Evaluating opportunities for sustainable rural water provision using solar PV in sub-Saharan Africa: a case study of Malawi

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Evaluating opportunities for sustainable rural water provision using solar PV in Sub-Saharan Africa: A case study of Malawi

by

Esther Phiri

Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of

Doctor of Philosophy of Loughborough University
November 2017

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To the memory of my late parents,

To my nieces and nephews: it is never too late to start over!

and

To God who sets the times and the seasons and to whom I am grateful!
Abstract

Globally, approximately 663 million people lack access to safe drinking water sources and nearly half of these people live in Sub-Saharan Africa (SSA), where only 68% of the population has access to improved drinking water sources. Globally, it is estimated that 79% of the people using unimproved sources and 93% of people using surface water live in rural areas. In terms of water for agriculture, most of the countries in Sub-Saharan Africa rely on rain-fed agriculture, which is threatened by the effects of climate change thereby worsening food insecurity. Adequate provision of drinking and irrigation water is believed to enhance development in areas such as health, education, food security and women empowerment.

This interdisciplinary study used a mixed methods approach to develop a financing and decision support model for planning and analysing of sustainable rural water provision using solar photovoltaics (PV) in SSA, with Malawi as a case study country. The research methods included household surveys, stakeholder interviews, field visits and techno-economic analysis.

Findings from the household surveys show that the current water sources are inadequate; the majority of the households used boreholes as their main source of water and they faced challenges, which included queuing, low yield, non-functionality, disparity in number of water points, theft and vandalism. For irrigation, households still rely on traditional methods of irrigation namely; watering cans with very few having treadle pumps, which are all labour intensive. From the stakeholders' point of view, challenges included lack of finances, failure of current community management system, lack of coordination and lack of enabling policies.

In the techno-economic analysis, a solar PV system was designed to supply approximately 200 households with drinking water. The design cost was calculated to be US$18,600 and the levelized cost of water was US$0.34/m³. The levelized cost was found to be almost six times what the households are currently paying and three times what they are willing to pay. To address this issue, the study developed a cross-subsidy model for the cost of water with that of basic energy services, particularly rechargeable lantern lighting and mobile phone charging. Using this model, the levelized cost of water was reduced by over half but is still two and a half times what they are currently paying for water. Further innovations were found to reduce the breakeven cost to only US$0.06 more of what they are currently paying.

The novelty of the research is that no work in SSA, particularly in Malawi has developed such an all-inclusive integrated needs-driven approach that helps identify solar PV powered water provision solutions. These results provide baseline data for researchers, policymakers, planners, entrepreneurs and other stakeholders with interest in providing water and energy to
the rural areas. This thesis recommends that with proper finance and management policies, enforcement of product and installation standards and training of households, solar PV can be used to improve access for drinking and irrigation water and at the same time provide basic energy services to the people living in the rural areas of SSA.

Keywords: solar PV, water-pumping system, techno-economic analysis, levelized cost of water, Malawi, Sub-Saharan Africa
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I thank my research assistants (Christina, Ida, Ignatius, Jacqueline, and Jambo) for collecting data and the memorable experiences in the field; all interviewees (stakeholders, village heads and households) for providing the data and the Health Surveillance Assistants for guiding us to the villages. Further, I thank the following colleagues: Save, Kondwani and Khumbo for their assistance in the household survey logistics and introduction to statistical analyses; Angela, Evans, Faggie, Jeremy, Michael and Timothy for reviewing portions of my draft thesis; and to Collen and Sibel for making my stay in Loughborough stress-free.

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# Table of Contents

Abstract ........................................................................................................................................ vi
Acknowledgments ..................................................................................................................... vii
Table of Contents ....................................................................................................................... viii
Table of Figures ........................................................................................................................ xvi
List of Tables ............................................................................................................................. xix
Abbreviations ........................................................................................................................... xxi

1 Introduction ............................................................................................................................. 22
   1.1 Chapter outline ................................................................................................................ 22

   1.2 Research background .................................................................................................... 22

   1.3 Significance of the research ........................................................................................... 23

   1.4 Aim of the study ............................................................................................................ 26

       1.4.1 Specific objectives .................................................................................................. 26

   1.5 Thesis outline ................................................................................................................ 27

2 Literature Review on Sustainable Development, Energy, and Water ............................. 30
   2.1 Introduction .................................................................................................................... 30

   2.2 Sustainable development and the development goals .................................................. 30

   2.3 Role of water and energy in the MDGs ....................................................................... 35

   2.4 Sustainable livelihoods framework .............................................................................. 39

   2.5 Malawi water overview ............................................................................................... 41

       2.5.1 Water policy in Malawi ......................................................................................... 41

       2.5.2 Stakeholders in the rural areas water supply sector ............................................ 42

       2.5.3 Water resources of Malawi ................................................................................ 42

       2.5.4 Water abstraction methods ................................................................................ 48

       2.5.5 Water quality in Malawi ...................................................................................... 50

       2.5.6 Management and sustainability of rural water supplies .................................... 51
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.7</td>
<td>Water for agriculture</td>
<td>54</td>
</tr>
<tr>
<td>2.6</td>
<td>Water pumping using RETs</td>
<td>56</td>
</tr>
<tr>
<td>2.6.1</td>
<td>Energy overview</td>
<td>56</td>
</tr>
<tr>
<td>2.6.2</td>
<td>Malawi energy overview</td>
<td>57</td>
</tr>
<tr>
<td>2.6.3</td>
<td>Water pumping using Solar PV</td>
<td>59</td>
</tr>
<tr>
<td>2.6.4</td>
<td>Techno-economic feasibility studies</td>
<td>62</td>
</tr>
<tr>
<td>2.6.5</td>
<td>Sensitivity analysis</td>
<td>66</td>
</tr>
<tr>
<td>2.7</td>
<td>Willingness to pay for water</td>
<td>67</td>
</tr>
<tr>
<td>2.7.1</td>
<td>Willingness and ability to pay</td>
<td>67</td>
</tr>
<tr>
<td>2.7.2</td>
<td>Contingency valuation method</td>
<td>67</td>
</tr>
<tr>
<td>2.7.3</td>
<td>Determinants of willingness to pay for water</td>
<td>68</td>
</tr>
<tr>
<td>2.8</td>
<td>Chapter summary</td>
<td>71</td>
</tr>
<tr>
<td>3</td>
<td>Research Methodology and Design</td>
<td>73</td>
</tr>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>73</td>
</tr>
<tr>
<td>3.2</td>
<td>Overview of research setting</td>
<td>73</td>
</tr>
<tr>
<td>3.3</td>
<td>Research design</td>
<td>76</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Household survey</td>
<td>79</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Stakeholder interviews</td>
<td>85</td>
</tr>
<tr>
<td>3.3.3</td>
<td>Focus group discussions</td>
<td>86</td>
</tr>
<tr>
<td>3.3.4</td>
<td>Observations</td>
<td>86</td>
</tr>
<tr>
<td>3.4</td>
<td>Data analysis</td>
<td>87</td>
</tr>
<tr>
<td>3.4.1</td>
<td>Household survey data analysis</td>
<td>87</td>
</tr>
<tr>
<td>3.4.2</td>
<td>Qualitative data analysis</td>
<td>89</td>
</tr>
<tr>
<td>3.5</td>
<td>Ethical considerations</td>
<td>90</td>
</tr>
</tbody>
</table>

ix
3.6 Limitations ......................................................................................................................... 91
3.7.1 Introduction .................................................................................................................. 92
3.7.2 System design ............................................................................................................... 93
3.7.3 Economic analysis ......................................................................................................... 94
3.7.4 Cross-subsidising the cost of water ............................................................................... 95
3.8 Chapter summary .............................................................................................................. 95
4 Household Water and Energy Needs Analysis .................................................................. 96
4.1 Introduction ...................................................................................................................... 96
4.2 Demographic and socio-economic characteristics of respondents ............................. 96
  4.2.1 Household size ............................................................................................................ 97
  4.2.2 Gender and marital status of head of household .......................................................... 99
  4.2.3 Educational qualification ............................................................................................ 99
  4.2.4 Main occupation ......................................................................................................... 100
  4.2.5 Income ....................................................................................................................... 101
4.3 Drinking water access ...................................................................................................... 104
  4.3.1 Main source of drinking water ..................................................................................... 104
  4.3.2 Who funded the water source? ..................................................................................... 106
  4.3.3 Who collects water? .................................................................................................... 106
  4.3.4 Time taken to collect water ......................................................................................... 107
  4.3.5 Water quantity, storage and household management ............................................... 109
  4.3.6 Management of water points ...................................................................................... 110
4.4 Challenges associated with water provision .................................................................... 111
  4.4.1 Queuing and low yield ............................................................................................... 111
  4.4.2 Distance ..................................................................................................................... 113
5.2.3 Step 3: Determination of the hydraulic equivalent energy ...................... 136
5.2.4 Step 4: Determination of solar irradiation ........................................... 137
5.2.5 Step 5: Determination of the pump size .............................................. 140
5.2.6 Step 6: Determination of solar array size ........................................... 141
5.3 Economic analysis ................................................................................. 141
5.3.1 Payback period .................................................................................... 141
5.3.2 Life cycle cost analysis ........................................................................ 142
5.3.3 Sensitivity analysis ............................................................................... 144
5.4 Results .................................................................................................... 145
5.4.1 Input parameters .................................................................................. 145
5.4.2 System costs ......................................................................................... 145
5.4.3 Quantity of water pumped ..................................................................... 148
5.4.4 Cost of water ......................................................................................... 148
5.4.5 Sensitivity analysis results ..................................................................... 150
5.4.6 Payback period and comparison of LCW with WTP ............................. 151
5.4.7 Cross-subsidising cost of water ............................................................. 153
5.5 Discussion and chapter summary ............................................................. 156

6 Findings from Stakeholder Interviews .......................................................... 158
6.1 Introduction ............................................................................................... 158
6.2 Stakeholders identification, roles and responsibilities ............................. 158
6.3 Emerging themes ....................................................................................... 162
6.3.1 Institutional, policy and regulatory issues ............................................ 162
6.3.2 Economic issues .................................................................................... 172
6.3.3 Technical issues ..................................................................................... 177
6.4 Drinking water case study: Water Mission ......................................................... 183
   6.4.1 Introduction to Water Mission ...................................................................... 183
   6.4.2 Why solar PV? ............................................................................................... 183
   6.4.3 Stakeholder roles and responsibilities .......................................................... 184
   6.4.4 Water Mission’s project life cycle of drinking water system .................... 185
   6.4.5 Operation stage.............................................................................................. 188
6.5 Water for irrigation case study: Tiyanjane Irrigation Scheme .................. 188
   6.5.1 Background to Tiyanjane Irrigation Scheme ................................................ 188
   6.5.2 System description ....................................................................................... 189
   6.5.3 Management of system ................................................................................ 190
   6.5.4 Benefits of system ....................................................................................... 191
   6.5.5 Challenges faced............................................................................................ 192
6.6 Chapter summary and discussion ................................................................. 193
7 Summary and Discussion of Findings .............................................................. 198
   7.1 Introduction ...................................................................................................... 198
   7.2 Summary of findings ....................................................................................... 198
      7.2.1 Households needs analysis ........................................................................ 198
      7.2.2 Water and energy access .......................................................................... 200
      7.2.3 Levelised cost of water .............................................................................. 202
      7.2.4 Meeting the cost of water ......................................................................... 203
      7.2.5 Stakeholders analysis and challenges of rural water provision ............ 204
   7.3 Applying the sustainable livelihoods framework ........................................... 205
      7.3.1 Vulnerability context .................................................................................. 206
      7.3.2 Livelihood assets ....................................................................................... 206
Appendix 7: Study results displayed on the SLF chart........................................... 239

Appendix 8: Publications & Presentations ................................................................. 240

