day load | Night load |                       |      |                |               | Day              | Night       |
| IL60                 |          | √          | 60                    | 1092 | 0.5            | 0.9           |                  | 29.5        |
| IL75                 | √        | √          | 75                    | 340  | 0.3            | 0.9           |                  | 11.5        |
| IL100                | √        | √          | 100                   | 16   | 0.3            | 0.9           |                  | 0.4         |
| Refrigerator         | √        | √          | 100                   | 8    | 0.3            | 0.2           | 0.05             | 0.05        |
| Electric Fan         | √        | √          | 60                    | 8    | 0.5            | 0.2           | 0.05             | 0.05        |
| Electric iron        | √        | √          | 750                   | 8    | 0.5            | 0.2           | 0.6              | 0.6         |
| Hot plate            | √        | √          | 1000                  | 178  | 0.3            | 0.3           | 16               | 16          |
| VCR/TV               | √        | √          | 100                   | 178  | 0.5            | 0.8           | 7.1              | 7.1         |
| Radio                | √        | √          | 15                    | 457  | 0.5            | 0.2           | 0.7              | 0.7         |
| Workshop             | √        |            | 11950                 | 2    | 1              | 0.2           | 4.8              |             |
| Maize mill           | √        |            | 20000                 | 1    | 1              | 0.2           | 4.0              |             |
| Shops                | √        |            | 2000                  | 3    | 1              | 0.8           | 4.8              |             |
| Egg Incubator        | √        | √          | 1000                  | 8    | 1              | 0.9           | 0.7              | 0.7         |
| Battery charger      | √        |            | 15                    | 15   | 1              | 0.9           | 0.2              |             |
| Electric Kettle      | √        |            | 2400                  | 8    | 0.3            | 0.1           | 0.6              | 0.6         |
| Barber machine       | √        |            | 75                    | 12   | 1              | 0.9           | 0.8              |             |
| DVD Player           | √        |            | 15                    | 8    | 0.5            | 0.2           | 0.01             | 0.01        |
| <b>Total</b>         |          |            |                       |      |                |               | <b>40.4</b>      | <b>67.2</b> |

Table F.2 Typical Poor Households Characteristics

| Electrical Appliance | Number | Capacity (W) | Daily Hours of operation (h/d) | Daily Electricity Consumption (kWh/d) | Annual Consumption (kWh/a) |
|----------------------|--------|--------------|--------------------------------|---------------------------------------|----------------------------|
| Light bulb           | 2      | 60           | 3                              | 0.36                                  | 131.4                      |
| Security bulb        | 1      | 100          | 2                              | 0.2                                   | 73                         |
| Radio cassette       | 1      | 15           | 3                              | 0.1                                   | 16.4                       |
| Total                |        | 175          |                                | 0.66                                  | 220.8                      |

Table F.3 Near - Poor Households Characteristics

| Electrical Appliance | Number | Capacity (W) | Daily Hours of operation (h/d) | Daily Electricity Consumption (kWh/d) | Annual Consumption (kWh/a) |
|----------------------|--------|--------------|--------------------------------|---------------------------------------|----------------------------|
| Light bulb           | 3      | 60           | 5                              | 0.9                                   | 328.5                      |
| Security bulb        | 2      | 75           | 3                              | 0.75                                  | 273.8                      |
| Radio cassette       | 1      | 15           | 3                              | 0.1                                   | 16.4                       |
| Hot plate            | 1      | 1000         | 1.5                            | 5                                     | 547.5                      |
| TV/VCR               | 1      | 100          | 3                              | 0.3                                   | 109.5                      |
| Total                |        | 450          |                                | 3.6                                   | 1,275.7                    |