References.................................................................................................................... 241
# Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Global MDGs target achievement of drinking water</td>
<td>23</td>
</tr>
<tr>
<td>1.2</td>
<td>Number and share of people without access to electricity by country, 2012</td>
<td>25</td>
</tr>
<tr>
<td>1.3</td>
<td>Thesis research structure</td>
<td>28</td>
</tr>
<tr>
<td>2.1</td>
<td>Illustration of the 17 sustainable development goals</td>
<td>32</td>
</tr>
<tr>
<td>2.2</td>
<td>Maslow’s hierarchy of needs</td>
<td>33</td>
</tr>
<tr>
<td>2.3</td>
<td>Relationship between water, KPAs, and subthemes</td>
<td>34</td>
</tr>
<tr>
<td>2.4</td>
<td>Potential benefits of water in the MDGs</td>
<td>36</td>
</tr>
<tr>
<td>2.5</td>
<td>Sustainable livelihood framework</td>
<td>39</td>
</tr>
<tr>
<td>2.6</td>
<td>Water resource areas and outline of the geology of Malawi</td>
<td>44</td>
</tr>
<tr>
<td>2.7</td>
<td>Correlation of rainfall with relief</td>
<td>45</td>
</tr>
<tr>
<td>2.8</td>
<td>Depth to groundwater map</td>
<td>47</td>
</tr>
<tr>
<td>2.9</td>
<td>Examples of handpumps used in Malawi</td>
<td>49</td>
</tr>
<tr>
<td>2.10</td>
<td>Distribution of water points in Chiradzulu District</td>
<td>52</td>
</tr>
<tr>
<td>2.11</td>
<td>New headlines about the extent of hunger in Malawi</td>
<td>55</td>
</tr>
<tr>
<td>2.12</td>
<td>Energy mix projection for Malawi 2000 – 2035</td>
<td>58</td>
</tr>
<tr>
<td>2.13</td>
<td>Schematic of a direct coupled SWPS with MPPT</td>
<td>60</td>
</tr>
<tr>
<td>2.14</td>
<td>Block diagram of a SWPS with solar battery storage</td>
<td>61</td>
</tr>
<tr>
<td>2.15</td>
<td>Block diagram of a direct coupled SWPS</td>
<td>61</td>
</tr>
<tr>
<td>2.16</td>
<td>Block diagram of an AC SWPS</td>
<td>62</td>
</tr>
<tr>
<td>3.1</td>
<td>Administrative Map of Malawi showing location of Chiradzulu District</td>
<td>75</td>
</tr>
<tr>
<td>3.2</td>
<td>Schematic representation of the methodology employed in this research</td>
<td>76</td>
</tr>
<tr>
<td>3.3</td>
<td>Map of Chiradzulu showing six TAs and location of the study villages</td>
<td>81</td>
</tr>
<tr>
<td>3.4</td>
<td>Pilot study interview with the village head, with the HSA in the background</td>
<td>84</td>
</tr>
<tr>
<td>3.5</td>
<td>Household interview in progress</td>
<td>84</td>
</tr>
<tr>
<td>3.6</td>
<td>Women’s FGD in progress</td>
<td>86</td>
</tr>
<tr>
<td>3.7</td>
<td>Flow chart of data analysis process</td>
<td>87</td>
</tr>
</tbody>
</table>
Figure 3.8: The six-stage thematic analysis method adapted from ................................................. 90
Figure 4.1: Gender vs marital status of the household heads, n=219 ............................................ 99
Figure 4.2: Educational qualification vs gender of the household heads, n=219 ......................... 100
Figure 4.3: Main occupation of the household head, n=219 ........................................................... 101
Figure 4.4: Water sources n=219 .................................................................................................. 105
Figure 4.5: Funding sources ........................................................................................................... 106
Figure 4.6: How many times is water collected? .............................................................................. 108
Figure 4.7: How long does a roundtrip take? .................................................................................. 108
Figure 4.8: Number of households and water consumption per day .............................................. 109
Figure 4.9: Households perception on severity of challenges, n=219 ........................................... 111
Figure 4.10: Queuing for water ........................................................................................................ 112
Figure 4.11: Reason for not treating water ..................................................................................... 114
Figure 4.12: Abandoned borehole at Kanyong’o Village ................................................................. 115
Figure 4.13: Concrete block built over hand-pump to protect from theft ..................................... 117
Figure 4.14: Women collecting water from a broken elephant pump .......................................... 118
Figure 4.15: Histogram showing WTP for Drinking Water ........................................................... 121
Figure 4.16: Histogram showing WTP for irrigation water ........................................................... 121
Figure 4.17: Percentage of households who reported any use of energy source ......................... 125
Figure 4.18: Main energy source for lighting .................................................................................. 129
Figure 5.1: Components of the direct-coupled SWPS .................................................................. 135
Figure 5.2: GHI long term averages of daily/yearly totals for Malawi ........................................ 138
Figure 5.3: Long-term monthly averages, minima and maxima of GHI for seven sites............ 139
Figure 5.4: Monthly Averaged Insolation for Potani village ......................................................... 140
Figure 5.5: System components percentage cost .......................................................................... 147
Figure 5.6: Average amount of water pumped per day in each month ....................................... 149
Figure 5.7: Variation of NPV with selected input parameters ...................................................... 151
Figure 5.8: Sensitivity Analysis for NPV vs input parameters ..................................................... 151
Figure 6.1: Major themes from the qualitative study ..................................................................... 162
Figure 6.2: Subthemes under institutional and regulatory issues ........................................ 163
Figure 6.3: Subthemes under Economical issues ................................................................ 172
Figure 6.4: A billboard reminding Malawians to stop corruption .................................... 176
Figure 6.5: Subthemes under technical issues ................................................................... 177
Figure 6.6: Project Life Cycle of drinking water system .................................................. 186
Figure 6.7: Control House at Tiyanjane Scheme with solar modules on top ..................... 190
Figure 6.8: Watering using a hosepipe at scheme .............................................................. 190
Figure 6.9: Role of water in development and required interventions ............................... 197
Figure 0.1: The Living Water Treatment System (Watermission, no date) ......................... 236
Figure 0.2: A Water kiosk that uses the LIFELINK unit .................................................... 237
Figure 0.3: A water kiosk operator demonstrates how to insert credit ............................. 237
Figure 0.4: Collecting Water from a LIFELINK Unit ......................................................... 238
List of Tables

Table 2.1: Characteristics of major aquifer systems in Malawi ........................................ 46
Table 2.2: Summary of techno-economic analysis results of SWPSs................................. 63
Table 2.3: Determinants of WTP for drinking water .......................................................... 71
Table 3.1: Characteristics of the Research Approaches ...................................................... 78
Table 4.1: Demographic data of the Chiradzulu rural households’ survey ......................... 97
Table 4.2: Village characteristics for 12 selected villages ................................................. 98
Table 4.3: Monthly income and expenditure quartiles for the households ....................... 102
Table 4.4: Spearman’s correlation of income and socio-economic variables ..................... 103
Table 4.5: The Mann-Whitney Rank-Sum of gender vs income ....................................... 103
Table 4.6: Income, current contribution, WTP for water and amount of water collected 120
Table 4.7: Coding of variables for WTP for water ............................................................ 122
Table 4.8: Results of logistic regression predicting WTP ................................................. 123
Table 4.9: Comparison with other studies on predictors of WTP for drinking water ....... 123
Table 4.10: The Mann-Whitney Rank-Sum of gender vs WTP ....................................... 124
Table 4.11: Reasons for dissatisfaction with current source of energy .......................... 126
Table 4.12: Cost of energy per month per household ....................................................... 127
Table 4.13: Summary of key findings and opportunities for intervention ....................... 131
Table 5.1: Calculation for water requirement for Potani Village .................................... 136
Table 5.2: Sensitivity analysis input parameters and possible causes .............................. 145
Table 5.3: Technical parameters used in the evaluation ................................................... 146
Table 5.4: Cost of system components .............................................................................. 146
Table 5.5: Cost of water comparison with other studies .................................................. 149
Table 5.6: Calculating the quantity of water per household ............................................. 152
Table 5.7: Designed LCW compared with WTP amounts ............................................. 152
Table 5.8: Cost of water, lighting and mobile phone charging; plus distance ................. 154
Table 5.9: Breakeven water cost with and without energy revenues ............................ 155
Table 5.10: Selected payment scenario illustrating payback period............................... 155
Table 6.1: Stakeholder roles and responsibilities .................................................................. 160
Table 6.2: Power vs interest matrix for SWPS in Malawi, researcher’s ranking ............ 161
Table 6.3: Summary of stakeholder findings ..................................................................... 195
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATP</td>
<td>Affordability or Ability to pay</td>
</tr>
<tr>
<td>DFID</td>
<td>Department for International Development</td>
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<td>FGD</td>
<td>Focus group discussion</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>Goma</td>
<td>Government of Malawi</td>
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<tr>
<td>GIS</td>
<td>Geographical Information System</td>
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<tr>
<td>IDR</td>
<td>Inter-disciplinary Research</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>Int.</td>
<td>Interview number see Appendix 6.1</td>
</tr>
<tr>
<td>IRENA</td>
<td>International Renewable Energy Agency</td>
</tr>
<tr>
<td>KPA</td>
<td>Key priority area</td>
</tr>
<tr>
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</tr>
<tr>
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<td>Contingency valuation method</td>
</tr>
<tr>
<td>MDGs</td>
<td>Millennium Development Goals</td>
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<td>MGDS</td>
<td>Malawi Growth and Development Strategy</td>
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<td>MDHS</td>
<td>Malawi Demographic and Health Survey</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration of the USA</td>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organisation</td>
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<td>NSO</td>
<td>National Statistical Office</td>
</tr>
<tr>
<td>NPV</td>
<td>Net present value</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and Maintenance</td>
</tr>
<tr>
<td>PV</td>
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</tr>
<tr>
<td>RET</td>
<td>Renewable energy technology</td>
</tr>
<tr>
<td>SDGs</td>
<td>Sustainable Development Goals</td>
</tr>
<tr>
<td>SE4All</td>
<td>Sustainable Energy for all</td>
</tr>
<tr>
<td>SNV</td>
<td>Netherlands Development Organisation</td>
</tr>
<tr>
<td>SLF</td>
<td>Sustainable livelihoods framework</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for Social Sciences</td>
</tr>
<tr>
<td>SSA</td>
<td>Sub-Saharan Africa</td>
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<tr>
<td>SWPS</td>
<td>Solar water pumping system</td>
</tr>
<tr>
<td>TA</td>
<td>Traditional Authority</td>
</tr>
<tr>
<td>TDH</td>
<td>Total Dynamic Height</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNICEF</td>
<td>United Nations Children's Fund</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
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<tr>
<td>VSL</td>
<td>Villages savings and loans</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organisation</td>
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<tr>
<td>WASH</td>
<td>Water, Sanitation and Hygiene</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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<tr>
<td>WPC</td>
<td>Water point committee</td>
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<tr>
<td>WTP</td>
<td>Willingness to pay</td>
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<tr>
<td>WWAP</td>
<td>World Water Assessment Programme</td>
</tr>
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</table>

### Currency

Malawian currency is the Malawi Kwacha (MWK).
At the beginning of the data collection phase, US$1 = MWK520.
1 Introduction

1.1 Chapter outline

This introductory chapter gives the background to the research, its significance, aims and objectives, and concludes with the thesis outline.

1.2 Research background

The motivation of this research arises from the need to address sustainable water access for countries in Sub-Saharan Africa (SSA) using renewable energy. Water access is one of the key aspects of the Millennium Development Goals (MDGs) (World Bank, 2008). SSA is one of the regions in the world that faces many developmental issues, which include health, education, food insecurity, infrastructure, energy and water and sanitation, among other needs. Malawi was used as a case study country because the country also faces these developmental challenges and it is where the researcher comes from. Water provision was identified as one of the pressing and essential needs and at the same time, water access crosscuts several other challenges.

Access to safe water and sanitation is essential for human health and development and is a fundamental human right (United Nations, 2010a; WHO & UNICEF, 2011). However, approximately 663 million people still do not have access to safe drinking water and use sources such as unprotected wells, springs and surface water (rivers, streams and dams). Furthermore, global demand for water is expected to rise (Bizikova et al., 2013). Nearly half of the people who lack access to improved water access live in SSA where only 68% of the population has access to improved drinking water sources (WHO & UNICEF, 2015). The research focused on the rural areas where the majority (>80%) of the Malawi population live and have less access to services such as water, health, education, electricity, and telecommunications as compared to those living in the urban areas.

In 2015, the global use of improved drinking water sources was 91% surpassing the MDGs target by 3% (WHO & UNICEF, 2015). Figure 1.1 shows the countries’ progress on the water target, and clearly illustrates that most of the countries that have not made good progress are in SSA. With 86.2% of the population having access to an improved water source, Malawi exceeded her water target by over 12% and is one of the few countries in SSA to do so (GoM, 2014). However, even for those with improved drinking water sources the quality, functionality and safety for many of these sources is questionable (Harvey, 2004; Pritchard, Mkandawire and O’Neill, 2007; United Nations, 2013). Additionally, there is a strong disparity in water
provision between urban and rural areas, 87% and 56%, respectively (Pullan et al., 2014; United Nations, 2015b).

Figure 1.1: Global MDGs target achievement of drinking water
Source: (WHO & UNICEF, 2015)

1.3 Significance of the research

Water is a global key issue because it influences all the three dimensions of sustainable development namely, social, economic and environment. It is essential for achieving developmental goals such as health, education, food security, energy, gender equality, and poverty alleviation (WWAP, 2015).

The role of water in health is one of the most important relationships. Diseases such as diarrhoea and cholera are prevalent in the developing countries and are preventable by availability of safe drinking water and good hygiene (Fewtrell et al., 2005). The majority of household in SSA have to leave their homes to collect water, which causes drudgery on the women and girls, who are the major water collectors. This is associated with musculoskeletal disorders and related disability (Geere, Hunter and Jagals, 2010; Graham et al., 2016). If the total time taken per round trip exceeds 30 minutes, households tend to collect less water, thus compromising their water needs for drinking, food preparation and personal hygiene (Howard and Bartram, 2003; Hunter and Wang, 2010; WHO & UNICEF, 2011). Water collection also negatively impacts education access, especially for girls who may be late for school, absent, or fail to concentrate in class because of fatigue, all caused by collecting water (Graham et al., 2016). Additionally, teachers are more willing to be posted to rural schools where water is available other than to where it is not (Gutierrez, 2007). Water
availability empowers women and girls by providing water for their sanitary needs and improves their safety, dignity and confidence. In addition, sexual harassment or other violence to women which has been reported to take place when collecting water (Blagbrough, 2001; House et al., 2014), can be avoided.