Table F.4 Affluent Household Characteristics

| Electrical Appliance | Number | Capacity (W) | Daily Hours of operation (h/d) | Daily Electricity Consumption (kWh/d) | Annual Consumption (kWh/a) |
|----------------------|--------|--------------|--------------------------------|---------------------------------------|----------------------------|
| Light bulb           | 3      | 60           | 5                              | 0.9                                   | 328.5                      |
| Security bulb        | 2      | 100          | 10                             | 2.0                                   | 730                        |
| Refrigerator         | 1      | 100          | 11.3                           | 1.13                                  | 412.5                      |
| Kettle               | 1      | 1500         | 0.45                           | 0.675                                 | 246.4                      |
| Electric fan         | 1      | 60           | 2.7                            | 0.162                                 | 59.13                      |
| Hot plate            | 1      | 1000         | 1.5                            | 1.5                                   | 547.5                      |
| DVD Player           | 1      | 15           | 3                              | 0.045                                 | 16.4                       |
| VCR/TV               | 1      | 100          | 4                              | 0.4                                   | 146                        |
| Electric iron        | 1      | 750          | 0.48                           | 0.36                                  | 131.4                      |
| Radio cassette       | 1      | 15           | 2.5                            | 0.04                                  | 13.7                       |
| Total                |        | 3,920        |                                | 7.21                                  | 2,631.5                    |

**Table F.5: Peak demand for various household sizes**

| Type of Households | Number | Unit        | Peak Demand (kW) |
|--------------------|--------|-------------|------------------|
| Poor               | 279    | Table 6.3.2 | 48.83            |
| Near poor          | 170    | Table 6.3.3 | 63.00            |
| Affluent           | 8      | Table 6.3.4 | 31.36            |
| Total              | 457    |             | 143.19           |

**Table F.6: Demand Forecast of Public Facilities**

| Facilities       | Consumption Power of Electric Appliances (kW) |     |          |                    |     |        |     |       |
|------------------|---|-----|----------|--------------------|-----|--------|-----|-------|
|                  | FL<br>Light                                   | TV  | Computer | Battery<br>charger | VCR | Barber | Fan | Total |
| Library          | 2.0   | NA  | NA       | NA                 | NA  | NA     | NA  | 2.00  |
| Subtotal (kW)    | 2.0   | NA  | NA       | NA                 | NA  | NA     | NA  | 2.00  |
| Control factor   | 0.7   | 0.7 | 0.8      | 0.3                | 0.3 | 0.5    | 0.8 | -     |
| Demand factor    | 0.9   | 0.8 | 0.2      | 0.2                | 0.8 | 0.2    | 0.2 | -     |
| Peak demand (kW) | 1.26  | NA  | NA       | NA                 | NA  | NA     | NA  | 1.26  |

**Table F.7: Demand Forecast of Groceries, and Small shops in Nkolokosa**

| Facilities       | Consumption Power of Electric Appliances (kW) |      |      |              |      |       | Total |
|------------------|---|------|------|--------------|------|-------|-------|
|                  | Light   | TV   | Fan  | Refrigerator | VCR  | Radio |       |
| Small shops      | 0.54  | 0.3  | 0.3  | 0.45         | 0.3  | 0.15  | 2.04  |
| Subtotal (kW)    | 0.54  | 0.3  | 0.3  | 0.45         | 0.3  | 0.15  | 2.04  |
| Control factor   | 0.7   | 0.5  | 0.8  | 0.3          | 0.5  | 0.5   |       |
| Demand factor    | 0.9   | 0.8  | 0.2  | 0.2          | 0.8  | 0.2   |       |
| Peak demand (kW) | 0.34  | 0.12 | 0.05 | 0.03         | 0.12 | 0.02  | 0.68  |

**Table F.8: Demand Forecast for Rural Industries**

| Power consumption of electric appliances (kW) |                 |        |                |              |            |       |
|---|-----------------|--------|----------------|--------------|------------|-------|
|   | Battery charger | Barber | Carpentry shop | Welding shop | Maize mill | Total |
| Light industry                                | 0.225           | 0.225  | 11.95          | -            | 20         | 51.98 |
| Subtotal (kW)                                 | 0.225           | 0.225  | 11.95          | -            | 20         | 51.98 |
| Control factor                                | 0.3             | 0.5    | 1              | 1            | 1          |       |
| Demand factor                                 | 0.2             | 0.2    | 0.2            | 0.2          | 0.2        |       |
| Peak Demand (kW)                              | 0.01            | 0.02   | 2.4            | -            | 4.0        | 6.43  |