Water also has a role to play in eradicating extreme poverty and hunger. Irrigation is believed to have a positive impact on food security and poverty reduction particularly in the face of climate variability (Burney and Naylor, 2012; Nkata, 2014). In their study for rural Malawi, (Mkondiwa, Jumbe and Wiyo, 2013) found that poverty was positively correlated with lack of access to safe and adequate water. Irrigated agriculture accounts for 70% of global freshwater withdrawals, and more than 90% of its consumptive use (FAO, 2012). More than 70% of Africa’s poor people live in rural areas and mostly depend on agriculture for their livelihoods but only about 6% of the total cultivated area is irrigated (You et al., 2011). In Malawi over 20% of the country’s area is water in form of lakes and rivers but the country still relies on rain-fed agriculture. Because of persistent droughts and floods, aggravated by climate change, there are insufficient harvests that results in famine and worsens poverty (Action Aid, 2006; Coulibaly et al., 2015). In 2016 Malawi went through such a food crisis with millions of people facing hunger as reported in the media (United Nations News Service, 2015; Nyasa Times Reporter, 2016).

Handpumps are widely used for domestic water abstraction and approximately a third and up to 60% of handpumps in SSA are reported to be non-functional at any time (SNV, 2013), which makes the people resort to collect water from their previous contaminated water sources. Handpumps are manually straining, are a physical burden to women and girls and are not user-friendly to vulnerable people such as the aged. Some of the handpumps are fitted on shallow wells which are more easily contaminated than deep wells and in the dry season most of them dry up (Pritchard, Mkandawire and O’Neill, 2007). Farmers use hand-dug wells for their irrigation requirements and the popular water abstraction methods are gravity fed canals, motorized pumps, treadle pumps, and watering cans (Mangisoni, 2008; Kamwamba-Mtethiwa et al., 2012). Though treadle pumps can assist smallholder farmer in irrigation, they can irrigate only small portions because they are labour-intensive and achieve very small discharge rates implying the operator has to pump for long hours (Chidanti-Malunga and Malunga, 2011). Some treadle pumps have been abandoned because of being heavy and hard to operate (Kamwamba-Mtethiwa et al., 2012).

Having discussed the role of water in development, and the current abstraction methods, it is apparent that there is need for improved water access technologies. Groundwater is available in SSA (MacDonald et al., 2012) and electric-powered pumping systems could be used for water pumping. However, energy access is another of the major challenges that the SSA
region faces. With over 620 million people, which are nearly half of the global total, with no electricity, it is the least electrified region in the world. The map of Figure 1.2 illustrates the number of people without electricity in Africa and the situation for Malawi.

Figure 1.2: Number and share of people without access to electricity by country, 2012

Source: (IEA, 2014)

Similarly, Malawi also lacks adequate grid electricity; the generation capacity for the whole country is approximately 350 MW and less than 10% of the population is connected to the grid and of these less than 1% are from the rural areas (Gamula, Hui and Peng, 2013; GoM, 2015). With problems such as high cost of capital equipment, isolated settlements, low incomes and low economic activities the country's power supply company is unable to extend electricity to the rural areas (Phiri, 2009).

Another option is diesel water pumping systems. Though they have a lower capital cost as compared to renewables, they have disadvantages such as vulnerability to oil prices, depletion of fossil fuels, pollution, noise and high maintenance costs (Al-Smairan, 2012; Chandel,
Nagaraju and Chandel, 2015), which make the diesel option less favourable. This is particularly the case for rural areas where the cost of fuel and the cost of transporting fuel to remote places and sometimes on impassable roads, makes it more challenging (Odeh, Yohanis and Norton, 2006a). Some motorised pumps were introduced by the Malawi Government and distributed freely to farmers but most of them are no longer in use due to farmers' inability to meet fuel costs and maintenance (Chidanti-Malunga, 2009; Kamwamba-Mtethiwa, 2016). Mobile phone operating companies use diesel for their off grid base stations which are in remote locations and they have cited challenges of diesel cost and difficult terrain and accessibility to the rural areas to transport fuel (GSMA & TNM, 2012).

With no grid electricity connection in most of the rural areas, and the disadvantages associated with diesel systems, renewable energy technologies (RETs) provide a viable option and at the same time could contribute towards the Sustainable Energy for All (SE4All) initiative (United Nations, 2010b). Thus, this study considers water pumping using solar photovoltaics (PV) because the country has relatively high insolation making solar PV a viable option.

The research worked across disciplines of Social Sciences and Engineering and Technology. It used mixed methods approaches which consisted of: (i) literature review (ii) household surveys for 219 households from 30 sample rural villages in Chiradzulu district (iii) 27 village head interviews which were used to triangulate the household surveys (iv) four focus group discussions also to triangulate the household surveys (v) stakeholder interviews with the key players in the water, energy and microfinance sectors and (vi) four field visits to complement the stakeholder interviews and (vii) techno-economic analysis of a solar PV water pumping system for drinking water.

1.4 Aim of the study

The main aim of the research was to develop a financing and a decision support model for planning and analysis of sustainable rural water provision using solar PV in SSA in order to aid development.

1.4.1 Specific objectives

The study had the following six specific objectives:

i. Evaluate the developmental concerns related to water and energy availability, use and quality in the context of socio-economic indicators, sustainable development, and human well-being;

ii. Analyse the water and energy needs, challenges and assess the willingness to pay for water for the rural household in Chiradzulu District;
iii. For a candidate water-provision platform, carry out a techno-economic analysis to assess water economics in terms of a ‘levelized cost of water’ metric;

iv. Identify potential integrated platforms to improve water accessibility and quality;

v. Identify the potential stakeholders in water provision using solar PV in Malawi and understand their roles, responsibilities and challenges; and

vi. Make recommendations for planning and analysis of solar PV water pumping systems for sustainable development in Malawi.

1.5 Thesis outline

This introductory chapter gives the background to the research, significance of the research, aim of the research, specific objectives and the thesis outline. The thesis comprises eight chapters as illustrated in the flowchart shown in Figure 1.3. Following this chapter, the rest of the thesis is organised as follows:

Chapter 2 reviews the literature. It gives a background to the study by discussing the role of water and energy in meeting the global needs with reference to sustainable development and development goals as specified in the MDGs. It also presents the sustainable livelihoods framework, which is a tool used to assess livelihoods. The chapter further presented the water and energy situation in Malawi followed by a review of literature on solar PV water pumping and willingness to pay for water.

Chapter 3 is the methodology chapter and gives a brief background of Malawi and Chiradzulu, the case study district. It details the research design and the methodology used for data collection, sampling and data analysis. The chapter also describes the ethical considerations and the research methodology limitations.

Chapter 4 is the first of the three results chapter and presents, analyses and discusses the findings of the household survey, placing them in the context of the wider body of literature and previous studies.

Chapter 5 is the second of the results chapters and presents the techno-economic analysis. It explains the design of a solar water pumping system for drinking water, carries out an economic analysis, and calculates the levelized cost of water. The chapter relates the results to the findings of the household survey in Chapter 4 and findings from previous researchers. Further, the chapter develops a financing model based on cross-subsidy of water and basic household energy costs.
Chapter 6 is the third and last of the results chapters and gives the results, analyses and discussion of the stakeholder interviews and also presents results of field visits. It discusses the stakeholders' roles, responsibilities, challenges and benefits and presents the results using stakeholder analysis and thematic analysis.

Chapter 7 synthesises and discusses the results from Chapters 4, 5 and 6 with reference to the study objectives and the sustainable livelihoods framework. Furthermore, the chapter reflects on the implications of the research and presents policy recommendations.
Chapter 8 is the conclusions chapter and presents the key findings, research novelty, contribution to knowledge, research limitations, and discusses the recommendations for future research.
2 Literature Review on Sustainable Development, Energy, and Water

‘As I see it, we have five imperatives ... five generational opportunities to shape the world of tomorrow by the decisions we make today. The first and greatest of these is sustainable development ... the imperative of the 21st century. Saving our planet, lifting people out of poverty, advancing economic growth... these are the same fight. We must connect the dots between climate change, water scarcity, energy shortages, global health, food security and women's empowerment. Solutions to one problem must be solutions for all’ (Ban Ki-moon, 2011)

‘Energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive. Development is not possible without energy, and sustainable development is not possible without sustainable energy’ (Ban Ki-moon, 2014)

2.1 Introduction

The main aim of the research was to develop a financing and decision support model for planning and analysis of sustainable rural water provision using solar Photovoltaics (PV) in Sub-Saharan Africa (SSA), which is one of the developing regions in the world. This research was inspired by the role of renewable energy to aid sustainable development in the rural areas of developing countries, particularly to assist in the fulfilment of the Millennium Development Goals (MDGs) which have now been superseded by Sustainable Development Goals (SDGs). This chapter reviews literature on sustainable development and the relationship of its indicators to water and energy. Malawi is used as the case study country; hence, the literature review highlights the situation for Malawi. Furthermore, the chapter reviews literature on solar PV water pumping systems (SWPS), techno-economic analysis of SWPSs and willingness to pay for water. The chapter concludes with a summary.

2.2 Sustainable development and the development goals

In the report of the World Commission on Environment and Development which is also called the Brundtland Commission or “Our Common Future”, sustainable development is explained as development that meets the needs of the present, without compromising the ability of future generations to meet their own needs (Brundtland, 1987). In addition to providing a definition
of sustainable development, the report introduced it as a component of international
developmental thinking and initiated work on the theme (Waas et al., 2011).

There are three pillars of sustainable development (Lozano, 2008) namely; economic,
environmental and social. Firstly, an economically sustainable system must continually
produce goods and services, maintain manageable levels of government and external debt,
and avoid extreme sectorial imbalances, which damage agricultural or industrial production.
Secondly, an environmentally sustainable system must maintain a stable resource base,
avoiding over-exploitation of renewable resource systems or environmental sink functions,
and depleting non-renewable resources only to the extent that investment is made in adequate
substitutes. Lastly, a socially sustainable system must achieve distributional equity, adequate
provision of social services including health and education, gender equity, and political
accountability and participation. There are many interpretation of sustainable development as
discussed by Hopwood, Mellor and O’Brien (2005) who argue that to achieve sustainable
development there is need for more clarity of meaning, concentrating on sustainable
livelihoods and well-being rather than long term environmental sustainability, which requires a
strong basis in principles that link the social and environmental aspects to human equity.

The United Nations Conference on Environment and Development also called the “Earth
Summit” held in Rio de Janeiro in 1992 was a follow up to the Brundtland Commission. The
meeting adopted the Agenda 21 which gave principles and objectives relating to
implementation at a national level, of policies and actions supporting sustainable development
and hence brought stakeholders to take action (Waas et al., 2011). In 2000 world leaders and
international organisation met at the Millennium Summit (United Nations, 2000) and adopted
the MDGs which ran from 2000 to 2015. The MDGs had eight goals with 21 specific targets
and the goals were to: (i) eradicate extreme poverty and hunger; (ii) achieve universal primary
education; (iii) promote gender equality and empower women; (iv) reduce child mortality; (v)
improve maternal health; (vi) combat HIV/AIDS, malaria and other diseases; (vii) ensure
environmental sustainability; and (viii) develop a global partnership for development (World
Bank, 2008).

Despite the progress registered in the achievements of the MDGs, there is disparity across
the regions and countries in the following areas:

i. Gender inequality still persists.

ii. Climate change and environmental degradation undermine progress achieved, and
poor people suffer the most.

iii. Big gaps exist between the poorest and richest households, and between rural and
urban areas.
iv. Millions of poor people still live in poverty and hunger, without access to basic services. (United Nations, 2015b)

In the MDGs energy was not one of the goals but was recognised as a catalyst to the fulfilment of the goals (DFID, 2002; Modi et al., 2005). In 2015, the MDGs were superseded by the SDGs, which are to run from 2016 to 2030. Countries adopted the ‘2030 Agenda for Sustainable Development’ and its 17 SDGs with 169 targets, which aim to end poverty, protect the planet, and ensure prosperity for all. Figure 2.1 illustrates the SDGs (United Nations, 2015a).

![Figure 2.1: Illustration of the 17 sustainable development goals](Image)

In Malawi, the MDGs were localised to the following strategies: Malawi Poverty and Reduction Strategy (GoM, 2002), Malawi Growth and Development Strategy (MGDS) I and II. The MGDS I ran from 2000 to 2011 (Goma, 2006) and MGDS II ran from 2011 to 2015 (GoM, 2012a). The main theme of these goals is reducing extreme poverty and meeting needs of Malawians such as food, safe drinking water, good health, education, and women empowerment among others. The MGDS II was structured with six thematic areas and nine key priority areas (KPAs) which were thought to be necessary to achieve rapid economic growth and improvement within the implementation period.

Considering that the needs of SSA countries including Malawi are numerous, Maslow’s hierarchy of needs was used to select the priority need to be addressed. Abraham Maslow, a psychologist developed a set of five needs which are usually represented as a five layer pyramid as shown in Figure 2.2 (Poston, 2009). Maslow argued that the needs in the first
layer must be met first before moving on to fulfil the needs in the next layer. The needs in the first layer called the physiological needs contain the basic needs which include food and water, among other needs (Huitt, 2007; Poston, 2009). Applying Maslow's hierarchy of needs to this research, water was selected, as a priority need. As introduced in Chapter 1, Malawi and other countries in Sub-Saharan countries lack access to improved drinking water and water for irrigation. Addressing the need for water has the potential to address the other developmental goals as well, as will be discussed in the next section.