**Table F.9: Forecast Demand of Nkolokosa**

| Consumers           | Number of consumers | Peak Demand (kW) |              | Reference |
|---------------------|---------------------|------------------|--------------|-----------|
|                     |                     | Unit Demand      | Total Demand |           |
| Households          | 457                 | 1.1              | 143.19       | Table F.5 |
| Public facilities   | 1                   | 1.1              | 1.26         | Table F.6 |
| Groceries and shops | 5                   | 0.2              | 0.68         | Table F.7 |
| Rural industries    | 4                   | 2.3              | 6.43         | Table F.8 |
| Total               |                     |                  | 151.56       |           |

**Table F.10: Forecasted Peak loads for Nkolokosa**

| Year | Number of households | Number of shops | Number of maize mills | Village peak load without shops and mills | Shops | Maize mills peak load(kW) | Village peak load (kW) |
|------|----------------------|-----------------|-----------------------|---|-------|---------------------------|------------------------|
| 2007 | 457                  | 1               | 1                     | 176.4                                     | 6.43  | 20                        | 202.83                 |
| 2012 | 487                  | 2               | 1                     | 423.476                                   | 6.76  | 20                        | 450.236                |
| 2017 | 519                  | 3               | 1                     | 451.38                                    | 7.1   | 20                        | 478.48                 |
| 2022 | 553                  | 4               | 1                     | 481.028                                   | 7.46  | 20                        | 508.488                |
| 2027 | 590                  | 4               | 2                     | 513.292                                   | 7.84  | 40                        | 561.132                |
| 2032 | 629                  | 5               | 2                     | 547.3                                     | 8.24  | 40                        | 595.54                 |