![Figure 2.2: Maslow’s hierarchy of needs](image)

**Figure 2.2: Maslow’s hierarchy of needs**

Source: (Poston, 2009)

For Malawi and with reference to the MGDS II, water in general has a role to play in all the six themes and nine KPAs, whereas potable water has a role to play in a majority of them as illustrated in Figure 2.3.
Figure 2.3: Relationship between water, KPAs, and subthemes

Adapted from: (GoM, 2012a)
The figure shows the links between the themes, KPAs (listed in box and numbered in brackets) and sub-themes that are linked to water. The KPAs are also linked amongst themselves but this is not shown in the diagram.

In the development goals, the goals/targets directly related to water are:

- Goal 7, target 10 of the MDGs which was to: “Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation; and

- Goal 6 of the SDGs which aims “to ensure availability and sustainable management of water and sanitation for all” and specifically, two targets which are “By 2030, achieve universal and equitable access to safe and affordable drinking water for all” and “to support and strengthen the participation of local communities in improving water and sanitation management”.

The current research proposes the provision of water using renewable energy, which brings in the application of the energy goal from the SDGs:

- Goal 7 aims “to ensure access to affordable, reliable sustainable and modern energy for all”.

These goals/targets form the motivation of this research and link the water and energy goals in terms of their potential to address other development goals including poverty reduction, food security, gender equality and women empowerment, education and health.

### 2.3 Role of water and energy in the MDGS

There is an inter-linkage (nexus) between the energy and water supply systems, which are both major considerations in the countries’ sustainable development strategies (Hussey and Pittock, 2012). Firstly, both water and energy have millions of people without access; secondly, both have rapidly growing demand; thirdly, both have interdependencies with climate change and the environment and lastly both have resource constraints. To this energy-water nexus, other authors add food and land as other linkages (Bazilian et al., 2011; IRENA, 2015). Water and energy problems are thought to be on the increase because of the rising global population, growing prosperity and climate change and by 2030 their demand is expected to rise by 30-50% (Bizikova et al., 2013; Wong, 2014). Benefits and potential benefits of water and modern energy services to human development in developing countries have been recognised in literature and are discussed in the rest of this section. Figure 2.4 illustrates the potential benefits of water access regarding the MDGs (in the diagram, the MDGs are shown in pink).
Figure 2.4: Potential benefits of water in the MDGs

Adapted from: (Gutierrez, 2007; Harvey, 2008; IRENA, 2016a)

Goal 1: To eradicate extreme poverty and hunger

Access to water has the following potential impacts on eradicating extreme poverty and promoting economic development (Gutierrez, 2007; Harvey, 2008; WWAP, 2015; IRENA, 2016a):

- Improved health which results in more time available for productive use.
- Higher productivity due to increased potential for water use for income generating activities.
- Avoidance of costs (monetary and time) spent on medicines and healthcare.
- Reduced drudgery on women and girls and hence frees up time for productive uses. Studies show that rural families can save up to five hours of time per day that is spent collecting domestic water (Harvey, 2008). On the contrary, other researchers found that women did not necessarily use the gained time for productive uses but used it for other household chores, rest, visiting with family and friends and sleeping since they no longer woke up while it was still dark to collect water (Van-Houweling, 2016).
- Improving access to water for irrigation leads to improved agricultural outputs and hence food security and increased incomes.
Harvey (2008) notes that the links between water and poverty are multidimensional and requires enhanced rural water provision and poverty focus. In a study of the rural areas of Malawi, poverty was found to be positively correlated with lack of access to safe and adequate water (Mkondiwa, Jumbe and Wiyo, 2013).

Similarly, access to energy can help to eradicate extreme poverty and hunger as demonstrated by several authors (DFID, 2002; Modi et al., 2005; United Nations, 2005; Bast and Krishnaswamy, 2011; Ray et al., 2016; IEA, 2017). These are summarised as follows:

- Electric pumping improves access to water for irrigation;
- Lighting extends the working day;
- Machines in agricultural processing increase output;
- Electricity powers up telecommunication equipment for example; mobile phones and radios that can help farmers to communicate about markets and track prices of produce; and
- For remote areas, the cost of decentralized, renewable energy can be less expensive than conventional, grid-powered electricity.

**Goal 2 and 3: To achieve universal primary education and, to promote gender equality and empowering women**

Education is believed to be critical for breaking the vicious cycle of poverty. In many developing countries, which is also the case in Malawi, women and girls are primarily responsible for most of the domestic chores, including farming. Many children especially girls are late for school or absent in order to collect firewood and water to meet family subsistence needs. Adequate water access would allow them to allocate time for education, thereby eliminating gender disparity in primary and secondary education and improving the ratio of literate women to men (Short and Thompson, 2003; Gutierrez, 2007; Harvey, 2008). In addition, access to water alleviates the following challenges:

- School attendance may be affected due to sickness caused by lack of safe drinking water;
- Providing adequate water for improvement of the females’ personal hygiene boosts their confidence;
- At puberty girls may drop out of school because of lack of water for their sanitation needs;
Provision of water improves teaching quality, as teachers often do not want to be posted in schools without water and energy (United Nations, 2005; Gutierrez, 2007); and

Water availability reduces the risk of sexual harassment on women and girls in instances where the water source is at a long distance or is collected at night (Blagbrough, 2001; House et al., 2014).

Studies by WaterAid in Ghana, Ethiopia and India (Blagbrough, 2001) found a range of impacts on education including: increase in attendance rates for both teachers and students, teachers readily accepted postings to rural communities, absenteeism and drop-out rates reduced, improvement in punctuality, students had time for studying, and improvement in women’s literacy levels.

Similar to water availability, modern energy reduces drudgery on women and girls in areas such as fetching firewood, collecting water or processing food thereby freeing time for education (United Nations, 2005). Modern energy gives adequate lighting by providing extra hours to study at night and increases security. Energy access enables the use of information and communication technologies (ICTs) in schools. Also, communities can improve their access to information by having readily available charging system for their mobile phones and radios (DFID, 2002) and women can be informed about gender issues. In addition, women can spend more time with the family and have time for active participation in the community such as attending to social and religious obligations (Van-Houweling, 2016).

Goals 4, 5, and 6: To reduce child mortality, to improve maternal health, and to combat HIV/AIDS, malaria, and other diseases

Studies have shown that improved water quality and management has great significance on reducing diarrhoea and other water-linked diseases (Esrey et al., 1991; Prüss et al., 2002; Fewtrell et al., 2005). In children, it lowers child mortality by reducing incidences of disease such as diarrhoea, which is one of the leading causes of child mortality and is caused by unsafe water. Access to clean water can reduce maternal mortality by providing an environment where traditional birth attendants can deliver babies more safely. Readily available water can help reduce pregnant women’s physical burdens, particularly in relation to collecting water, which results in safer pregnancies (Blagbrough, 2001).

Energy improves health care facilities in health clinics such as water provision, lighting, sterilisation, refrigeration of medicines and communication between health personnel and hence provides better care and treatment for those affected with HIV/AIDS, and other major diseases. Access to modern cooking and lighting energy decreases indoor air pollution which causes disease that affect women and children (Torres-Duque et al., 2008). In addition,
maternal health is improved by reducing the intensity of household chores and fire hazards from paraffin use.

**Goal 7: To ensure environmental sustainability**

Modern energy reduces the use of wood for heating and cooking hence reduces deforestation. Renewable energy helps combat climate change by using cleaner fuels well, which reduces emissions, and protects the local and global environment (DFID, 2002).

**2.4 Sustainable livelihoods framework**

The process of meeting the needs of rural livelihoods, which for this research is water, provision using solar PV, can be explained using the sustainable livelihoods framework (SLF). The SLF (Figure 2.5) was developed by the British Department for International Development (DFID) and is a way of thinking about the objectives, scope and priorities for development and is used as a tool to assess sustainable livelihoods (DFID, 1999). It is also used to understand the underlying causes of poverty and to identify the opportunities and challenges related to a livelihood improvement (Scoones, 2009).

As shown in Figure 2.5 and described in the guidance sheets (DFID, 1999), the SLF consists of five dimensions which include the vulnerability context, livelihood assets, transforming structures and processes, livelihood strategies and livelihood outcomes. Five types of
livelihoods assets or capital represented as a pentagon are used to assess the current living conditions in a given community and to realise the impact an external intervention, could have on those living conditions in the future. Developmental projects can help poor households to build up their assets especially their human and social capital (Carloni and Crowley, 2005).

The five assets include **human capital** (skills, knowledge, health and education), **natural capital** (land, forests, water, air, and wind), **financial capital** (wages, savings, and credits), **social capital** (social networks, community organizations and affiliations) and **physical capital** (infrastructure and technology). In addition, the SLF also recognises transforming structures and processes which refers to the organizations and procedures needed to safeguard people’s assets and to ensure access to these assets. Livelihood outcomes may include reduced vulnerability, food security, increased income and well-being. (DFID, 1999)

There are several advantages of the SLF which include that it can allow interdisciplinary research (Scoones, 2009), which is the case of the present research. SLF is flexible in the type of analysis tools that can be used; different countries/groups can use the ideas in ways that best suit their needs and purposes (Carney et al., 1999). Working on a wind farm project using the SLF method, Hinshelwood (2003) demonstrated that SLF can be adapted to meet the needs of individual projects and used it for planning and development of a community energy wind farm in the UK which ended up being a success. Nicol (2000) asserts: “Just as livelihoods are dynamic, so are the means by which to address them…a project-by-project basis should be adopted, but in a loosely networked fashion which allows for sharing between projects.” The SLF has been criticised for underestimating the importance of one or more critical factors such as vulnerability, gender, and markets; and for the need to use additional tools and skills to complement it (Carney, 2003). Regardless of the criticisms, the SLF has been used for many purposes such as to assess poverty reduction in energy provision (Barnes, 2000; Barnett, 2000; Bannister, 2002), and can also be used to explore the reasons why some energy projects may, or may not succeed in rural communities (González et al., 2016).

The SLF was also used to analyse water in the context of poor households (Nicol, 2000) and was anticipated that it could provide greater water security through addressing the productive use of water. In addition, Nicol’s study discusses the importance of closely linked institutions to benefit the poor, the significance of sequencing interventions to achieve desirable livelihood outcomes and dissemination of knowledge to portray how livelihoods are enhanced in the water sector. In the present research, the SLF has been applied in the rural areas of Malawi to assess the feasibility of solar PV to provide drinking and irrigation water coupled with basic household energy applications namely, lighting and mobile phone charging, all aimed at improving livelihoods.
2.5 Malawi water overview

2.5.1 Water policy in Malawi

In Malawi, water issues are under the department of Irrigation and Water Development, which falls under The Ministry of Agriculture, Irrigation and Water Development. There are several policies that are related to water but the main one is the National Water Policy (GoM, 2007). It was developed by the government of Malawi to guide the country in the areas of water resource management and development, improving the institutional and legal framework, ensuring sustainable delivery of water supply and sanitation services. In addition, it was to ensure effective involvement of the private sector, protection of the environment and conformity with the regional and international conventions and agreements in the management of shared water resources. The policy, among other issues, aims to:

i. Achieving sustainable and integrated water resources management and development that make water readily available and equitably accessible by all Malawians in pursuit of their socio-economic development and for environmental sustenance;

ii. Ensuring water of acceptable quality for all the needs in Malawi;

iii. Achieving sustainable provision of water supply and sanitation services that are equitably accessible and used by individuals and entrepreneurs for socio-economic development at affordable cost;

iv. Undertaking the rehabilitation, upgrading, extension and construction of water infrastructure;

v. Promoting the participation of the private sector in water resources development, management and service delivery;

vi. Strengthening and building capacity in the water sector; and

vii. Clarifying the roles of the Ministry and other stakeholders in the water sector (GoM, 2007).

Of relevance to this study is that the policy acknowledges promoting the use of alternative energy sources for supplying piped water in rural areas. Other points worth noting are use of water for socio-economic development and entrepreneurship in the rural areas and promoting the participation of the private sector. Hence, research on renewable energy for water pumping is within the framework of the water policy. Data on the progress of the water policy was not accessible.
2.5.2 Stakeholders in the rural areas water supply sector

The following are the actors in the rural water supply sector of Malawi as discussed in literature (Chipofya, Kainja and Botha, 2009; Chowns, 2014; Scanlon et al., 2016):

i. **National government**: The Ministry for Irrigation and Water Development is responsible for rural water supply.

ii. **Local government**: Rural water supply was decentralised to District level in 2006 (whereas energy is not currently decentralised).


iv. **NGOs**: Key international NGOs include WaterAid, Concern Universal, World Vision International, Emmanuel International, Engineers without Borders (EWB), InterAide, and Water for People. There are few national NGOs.

v. **Communities**: These are made up of the households and are represented by the water point committee (WPC) and other important individuals or institutions that include traditional leaders, religious leaders and other committees in the community.

vi. **Academia**: Universities and colleges provide basic training in water related subjects and also carry out research.

vii. **Private Sector (Entrepreneurs)**: Provide technical services, supply of technology, and supply of raw materials.

viii. **Media**: Sensitization, awareness and accountability.

ix. **Politicians**: Lobbying, advocacy, and legislation.

Despite having all these actors in place, the water sector in the rural areas of Malawi still faces some challenges as will be discussed in the subsequent sections. Hence, this research will also carry out a stakeholder analysis which helps in understanding how people affect policies and institutions, and how policies and institutions affect people and also highlights the challenges that are faced and recommendations on how to solve them (Mayers, 2005).

2.5.3 Water resources of Malawi

There are two main types of water resources in Malawi namely, surface water and groundwater. Utilisation of water resources is mostly heavily dependent on run-of-the-river schemes and finds application in several areas, which include agriculture, irrigation, water
supply and sanitation, hydropower, industry, navigation, fisheries, and bio-diversity (Chipofya, Kainja and Botha, 2012). The sectorial distribution of water in Malawi is estimated to be 49% agriculture and natural resources, 34% domestic, and 17% industry, which shows agriculture is the greatest user of water (Mulwafu et al., 2003).

The drainage system of Malawi is divided into 17 administrative water resource areas (WRAs) as shown in Figure 2.6. The figure also shows the aquifers of Malawi which will be discussed later in the section. Each WRA represents one basin comprising surface and groundwater catchments and sub-catchments. Rainfall variability has a significant impact on variations in both water availability and the total potential discharge in a particular catchment. Malawi has a sub-tropical climate, which is relatively dry, strongly seasonal, and is influenced by the country’s geographical location. The warm-wet season stretches from November to April, during which 95% of the annual precipitation takes place. (Robins, Davies and Farr, 2013).

Annual average rainfall varies from 725 mm to 2,500 mm depending on location. Extreme conditions include droughts and floods with the low-lying areas such as Lower Shire Valley and some areas in Salima and Karonga more vulnerable to floods than higher grounds. The amounts and patterns of rainfall closely correlate with relief, such that highlands of Mulanje, Zomba, Nyika, Vipya and escarpment areas experience greater precipitation in the excess of 1800 mm per annum. The low-lying areas such as the Shire Valley, rain shadow areas, and the plateau regions to the west receive low rainfall. Figure 2.7 shows the relationship between rainfall and relief. (Kumambala and Ervine, 2009; Chipofya, Kainja and Botha, 2012).
Figure 2.6: Water resource areas and outline of the geology of Malawi

Source: (Robins, Davies and Farr, 2013)
Surface water resources include Lake Malawi, which is the third largest in Africa and stores the bulk of the renewable surface water resources, with an average of 90 km³ of live storage. Lake Malawi has a surface area of 28,760 km² and an estimated total volume of water of 7.725 x 10⁹ m³ with a mean level of 474 m above sea level. In addition, the country has other smaller lakes and an extensive network of river systems; major rivers are perennial, but due to the seasonal rainfall, most of the smaller rivers are not. According to (Chipofya, Kainja and Botha, 2012) there are about 700 small to medium dams in Malawi, with reservoir capacities ranging from a few cubic metres to about 5 million cubic metres. Most of the dams were constructed in the 1950’s to supply drinking water for livestock. The large dams were constructed by the Water Board organisations for urban water supply.
Globally, groundwater is one of the most important natural resources and has been exploited for drinking water supply, primarily for both rural and urban areas. Early studies of groundwater in Malawi showed that the availability of groundwater is associated with two major aquifer types: the basement (weathered and fractured basements) and quaternary alluvial aquifers. The geochemical quality of both aquifer types are classified as good (Chilton and Smith-Carington, 1984; Robins, Davies and Farr, 2013; Mapoma and Xie, 2014). The distribution of the aquifers is shown in Figure 2.6 together with the previously discussed WRAs. The characteristics of the aquifers are summarised in Table 2.1

**Table 2.1: Characteristics of major aquifer systems in Malawi**  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weathered basement complex</th>
<th>Alluvial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borehole yield (L/s)</td>
<td>1 to 2</td>
<td>15</td>
</tr>
<tr>
<td>Hydraulic conductivity (m/d)</td>
<td>0.5 to 1.5</td>
<td>1 to 10</td>
</tr>
<tr>
<td>Depth of boreholes (m)</td>
<td>45 to 50</td>
<td>60</td>
</tr>
<tr>
<td>Depth of water table (m)</td>
<td>15 to 25</td>
<td>5 to 10</td>
</tr>
<tr>
<td>Transmissivity (m²/d)</td>
<td>5 to 35</td>
<td>50 to 300</td>
</tr>
<tr>
<td>Storage coefficient</td>
<td>5 x10⁻³ to 1x10⁻²</td>
<td>1x10⁻² to 5x10⁻²</td>
</tr>
</tbody>
</table>

Yields of up to 5 litres per second are obtainable in the weathered basement aquifer, which is usually adequate for handpumped supplies. Alluvial aquifers yield high groundwater in excess of 10 l/s, which is more mineralized than from basement aquifers (Chilton and Smith-Carington, 1984). The groundwater map atlas produced by British Geological Survey (MacDonald et al., 2012) shows the estimated depth to groundwater (in metres below ground level, mbgl) for Africa. In Malawi, the majority of places are below 25 mbgl as illustrated in Figure 2.8 and Table 2.1.

An area of concern is that there is inherent uncertainty in the water-balance estimates and the likelihood that rural demand is exceeding long-term average recharge in some few WRAs (Robins, Davies and Farr, 2013). However, the authors recommend further research and observation. In agreement, (Mapoma and Xie, 2014) also call for more groundwater research, monitoring, and data archiving.
Studies show that although the abundant ground and surface water resources of Malawi are presently sufficient for domestic, agricultural, commercial and industrial use, they are slowly and steadily being degraded. This is due to many interrelated factors that include: (i) poor management of catchment areas, (ii) environmentally-unfriendly agricultural practices, (iii) ground and surface water pollution from faecal concentrations, (iv) inappropriate discharge of industrial and hazardous wastes, (v) untreated municipal wastes agro-chemical run-off, (vi) sedimentation or siltation from suspended particles and soil erosion, (vii) drying of perennial rivers from low rainfall, (vii) dwindling groundwater resources, (viii) rapid population growth, and (ix) the weak institutional structures for enforcing the Water Resources Act of 1969 (GOM, 2011; Chavula, 2012; Chipofya, Kainja and Botha, 2012).
2.5.4 Water abstraction methods

The World Health Organization (WHO, 2011) defines access to water supply in terms of the types of technology and levels of service afforded. Access to basic water-supply services is the availability of at least 20 litres per person per day from an “improved” source within 1 kilometre of the user’s dwelling. They further classify improved drinking-water sources as, piped water into dwelling, yard or plot, public tap or standpipe, tube well or borehole, protected dug well, protected spring, rainwater collection. Unimproved drinking-water sources are classified as: unprotected dug well, unprotected spring, cart with small tank or drum provided by water vendor, tanker truck provision of water, surface water (river, dam, lake, pond, stream, canal, irrigation channel), and bottled water.

In the rural areas of Malawi, ground water is the most common source for drinking water and it is generally believed to be safe to drink, though disinfection may be necessary to prevent waterborne diseases (Chavula, 2012). Globally, groundwater is also generally preferred as a drinking water source because it is close to where the dwellings are, and the quality is generally acceptable for human consumption. Furthermore, the cost of extracting groundwater is less than that of extracting and treating surface water. In addition, ground water offers reliability of supply and a buffer against drought (Calow et al., 2010; MacDonald et al., 2012). In irrigation, groundwater allows for efficiency and flexibility (Calow et al., 2010). Hence, for these reasons groundwater is preferred to surface water for the rural areas of Asia and Africa. However, of concern are various human activities that introduce contamination to the groundwater. The Malawi Standards Board and the WHO (Kanyerere et al., 2012; Taylor et al., 2012) have set standards to be followed in order to avoid such contamination. Areas of concern include:

i) Depth of well;
ii) Water source types and well construction methods: open, shallow, and boreholes
iii) Condition of well: cracks in the base, visible pathways, drainage;
iv) Proximity to source of contamination such as: toilets, cemeteries, animal kraals, septic tanks, silage pits, dip tanks, garbage disposal places or garbage around the well premises;
v) Slope of the land;
vi) Fertilisers and pesticides; and
vii) Flowing contaminated surface water.

Similar to SSA, handpumps are widely used for groundwater abstraction in the rural areas of Malawi (Taylor et al., 2012). The common pumps in Malawi are the AFRIDEV and MALDA
which are both designed to serve up to 300 people (or 30 to 50 households) with a water
demand of 15 to 20 litres per person per day (Baumann and Danert, 2008; Baumann and
Furey, 2013). The AFRIDEV pump has a higher lift between the two with a maximum
recommended lift of 45 m (Furey, 2014); the MALDA can be used up to 15 m (RWSN, 2017).
Both are excellent for community-based maintenance commonly called village level operation
and maintenance (VLOM) (Furey, 2014). On the contrary, Chisenga (2014) found that the
communities in her study were able to repair the MALDA but not the AFRIDEV pumps. Other
pumps used in Malawi are the elephant pump suitable for small communities of up to 150
people, and rope and washer pumps designed for self-supply (Pump Aid, 2016). Figure 2.9
shows three of these handpumps. A problem with handpumps is that they are labour intensive
and some of them are not appropriate for great depths making them susceptible to
contamination, low yields and drying up (MacDonald and Calow, 2009; Bonsor, MacDonald
and Calow, 2010).

Figure 2.9: Examples of handpumps used in Malawi
Source: (Pritchard et al., 2008)
Gravity fed systems (GFSs) are also used in Malawi both for drinking and irrigation water
(Kleemeier, 2000; Zuzani, Ackim and Kalulu, 2013). The source of water for GFSs is an upland
river, stream or spring and uses the force of gravity to transport water to communal tap stands
or irrigation canals, therefore is dependent on having a source of water on upland. The cost
of GFSs is higher than that of underground sources. However, GFSs have higher coverage
compared to handpumps (Baumann and Danert, 2008). Spring protection is another water
abstraction method used in Malawi, whereby the catchment and the head of a naturally
occurring spring are protected from pollution by constructing a collection chamber and layering
of impervious material above the springhead. In addition, the upstream is checked for
possibilities of pollution and if present they are corrected (Meuli, Vad and Wehrle, 2001).
2.5.5 Water quality in Malawi

Malawi is one of the 42% of least developed countries that met the MDGs target for drinking water, which was to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water”. The country progressed from 47% in 1990 to 86.2% in 2014, exceeding the country’s MDGs target of 74% (GoM, 2014; WHO & UNICEF, 2015). The WHO classifies boreholes as improved water sources, and acceptable for human consumption. However, in their research carried out in Blantyre, Chiradzulu and Mulanje (Pritchard, Mkandawire and O’Neill, 2007) found that water from the improved sources was contaminated with faecal coliforms, which are likely to cause disease. In their study in Chikhwawa, Zomba and Balaka (Pritchard, Mkandawire and O’Neill, 2008) indicated that around 80% of the samples, obtained from the covered wells, failed to meet safe drinking microbiological data water limits, set by WHO guidelines and Malawi Bureau of Standards. In terms of chemical quality the groundwater in Malawi was found to be generally good, although in a fewer localised locations such as in Chikhwawa the water was found to be saline (Monjerezi and Ngongondo, 2012; Grimason et al., 2013). Groundwater with excess fluoride content was found in Salima, Nkhotakota and Karonga lakeshore areas, and high sulphate was common in Dowa district (Msonda, Masamba and Fabiano, 2007; Chavula, 2012).

In Malawi, diarrhoeal diseases causes 18% of infant death (WHO, 2014a). One of the major reasons of the prevalence of diarrhoea is low access to safe drinking water, poor hygiene and sanitation (UNICEF and WHO, 2009). (Esrey et al., 1991) found that adequate safe water supply was important in reducing the rates of water related diseases such as ascariasis, diarrhoea, schistosomiasis, and trachoma. (Fewtrell et al., 2005) demonstrated that water, hygiene and sanitation interventions and their combinations were able to reduce diarrhoea disease by up to 42% depending on the intervention. Thus, domestic water interventions are carried hand in hand with hygiene and sanitation services in what is referred to as WASH (Water, Sanitation and Hygiene).

Another disease is Cholera, which has 3-5 million estimated global cases, and causes 100,000-120,000 deaths every year (WHO, 2014b). According to the World Health Organisation (WHO, 2010) cholera outbreak in Malawi is seasonal and occurs from September/October to April/May each year; which corresponds to the rainy season. This observation correlates with the findings of (Pritchard, Mkandawire and O’Neill, 2007, 2008) who found that water from shallow wells is more contaminated in the rain season than in the dry season. This is because the form of construction and method of water extraction for some of the boreholes allowed for contamination of water. Hardest hit by cholera, are districts subject to annual flooding (including lakeside fishing communities), areas with large migratory
populations and poor urban and peri-urban areas (UNICEF, 2004; WHO, 2010; Khonje et al., 2012; Msyamboza et al., 2014).

In summary, both the international and national studies point to the importance of improved drinking water, sanitation facilities and hygiene practices as a way of reducing most of the water-related diseases, particularly in developing countries. Therefore, researching on methods of improving water quality and quantity is quite significant for Malawi’s human well-being.

2.5.6 Management and sustainability of rural water supplies

The community-based management model is the accepted management model for rural water supply in low and middle-income countries (Baumann, 2006; Harvey and Reed, 2006; Moriarty, Smits and Butterworth, 2013; Hutchings et al., 2015). Under this model, the external institutions such as the government or donors pay the bulk of initial capital investment, with a contribution from users that is high enough to create a sense of ownership. However, this model has been found to have a number of challenges that include poor performance of service providers, high rates of hardware failure, and very low levels of service which raises questions about the effectiveness and sustainability of the model (Foster, 2013; Moriarty, Smits and Butterworth, 2013; Chowns, 2014). Non-functionality of handpumps is one of the impacts of failed management.