Table F.11: Nkolokosa power and energy forecast BEPP2 scenario

| Annual growth rate              | 0.60%      | Domestic        | 85 kWh/yr            | Yearly growth rate   | 1.21%               |            |                 |                    |                      |
|---------------------------------|------------|-----------------|----------------------|----------------------|---------------------|------------|-----------------|--------------------|----------------------|
| Number of persons per household | 5.3        | Commercial      | 50 kWh/yr            |                      | 2.00%               |            |                 |                    |                      |
| Initial penetration rate        | 10%        | Agro-industrial | 150 kWh/yr           |                      | 0.50%               |            |                 |                    |                      |
| Yearly growth of penetration    | 2%         | Load factor     | 30%                  |                      |                     |            |                 |                    |                      |
| Maximum penetration             | 50%        | Peak factor     | 3.3                  |                      |                     |            |                 |                    |                      |
| Year                            | Population | Households      | Penetration rate (%) | Households connected | Energy Demand (kWh) |            |                 | Total energy (kWh) | Capacity demand (kW) |
|                                 |            |                 |                      |                      | Domestic            | Commercial | Agro-industrial |                    |                      |
| 2007                            | 2,758      | 520             | 10                   | 52                   | 4,420               | 2,600      | 7,800           | 14,820             | 6                    |
| 2008                            | 2,775      | 524             | 12                   | 63                   | 5,409               | 3,207      | 9,479           | 18,095             | 7                    |
| 2009                            | 2,792      | 527             | 14                   | 74                   | 6,424               | 3,838      | 11,178          | 21,440             | 8                    |
| 2010                            | 2,809      | 530             | 16                   | 85                   | 7,473               | 4,500      | 12,912          | 24,885             | 9                    |
| 2011                            | 2,826      | 533             | 18                   | 96                   | 8,557               | 5,192      | 14,681          | 28,430             | 11                   |
| 2012                            | 2,843      | 536             | 20                   | 107                  | 9,677               | 5,918      | 16,486          | 32,081             | 12                   |
| 2013                            | 2,860      | 540             | 22                   | 119                  | 10,854              | 6,689      | 18,361          | 35,904             | 14                   |
| 2014                            | 2,877      | 543             | 24                   | 130                  | 12,050              | 7,485      | 20,243          | 39,778             | 15                   |
| 2015                            | 2,894      | 546             | 26                   | 142                  | 13,285              | 8,316      | 22,161          | 43,762             | 17                   |
| 2016                            | 2,911      | 549             | 28                   | 154                  | 14,560              | 9,185      | 24,117          | 47,862             | 18                   |
| 2017                            | 2,928      | 552             | 30                   | 166                  | 15,875              | 10,093     | 26,110          | 52,078             | 20                   |
| 2018                            | 2,946      | 556             | 32                   | 178                  | 17,262              | 11,061     | 28,193          | 56,516             | 22                   |
| 2019                            | 2,964      | 559             | 34                   | 190                  | 18,663              | 12,052     | 30,267          | 60,982             | 23                   |
| 2020                            | 2,982      | 563             | 36                   | 203                  | 20,143              | 13,109     | 32,439          | 65,691             | 25                   |
| 2021                            | 3,000      | 566             | 38                   | 215                  | 21,635              | 14,190     | 34,595          | 70,420             | 27                   |
| 2022                            | 3,018      | 569             | 40                   | 228                  | 23,171              | 15,316     | 36,792          | 75,279             | 29                   |
| 2023                            | 3,036      | 573             | 42                   | 241                  | 24,797              | 16,519     | 39,098          | 80,414             | 31                   |
| 2024                            | 3,054      | 576             | 44                   | 253                  | 26,430              | 17,744     | 41,380          | 85,554             | 33                   |
| 2025                            | 3,072      | 580             | 46                   | 267                  | 28,160              | 19,053     | 43,779          | 90,992             | 35                   |
| 2026                            | 3,090      | 583             | 48                   | 280                  | 29,893              | 20,384     | 46,148          | 96,425             | 37                   |
| 2027                            | 3,109      | 587             | 50                   | 294                  | 31,732              | 21,806     | 48,643          | 102,181            | 39                   |

**Annex G**  
**Results of economic analysis**

**Table G.1: General assumptions**

| Parameter                       | Unit      | Hydro | Diesel |
|---------------------------------|-----------|-------|--------|
| <b>Technical data:</b>          |           |       |        |
| Annual operating hours          | hrs       | 5610  | 3000   |
| Installed capacity              | kW        | 40    | 160    |
| Load factor                     | %         | 50    | 30     |
| Design efficiency               | %         | 35    | 30     |
| Service life                    | years     | 35    | 15     |
| <b>Financial data:</b>          |           |       |        |
| Discount rate (real)            | %         | 12    | 6      |
| Escalation rate (real)          | %         | 10    | 10     |
| Residual value                  | %         | 10    | 10     |
| Exchange rates (September,2007) | MWK       | 145   | 145    |
| Operation and maintenance costs | %         | 1.5   | 5      |
| Fuel cost                       | MWK/litre | -     | 250    |

**Table G.2: Summary of costs for Nkolokosa Hydropower Scheme**

| Item | Description                     | Amount (MWK)        | Remarks     |
|------|---------------------------------|---------------------|-------------|
| 1    | Intake structures               | 3,396,449.3         |             |
| 2    | Power canal and desilting basin | 2,214,450           |             |
| 3    | Fore bay and spillway           | 1,707,000           |             |
| 4    | Penstock                        | 422,500             | 2007 prices |
| 5    | Power and tail race             | 1,833,250           |             |
|      | <b>Total</b>                    | <b>9,573,649.30</b> |             |
| 6    | Turbine and generator           | 15,194,051.65       |             |
| 7    | Hydro mechanical components     | 800,000             |             |