Authors such as (Harvey, 2004; Baraki and Brent, 2013) report that use of handpumps in Africa has been associated with high failure rate and lack of maintenance. For instance in 2007 access to safe water in Malawi was estimated at 75%, however, 31% of the water points were not working, and thus reduced the effective coverage to 55% (Baumann and Danert, 2008). Figure 2.10 illustrates the problem of non-functional boreholes and shows a map of Chiradzulu created in ArcGIS, a geographic information system (GIS) software. Chiradzulu is a district in the Southern Region of Malawi with an area of 767 km² and population of 236,050 (National Statistical Office, 2010). The map shows the working (green) and non-working (red) water points. The map also illustrates the urban-rural divide which can be appreciated by the plentiful number of water points at Chiradzulu Boma (which is urban) as compared to the six traditional authorities (TAs) which are predominantly rural area. (Chiradzulu District Assembly, 2007)
In a study of GFSs in rural Malawi, Zuzani et al. (2013), found that the systems were not sustainable and problems emanated from insufficient funding, ineffective community WPC, lack of training, age of the system and political interference. Similarly in another research in four districts of Malawi (Chowns, 2014) found that determinants of functionality were: water point type and installation quality, availability of funds, availability of skills, misuse of funds by WPC, frequency of maintenance and incidence of theft. In his research (Harvey, 2007) mentions challenges of lack of incentive for WPC who work on voluntary basis, departure of key individuals on the WPC with no mechanism to replace them, and loss of trust and respect of the WPC caused by lack of transparency and accountability. He further mentions failure to contribute maintenance fees, lack of contact with the implementing institution and sometimes communities were too poor to replace major capital items when they break down. He further notes that the perception that ownership leads to contribution of fees does not mean the
community will pay. In developing countries, solar water pumping systems face similar issues to handpumps such as ownership challenges, and theft and vandalism. (Short and Thompson, 2003) further notes that in some cases the application of the technology ignores the sociological and economic needs of the users, leading to lack of maintenance, inappropriate financing schemes, inadequate system management and, ultimately, failure of the pump.

Many donors or governments do not support the financing of operation, maintenance and rehabilitation costs of rural water supplies and assume communities would do so which, however, is not the case in many parts of Sub-Saharan Africa (Baumann, 2006; Harvey, 2007). In his research in Ghana, Harvey (2007) found out that direct operation and maintenance costs are generally affordable for rural communities, and he proposes that these costs be determined, so that communities, local authorities and implementing agencies are aware and can take action to sustain willingness to pay. In addition, he recommends development of appropriate community financing strategies, which are matched to the specific characteristics of the communities. On his part, (Baumann, 2006) proposes a system he calls ‘Community Management Plus’ which consists of a comprehensive operation and maintenance policy calculated and agreed upon by the community and government; the community pays more but the services are improved.

In their study (Harvey and Reed, 2006), recommend provision of institutional support to communities, provision of household and small user-group water supplies, and implementation of private sector service delivery models. Whereas (Chowns, 2014), firstly recommends the overhauling of the current financial model in the rural water supply which would emphasize payment for performance, rather than installations, such as an improved financial model would instead reward positives (such as continuous water point functionality) and penalise negatives (such as poor accountability). Secondly, she recommends professionalization of water point management by creating professional roles and incentive structures capable of delivering a steadily improving level of service rather than relying on poorly trained and demotivated WPC. Thirdly, she recommends transparency and accountability in construction standards, which the author found, was virtually non-existent at village level and sporadic at district level.

From their study (Moriarty, Smits and Butterworth, 2013), make several recommendations. Firstly, adoption of a range of contextually appropriate service levels which include indicators such as: quantity, quality, reliability, accessibility and service delivery models, which may include professionalization and support to community management such as involvement of private operators in a range of modalities and variation or self-supply. Secondly, life-cycle costing and asset management which considers the total costs of providing services at a defined level to a defined user population over time (Fonseca, Franceys and Batchelor, 2011).
The costs can be met by tariffs (user fees), taxes (internal public finance) and transfers (external development aid) (OECD, 2009). Thirdly, strengthening of the enabling environment like shifts in the legislative, policy and regulatory sectors to become more professional and service delivery oriented, and the need to clarify roles and responsibilities under different service delivery models, especially an appropriate balance between local government and communities.

In summary, the majority of these authors all agree that the current model has failed and requires change in such areas as alternative service delivery models, professionalization of community management, change in policy and regulation and adoption of life cycle costing for communities to pay, among other recommendations. To respond to these recommendations, the current research includes carrying out a techno-economic analysis to assess the life cycle costs and levelized cost of water, exploring the options of paying for water by carrying out a willingness to pay study, and understanding the country's rural water provision environment by carrying out a stakeholder analysis.

### 2.5.7 Water for agriculture

On the global scene irrigated agriculture is the biggest water user, with irrigation accounting for 70% of global water withdrawals, industry account for 20% and the rest 10% is for domestic sectors (Ringler and Lawford, 2013; UN WATER, 2014). Globally, agriculture is also the largest employer in the world and similarly in Malawi it contributes a large proportion to the country's economy and accounts for approximately 37% of the gross domestic product (GDP) and employs over 80% of the rural population. Irrigation is one of the actions that can enhance sustainable productivity in agriculture, which is one of the most effective ways to fight poverty and stimulate economic growth, particularly in the rural areas of developing countries. (FAO, 2011).

According to (Chavula, 2012) groundwater potential has not been fully exploited for irrigated agriculture. Studies to assess the quality of water for its suitability for irrigation have found that water in some parts of Chikhwawa is unsuitable for irrigation (and domestic) use because of high quantity of minerals with potential risks of low yield and damage to irrigation pipes (Monjerezi and Ngongondo, 2012). However in other places such as Rumphi and Karonga the groundwater was found to have low mineralisation indicating it was suitable for agriculture (Wanda, Gulula and Phiri, 2013). The authors suggest further investigations in the spatial variation of water quality for irrigation purposes. In agreement (Chavula, 2012; Mapoma and Xie, 2014) also recommend countrywide studies to assess the current quantity and quality of groundwater to understand how the resource has changed over time with a view to developing groundwater resources for the country.
Though Malawi is an agricultural country and recognises that irrigation plays a vital role in increasing agricultural productivity and achieving food security (GOM, 2002), still more than 99% of agricultural land at national level remains under rain-fed cultivation. This affects agricultural productivity owing to weather shocks and natural disasters such as droughts and floods (Action Aid, 2006; AfDB, 2013; Coulibaly et al., 2015), which are expected to continue because of the effects of climate change. The most recent drought in 2016 caused a food crisis in the country and it was declared a state of emergency (ALJAZEERA News, 2016), which drew international attention as shown in the news headlines excerpts in Figure 2.11. The country spent substantive amounts of money to import maize with borrowed money or donations (Capital FM, 2016; The Nation, 2016; The Times Group, 2016).

![News](image)

**Figure 2.11: New headlines about the extent of hunger in Malawi**

There are a variety of irrigation interventions that the government has done or has planned such as distribution of treadle and motorised pumps (Chidanti-Malunga, 2009; Kamwamba-Mtethiwa, 2016). According to the MGDS II (GoM, 2012a), the country intends to limit dependency on rain-fed agriculture, by utilizing water from lakes and perennial rivers to enhance the country’s production of a variety of crops, livestock and fisheries through a number of initiatives including irrigation so as to increase agricultural production and productivity through intensified farming such as the “Greenbelt initiative”. Using irrigation, households can plant more than once a year, which would increase agricultural productivity, and hence ensure food security, increased income and help reduce rural poverty. With increased income, the households would be able to send children to school, ensuring a more educated society and help break the vicious cycle of poverty (Burney and Naylor, 2012). RETs have the potential to provide innovative methods to improve the water sector in the rural areas where access to grid is not possible or may be uneconomical. At the same time, RETs can provide mitigation and adaptation to climate change.
2.6 Water pumping using RETs

2.6.1 Energy overview

Modern energy has the potential to address most of the global challenges and contribute positively to a country’s socio-economic development and human wellbeing as discussed in section 2.3. Energy economics studies are inconclusive on the role of energy in socio-economic development. For instance (Payne, 2010), had mixed results from a survey on the causal relationship between electricity consumption and economic growth. On the other hand, (Lee, 2005) shows that high energy consumption tends to have high economic growth and (Birol, 2007) suggests that making available relatively small quantities of modern energy services can bring about significant improvements in human welfare at relatively modest cost. He further argues that for the developed countries, energy played a role in their development and growing prosperity, though energy on its own does not cause development. In developing countries, limited access to electricity is a major obstacle to development and it is coupled with environmental degradation caused by overgrazing, deforestation and low-productivity agricultural methods which lead to soil erosion (Bazilian et al., 2011).

Though energy is a fundamental and vital service, almost 1.2 billion people representing 17% of the global population, did not have access to electricity in 2013, and even for those with electricity it is not without such problems as blackouts, intermittency and poor quality (Kessides, 2014). Additionally, more than 2.7 billion people which represent 38% of the world’s population are estimated to have relied on the traditional use of solid biomass for cooking (IEA, 2015). Most of the people who lack electricity and modern cooking fuels are from developing Asia and Sub-Saharan Africa, particularly from their rural areas. With 635 million people without electricity in SSA, it is the region with the highest energy poverty with an electrification rate of 43%, and rapid population growth playing a part. Developing Asia comes second with 526 million people without electricity and an electrification rate of 86% (IEA, 2015). (Birol, 2007) argues that the extensive use of traditional biomass and the limited availability of electricity and modern fuels for cooking and heating are causes, as well as manifestations, of poverty. On the other hand, to get out of poverty, modern energy services have to play a part even if the modern energy services are increased in small quantities.

To increase access, the governments of developing countries have to take profound action by putting enabling policies in place. Globally there are efforts to improve access such as the SDGs, earlier discussed. Another initiative is the Sustainable Energy for All (SE4All) (United Nations, 2010b) which was promoted by Ban Ki-moon through the Secretary-General’s Advisory Group on Energy and Climate Change and aims to support the world’s energy needs.
for development while at the same time contributing towards climate. Through these initiatives, countries are advised to take action in the way they produce, distribute and consume energy. Furthermore, the countries are advised to put in place financing mechanisms for RETs projects.

2.6.2 Malawi energy overview

The first Malawi national energy policy (GoM, 2003) was developed in 2003 and it summarised the needs of the country in terms of rural electrification, affordable energy, energy efficiency, renewable energy, mitigation of greenhouse gases, market reform and research and development. A new version of the energy policy is being prepared (GoM, 2015) and aims to address a variety of issues which include: addressing energy access in line with the SE4ALL, provision of sustainable and reliable energy, energy pricing, energy and climate, decentralisation of the department of energy, and social and gender commitments.

Figure 2.12 shows the past and projected energy mix patterns for Malawi. The utilized energy sources in Malawi are biomass, liquid fuels, electricity, coal and renewable energy. The data for 2008 to 2035 were obtained from the Malawi draft energy policy (GoM, 2015), whereas the data for 2000 are from the 2003 Malawi energy policy (GoM, 2003). The increase and decrease trend appearing on some of the data were on the assumption that these are short-term oscillations and would not be repeated. The diagram shows that the country is highly dependent on biomass. From 2003 to 2015, the proportion of biomass use reduced very little from 93% to 85.64%. The use of biomass is unsustainable and is one of the major causes of deforestation, exacerbated by high population growth and poverty. The use of liquid fuels increased from 4% to 9.74%. All liquid fuels are imported, which increases vulnerability and shocks due to the country's volatile economy.
The electricity category comprises large hydro and thermal (coal, heavy fuel oil and diesel) and in the energy mix, electricity represents a slight drop from 2.3% to 2.17%. Electrification rate is still low with only approximately 10% of the population connected to the grid and approximately 1% of these from the rural areas. The bulk of Malawi’s electricity supply is provided by hydropower from a cascaded group of interconnected power plants located on the Shire River in the South and a mini hydro plant on the Wovwe River in the North. This is discussed in detail in (Phiri, 2009). The generated capacity for the whole country is 351.64 with a customer base of 240,000 consumers (ESCOM, 2014). With this generating capacity for a population of almost 17 million, Malawi is one of the countries with the lowest energy access (IEA, 2015), therefore ways to improve access are required. Using renewables is one way of expanding energy access.

In the energy mix, the use of renewables increased from 0.2% to 2.17%. The renewable energy resources are not fully exploited. These include wind speed of between 2 and 6 m/s, solar radiation resources with maximum irradiation of 6.5-7.0 kWh/day/m² which occurs in September-October and minimum of 4.3-4.6 kWh/day/m² which occurs in January-February or in June-July according to location. There are also perennial rivers with a potential of 900 MW, large livestock population for biogas generation, and several hot springs that can be exploited for geothermal electricity production (GoM, 2003).

The Government of Malawi (Goma) has carried out several programmes and project to address the energy challenges and to promote renewables. These interventions include Barrier Removal to Renewable Energy in Malawi (BARREM), National Sustainable and
Renewable Energy Programme (NSREP), Programme for Biomass Energy Conservation (ProBEC), establishment of the Training and Testing Centre for Renewable Energy Technologies (TCRET) at Mzuzu University. Also included are the Malawi Rural Electrification Program (MAREP) and awareness campaigns on the radio and Village Community Solar/Wind pilot projects in six villages across the country. These interventions were discussed in (Phiri, 2009).

2.6.3 Water pumping using Solar PV

Renewable energy resources are defined by (Sorensen, 2004; Twidell and Weir, 2006) and include hydro, solar PV, solar thermal, wind, geothermal energy and marine (wave energy and tidal power). Furthermore, RETs are acceptable with the sustainable development drive in contrast to fossil and nuclear fuels. They can serve remote and rural areas where the national grid is not available, are environmentally friendly, have minimal operation and maintenance costs and reduce dependence on fossil fuels which face depletion (Sontake and Kalamkar, 2016). The major disadvantage of RETs is high capital costs.

Renewable energy sources for water pumping include solar PV, solar thermal, wind energy, biomass and hybrid with the most popular being solar PV and wind (Gopal et al., 2013; Chandel, Nagaraju and Chandel, 2015; Sontake and Kalamkar, 2016). These authors found that solar PV followed by the wind energy are the mostly widely used energy sources for water pumping, depending on the resource availability (Biswas, 2011; Gonçalves, Costa and Ramos, 2011). Despite the high capital costs, solar PV was rated highly over wind because it has low operation and maintenance (O&M) in addition to being environmentally friendly. Wind also has minimal maintenance and it is not prone to theft as compared to solar PV. Wind was generally recommended over solar in high wind regions (Suleimani and Rao, 2000; Omer, 2001; Biswas, 2011; Bouzidi, 2011). As for water purification, renewable energy found applications in water desalination albeit with need for further research (Eltawil, Zhengming and Yuan, 2009).

Global studies on solar PV water pumping systems (SWPS) span across engineering disciplines of mechanical, electrical, electronics, computer, control and civil engineering (Gopal et al., 2013; Chandel, Nagaraju and Chandel, 2015; Sontake and Kalamkar, 2016). The types of research areas covered include but are not limited to solar water pumping technology, performance analysis, optimum sizing, solar PV module performance, maximum power point tracking, pump and motor performance, technical design, economic viability, environmental aspects, advances in PV materials and efficiency improvements. The research approaches also vary and include experimental, theoretical and mathematical modelling. In view of the above-specified research areas, and the identified research gaps and the
objectives of this study, the fitting research area selected for the current study was to assess the technical and economic viability of SWPS in the rural areas of SSA with a case study of Malawi.

The main components of a SWPS consists of a water source, the solar array, motor-pump set, pump controller, charge controller, storage (solar batteries or tank), inverter, mounting structure, security fencing, balance of system, and discharge piping (Argaw, 2004; Meah, Fletcher and Ula, 2008; Gopal et al., 2013). The actual system equipment varies and can be classified depending on energy storage (battery coupled or direct driven), power input (DC or AC), type of pump (surface or submersible), and tracking of power source (fixed or tracking) (Chandel, Nagaraju and Chandel, 2015; Sontake and Kalamkar, 2016).

Four of the popular configurations are illustrated in Figures 2.13 to 2.16. Figures 2.13 also illustrates the total dynamic head (TDH) which is sum of suction head (height from suction point till pump), discharge head (height from pump to storage inlet) and frictional losses.

Figure 2.13: Schematic of a direct coupled SWPS with MPPT

Source: (Chandel, Nagaraju and Chandel, 2015)
Figure 2.14: Block diagram of a SWPS with solar battery storage

Source: (Chandel, Nagaraju and Chandel, 2015)

Figure 2.15: Block diagram of a direct coupled SWPS

Source: (Chandel, Nagaraju and Chandel, 2015)
A suitable water pumping system is selected by considering the wind/solar resource and the daily water requirement. According to (Argaw, 2004), a SWPS can be considered for areas with wind speed of less than 3 m/s, solar radiation of greater than 3 kWh/m²/day and at the same time the water requirement of a hydraulic load equivalent of between 250 m⁴ and 1000 m⁴. (Hydraulic equivalent load is explained in section 5.2.3). Otherwise, a handpump or diesel pump is considered. For lower capital and maintenance costs, the direct-coupled system is preferred; this stores water in a tank rather than storing energy using solar batteries.

2.6.4 Techno-economic feasibility studies

Economic evaluation is carried out using the life cycle cost analysis (LCCA). Since the generated electricity is used to pump water, the levelized cost of water (LCW) is calculated, though some authors also calculate the levelized cost of energy (Branker, Pathak and Pearce, 2011). A variety of tools can be used in the analyses of SWPS and may include worksheet-based tools and software tools such as HOMER, PVSYT, and RETSCREEN (Qoaider and Steinbrecht, 2010). For techno-economic feasibility studies, various authors widely used the worksheet-based tools method, which was adopted for this research.

(Parajuli, Pokharel and Østergaard, 2014), carried out financial modelling in a spreadsheet using net present value (NPV), LCW and annualised equivalent cost methodologies. The purpose of their study was to compare water-pumping costs for drinking water using solar PV, diesel and biodiesel for Nepal. The results showed that from the designed systems, solar PV was the most viable method in the study area. Using a similar methodology for a study in
Nigeria, (Cloutier and Rowley, 2011) carried out a techno-economic analysis to assess the feasibility of renewable energy sources and technologies to substitute fossil fuel-powered pumping platforms. In addition to solar PV, Cloutier and Rowley recommend wind-based systems over petrol, though wind was less favoured because of less resource availability and lack of suppliers in the study area.

For widely distributed populations these authors recommend handpumps which is in agreement with (Argaw, 2004) who recommends handpumps for loads of equivalent hydraulic energy of less than 250 m³ (see section 5.2.3) which are more economic in such instances. In many other cases SWPS were found to be viable over diesel such as a case study of Tall Hassan Station in Jordan Badia (Al-Smaïran, 2012). For refugee camps in Kenya, (Kraehenbuehl, Ibanez and Burt, 2015), it was necessary to have solar-diesel hybrid when the required pumping hours exceeded the sunlight hours.

Results of techno-economic analyses carried out by several authors are shown in Table 2.2. The table shows the array size, water demand, cost of system and LCW. The LCW range from US$0.03 to US$1.14 and is dependent on the system capacity and what components are included in the design as discussed in section 5.4.4.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Array size (kWp)</th>
<th>Water Demand (m³)</th>
<th>Cost of system (US$)</th>
<th>LCW (US$/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahin and Rehman (2012)</td>
<td>-</td>
<td>200</td>
<td>79,920</td>
<td>0.03</td>
</tr>
<tr>
<td>Bouzidi (2011)</td>
<td>-</td>
<td>60</td>
<td>24,450</td>
<td>0.14</td>
</tr>
<tr>
<td>Al-Smaïran (2012)</td>
<td>5.94</td>
<td>45</td>
<td>20,790</td>
<td>0.20</td>
</tr>
<tr>
<td>Cloutier &amp; Rowley (2011)</td>
<td>1.68</td>
<td>20</td>
<td>28,000</td>
<td>0.68</td>
</tr>
<tr>
<td>Raturi (2011)</td>
<td>6.40</td>
<td>26</td>
<td>43,300</td>
<td>0.70</td>
</tr>
<tr>
<td>Cloutier &amp; Rowley (2011)</td>
<td>2.52</td>
<td>30</td>
<td>38,700</td>
<td>0.87</td>
</tr>
<tr>
<td>Ramos &amp; Ramos (2009)</td>
<td>0.20</td>
<td>1</td>
<td>3,200</td>
<td>1.14</td>
</tr>
</tbody>
</table>

The other authors recommended solar PV because it has a reasonable payback time. A survey of 46 SWPS was carried out in rural areas of Mexico, which were installed to replace diesel systems in areas with no grid electricity. Ten years after installation, the majority of the systems were reported to be functioning with over 80% of the users satisfied with their reliability and performance (Espericueta, Pronaf and Juárez, 2004). The average investment payback was five to six years with the lowest reporting a payback period of two and a half years. (Jamil,
Anees and Rizwan, 2012) reports a payback period of less than four years for a water pumping system in India with an estimated life of 20 years translating into supply of free water for 16 years which is a huge saving; this though was for an academic institution rather than for rural dwellers.

In the same range a payback period of six years was also found by (Pande et al., 2003) who designed a drip irrigation for an orchard in the Indian arid zone and the system was considered to be an appropriate technology for the development of the region. Another application for irrigation water was carried out by (Mahmoud and el Nather, 2003) who found out that the cost of the water unit pumped by PV systems was much less than that pumped using diesel systems. The water cost was more sensitive to the PV cell's prices rather than the lifetime periods. From five sites of their research, Sahin and Rehman (2012) found payback period of 9.7 years and 11.7 years for their best and worst location, respectively.

Contrary to the other researchers, (Purohit and Kandpal, 2011) concluded that, with the prevailing costs and performance characteristics during the time of their study, SWPS were not financially viable to potential users in India. They however argued that provision of financial incentives such as capital subsidy and low interest loans or other suitable financial/fiscal incentives would improve their financial attractiveness. In addition to economic and technical viability, authors also cite other benefits such as being an environmentally friendly solution and that it contributes substantially to the satisfaction of remote communities' water consumption needs. In addition, adequate irradiance is readily available in most of the developing countries that lack water (Kaldellis, Meidanis and Zafirakis, 2011).

For projects to be successful and sustainable, authors recommend that the understanding of the community, water demand, the supply patterns and the technology's limitations have to be taken into account (Odeh, Yohanis and Norton, 2006a; Fedrizzi, Ribeiro and Zilles, 2009). Other factors to be considered include technology choice, affordability, social safeguards, environmental considerations, opportunities to initiate and enhance productive activities and institutional applications (Terrado, Cabraal and Mukherjee, 2008). In addition (Parajuli, Pokharel and Østergaard, 2014) recommends that stakeholders should have roles and responsibilities clearly defined regarding implementation and management of a water pumping system. In India, (Chandel, Nagaraju and Chandel, 2015) reports that the government provided guidelines to the manufacturers of PV panels and approved technical specification for SWPS, illustrating that the political will of a country also plays a role.

The high capital costs of SWPS make it one of the major disadvantages for people living in the rural areas of developing countries like Malawi. Several access models have been used in the past such as (Terrado, Cabraal and Mukherjee, 2008) who recommends consideration
of subsidies, consumer financing, low-cost technology options, and appropriate policies and business practices. For rural off-grid systems, (Bhattacharyya, 2013), discusses the following similar financing instruments:

i. rural electrification assistance (subsidy, donations and discounts);  
ii. funds (national or international, grants and partnerships);  
iii. micro-finance (credit, leasing and fee for service);  
iv. fiscal instruments (tax-exemption/reduction and bulk tendering; and  
v. other methods (quotas, feed-in-tariffs, and green certificate).

In Nepal the available RETs financing models include (Mainali et al., 2014):

i. Cash: Private or communities pay for cash and technologies included Solar Home System (SHS) and pico-hydro.  
ii. Credit: Dealers install for the rural people on credit and they pay monthly instalments and the technology normally are SHSs.  
iii. Mixed finance: The government is involved and offers subsidilys and the people pay the balance using bank credit or equity. The technologies in this model include SHSs, pico-hydro and micro-hydro.

This research adapted financing models proposed by (Biswas, Bryce and Diesendorf, 2001; Harvey, 2007). Harvey (2007) proposes the cross-subsidy financing model for SSA in which water is provided by a community-based organisation, individual or private organization. The model allows the poorest and most vulnerable to be supported and protected by the rest of the community. For the model to be effective, the community management has to be strong. Biswas et al. (2001) proposed their model for Bangladesh. With the assistance of an NGO, business, government or university representatives the communities would form organizations, comprising cooperatives or other forms of business. They would borrow money from a bank or large NGO, and purchase an RET to create income-generating activities based on biogas, solar or wind, depending upon location. By selling energy to wealthier members of the village, the communities would repay their loans, thus gaining direct ownership and control over the technology and its applications.

In Malawi financing of large projects is accomplished by utilising donations from multilateral organisations external governments and organisations such as UNDP, Practical Action, European Union and others (Phiri, 2009; Kaunda, 2013; Zalengera et al., 2014). However it has been reported that donations are unsustainable and sometimes have negative conditions attached to them (Zalengera et al., 2014). For small scale RETs households use their own
cash or get donations from well-wishers or politicians (Zalengera et al., 2014; Scott et al., 2016).

In summary the literature points out that for sustainable deployment of RETs, it is necessary to have appropriate business models depending on the country, community and type of technology.

2.6.5 Sensitivity analysis

Stakeholders such as investors, regulators, policy makers, funding agents, utility companies, and technology developers want to understand how the installation will compete relative to other technologies. They need to ascertain the risk associated with a new installation over its life cycle. Sensitivity analysis is used to evaluate the effects of uncertainty in an economic or financial analysis (Argaw, 2004; Darling et al., 2011), such as accepting or rejecting decision or investing in a new technology. Also, when trying to predict the economic decisions, such as predicting how consumers will react to an increase in electricity prices (Short, Packey and Holt, 1995).

Deterministic or stochastic methods can be used for sensitivity analysis (Soroudi and Amraee, 2013; Santos, Ferreira and Araújo, 2016). Deterministic methods are for short-term valuation of projects with little uncertainty. Stochastic methods such as Monte Carlo analysis allow for risk and uncertain parameters to be accounted for in quantitative analysis, decision-making, and are suitable for long-term valuations (Short, Packey and Holt, 1995; Jeon and Shin, 2014). One limitation of deterministic methods is that they do not give explicit probabilistic measure of risk exposure and includes no explicit treatment of risk attitude. On the other hand, the advantages of the method are that it can be used where there is little information, resources, or time to use more sophisticated techniques (Marshall, 1988).

The economic factors that cause data uncertainties and risk in the energy sector include salvage value, operating hours, fuel costs, and inflation, quantity of wind, solar irradiation and discount rates. The key technical factors include component life (economic life), major maintenance, and engine overhaul. After the life cycle costs (LCC), or net present value (NPV) of the system has been determined; the risk factors are varied from a common base-case assumption by a certain amount or percentage from the expected value. By varying the economic parameters between the worst and best conditions, the viability limits can be easily compared (Argaw, 2004; Soroudi and Amraee, 2013).

To conclude this section, published research on SWPS in Malawi is minimal hence this study aims to bridge that gap by contributing towards the topic, by evaluating the feasibility of SWPS with regards to the country’s geographical, technological and economic conditions. Though
solar PV is promising, just like in other developing countries economic barriers makes solar PV inaccessible to the rural communities of Malawi. Available SWPS are donor funded projects such as for demonstration initiatives and pilot studies such as the SWPS in the solar-wind hybrid villages, some health centre and schools (Phiri, 2009). Other SWPS have been installed, but data on these is hard to come by because there is no accessible database for the country and publications on such were also scarce.

2.7 Willingness to pay for water

2.7.1 Willingness and ability to pay

Willingness to pay (WTP) means the maximum amount that a person would be willing to pay for a service rather than do without it. Results of WTP studies are used in a variety of policy settings in providing improved water services such as to assist decision makers to develop a tariff structure and cost-benefit analyses (Al-Ghuraiz and Enshassi, 2005). On the other hand, affordability or ability to pay (ATP) is determined by the ratio of the amount paid for water to income. It is generally assumed that an ATP of no more than 5% is acceptable (The World Bank, 1993; Whittington, 1998). Results by this World Bank study found that ATP for water varied from less than 0.5% in Zimbabwe to as high as 10% in Nigeria. In Bangladesh the ATP for a public stand post was found to be approximately 0.7% and 1.7 % for the non-poor and the poor households respectively with an average of 1.1 % (Ahmad et al., 2003). Research on WTP is available for developed and developing countries; however, for Malawi such research was rare. Hence, the current research assessed willingness to pay for water for the rural households, to contribute to literature on the experiences of WTP in the rural areas of Malawi.

2.7.2 Contingency valuation method

The contingency valuation method (CVM) is a popular method that is commonly used by economists, policy makers, water utility organisations and market researchers to determine WTP of the respondents (Whittington, 1998; Alberini and Cooper, 2000; Carson, Flores and Meade, 2001; Koss and Khawaja, 2001). On the other hand the CVM is often criticized because of its hypothetical nature as discussed by (Carson, Flores and Meade, 2001). Despite the criticisms, international organisation such as The World Bank, Food and Agriculture Organisation (FAO) and Department for International Development (DFID) recommend the method and consider it as one of the most reliable methods to assess the demand for water and assess tariff for water projects (The World Bank, 1993; Batteson, Davey and Shaw, 1998; Alberini and Cooper, 2000).
In the CVM individuals are asked hypothetical questions on how much they would be willing to pay to access a resource or goods (Whittington et al., 1990). CVM is implemented in one of two ways. First is the open-ended or discrete choice method in which the respondents are directly asked to state their maximum WTP. In the second method called the dichotomous choice, referendum or bidding game approach, the respondent is asked whether they are willing to pay a specific amount of money and the question is repeated for a higher sum of money until settling for a maximum offered price.

There are several biases associated with the CVM method. The first one is hypothetical bias in which the respondents are not in a position where they actually make a payment, and therefore they do not recognize the implication of the scenario under consideration. Second is compliance bias in which the respondents provide answers, which they think the enumerator's organisation wants to hear. Third is information bias in which the information provided to the respondents does not truly represent the scenario under consideration (Piper and Martin, 1997). These biases may be avoided by good questionnaire design and the method of administration of the survey. Also the goods or services to be valued have to be explained properly (Carson, Flores and Meade, 2001). And in some cases CVM may need to be complemented by another investigation methods such as focus group discussions (Batteson, Davey and Shaw, 1998). Studies from developing countries on WTP for drinking water that used the CVM include Haiti (Whittington et al., 1990), Lao People’s Democratic Republic (Lopaying, 2004), Bangladesh (Ahmad et al., 2003) and (The World Bank, 1993).

2.7.3 Determinants of willingness to pay for water

Factors that influence a household’s willingness to use, or to pay for an improved water supply are socioeconomic and demographic characteristics of the household. In addition, the characteristics of the existing or traditional source of water compared to those of the improved water supply, and households’ attitudes toward government policy in the water supply sector and their sense of entitlement to government services (The World Bank, 1993; Whittington and Swarna, 1994; Ahmad et al., 2003). These characteristics will now be discussed.

2.7.3.1 Income level, expenditures, and assets

Income was found to be a significant determinant of WTP for water (Whittington et al., 1990; The World Bank, 1993; Ahmad et al., 2003). The World Bank Study suggests that income however was not the principal determinant of WTP but there were other contributing characteristics such as accessibility of current water supply, whether supply is public or private connection, or vendor-supplied. For a study in Lao PDR (Lopaying, 2004) found that the
significance of income as a determinant of WTP in the studied towns, depended on how much a particular town was paying at the time of the study.

2.7.3.2 Level of education

Educated households would be more aware of the health benefits of improved water supplies and hence would be more likely to use and be willing to pay more for improved services than households with lower educational levels. In addition, educated households might have higher opportunity costs for time spent collecting water hence they might be willing to pay more for improved service than would other households. For different developing countries, The World Bank study demonstrated that households with a few more years of education (one to five years) were willing to pay 7% to 50% more than less educated households. In agreement (Whittington et al., 1990; Ahmad et al., 2003) also found that education increased the WTP for water.

2.7.3.3 Gender

In developing countries, it is mostly women who bear the burden of collecting water including time costs. Women also have gender-specific needs in relation to sanitation leading to the belief that women should be willing to pay more for water (The World Bank, 1993; Batteson, Davey and Shaw, 1998). However, though the World Bank concluded that the gender of the respondent played an important influence in WTP, they found that the direction of the influence depended on the cultural context of the study. For example, in some cultures women do not have control over the households' finances hence would be unwilling to promise payment for water though they might have felt the need to do so. For a study in Haiti (Whittington et al., 1990), the results on gender were mixed and depended on whether the connection was public or private. In the rural areas of Kazakhstan (Tussupova et al., 2015), found that gender was not significant in determining willingness to pay for water.

2.7.3.4 Occupation

Farming families are compared with nonfarm families, or those in formal and non-formal employment, or between civil servants and non-civil servants. The results for the World Bank study were mixed, whereas for Bangladesh (Ahmad et al., 2003) found that households where the head was a farmer or in business or service, were willing to pay more for improved water services than households where the head was an agricultural labourer or engaged in other types of manual work. On the other hand, for Haiti (Whittington et al., 1990), found that differences in WTP between farming and non-farming households was not significant.
2.7.3.5 Size and composition of family

The test variables for WTP may include household size, proportion of adult women in the family, proportion of children in the family, age of respondent, religion, and work experience outside the community. The World Bank study found that household size and composition was not significant in determining WTP for water.

2.7.3.6 Cost

The World Bank Study found that costs in terms of both money and in time required to collect water were significant in determining WTP for water. For example, the study found that people living in water-abundant areas and spent less time collecting water are willing to pay less than people without readily available water. In Haiti (Whittington et al., 1990) also found that distance was significant in WTP. Related to distance is the level of service, which differentiates whether a connection is public or private. The World Bank Study found that households were willing to pay more for private connections than for access to a public tap. For a study in Lao PDR (Lopaying, 2004) found out that the ATP was greater when traditional water sources involved greater opportunity cost such as longer walking distance to get water or longer time for water collection. (Ahmad et al., 2003) also found out that people were willing to pay more to have a private connection than the public one because of the convenience of distance. On the other hand in Kazakhstan (Tussupova et al., 2015), found that those who already owned a private connection were willing to pay less than those who owned a public source because of the convenience of distance and charges; those who used public water sources had to travel longer distances and pay some charges.

2.7.3.7 Perceived quality and reliability

The World Bank Study showed that household would be more willing to pay for an improved source when the perceived quality of the existing or an alternative water source is poor and if the water source is reliable. For example, households were willing to pay more if they had saline water than households with good quality groundwater. In Bangladesh (Ahmad et al., 2003) found that the higher the awareness and concern for arsenic contamination the greater the WTP for improved water services, implying health benefits where a determinant of WTP. Similarly in Kazakhstan, private water users who perceived their water to be of good quality were willing to pay less than those who used public sources (Tussupova et al., 2015).

2.7.3.8 Attitude

The World Bank study found that the attitude of the households toward government provision of water services was significant in determining the WTP for water. For example, those
households who felt they were entitled to free or subsidized water were willing to pay less for water services. For example, when new Governments promise free water just before elections, the rural households perceive the provision of clean water to be a necessary government responsibility. However other households who had given up on the promises of free water were willing to pay more than those who still believed it was the government's responsibility (The World Bank, 1993). Table 2.3 summarizes results on determinants of WTP as discussed in this section.

Other determinants are particular to irrigation water and include family labour force, area under cultivation, water requirement, type of supply, distance to market, access to credit, access to training and extension services and years of experience in farming (Chandrasekaran, Devarajulu and Kuppannan, 2009; Tang, Nan and Liu, 2013; Namyenya, Sserunkuuma and Bagamba, 2014; Urujeni and Ngabitsinze, 2015).

Table 2.3: Determinants of WTP for drinking water

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>The World Bank</th>
<th>Ahmad</th>
<th>Whittington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>sig</td>
<td>sig</td>
<td>sig</td>
</tr>
<tr>
<td>Education</td>
<td>sig</td>
<td>sig</td>
<td>sig</td>
</tr>
<tr>
<td>Gender</td>
<td>sig</td>
<td>n/a</td>
<td>mixed</td>
</tr>
<tr>
<td>Occupation</td>
<td>mixed</td>
<td>n/a</td>
<td>ns</td>
</tr>
<tr>
<td>Household size</td>
<td>ns</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Distance</td>
<td>sig</td>
<td>n/a</td>
<td>sig</td>
</tr>
</tbody>
</table>

sig=significant, ns=not significant, n/a=not applicable

2.8 Chapter summary

This chapter described sustainable development with reference to the MDGs, SDGs and the MGDS at Malawi national level. The research selected water provision as the basic need to be addressed and the study was guided by the SLF. Water provision has the potential of affecting other developmental sectors such as health, education, gender equality and women empowerment, health and education. An overview of the current water situation in Malawi established that both surface and groundwater are available but that the water sector faces many challenges, among them financing issues, quality and non-functionality. In addition, the literature review revealed that the community water-management model, used for rural water provision in the rural areas, has failed and needs review. One of the ways to finance rural water supplies is to pay for water; hence, literature on the contingency valuation method which is used to assess willingness to pay was discussed. It was proposed to use solar PV for water pumping; therefore, literature on the techno-economic feasibility of SWPS was reviewed.
The literature review revealed that there was limited published research on SWPS, willingness to pay and stakeholder analysis for Sub-Saharan Africa and particularly for Malawi. Unlike, previous research which looked at each of these topics independently, this study integrated these studies. Having identified the gaps, the next chapter discusses the methodology employed for this study.
3 Research Methodology and Design

3.1 Introduction

This chapter describes the detailed approach and methods used to conduct this research. The aim of the research was to develop a planning and investment decision-support model for sustainable water provision in the rural areas of Malawi based upon renewable energy sources. Using a mixed methods approach, the research consisted of quantitative, qualitative and techno-economic evaluation components and cuts across issues of energy and water. Further, the chapter describes the geographical setting of the research followed by the research design, which highlights the methodology used to achieve the objectives. Furthermore, the chapter describes the data collection methods, which consisted of a household survey, semi-structured interviews, focus group discussions (FGDs) field visits and observations. The quantitative data were analysed using descriptive and statistical analyses whereas the qualitative data were analysed using thematic and stakeholder analyses. The ethical considerations and limitations of the mixed research components of the study were also discussed. The chapter further describes the technical design and economic analysis of a solar PV water pumping system for a case study village, and concludes with a summary and discussion.

3.2 Overview of research setting

The study was carried out in Malawi, which is located in Southern Africa and is the researcher’s country of origin and normal residence. Malawi provided a suitable case study for the exploration and application of renewable energy to aid sustainable development, with particular emphasis on water provision for two reasons. Firstly, Malawi is one of the 10 countries with least access to electricity with a national electrification rate of 12% (IEA, 2016). Only 4% of rural households have access to electricity as compared with 49% in urban areas (National Statistical Office and ICF, 2017). Secondly, the majority of the people live in poverty; Malawi has a Human Development Index ranking of 170/188, with 50.7% of the population living below the national poverty line and 70.9% of the population living on less than purchasing power parity of US$1.90 per day (UNDP, 2016).

Figure 3.1 is a map of Malawi, which shows the three regions, 28 districts, and the location of Chiradzulu, the case study district. Malawi lies between latitudes 9°22’S and 17°03’S and longitudes 33°40’E and 35°55’E. It is a landlocked country bordered by the United Republic of Tanzania to the north and northeast, Mozambique to the east, south and southwest, and Zambia to the west. The country has a total area of 118 480 km² and is approximately 900 km
long, with a maximum width of approximately 250 km. Lake Malawi is a fresh water lake (also referred to as Lake Nyasa in Tanzania) and is the third largest in Africa. With the addition of a few other smaller lakes and many rivers and streams, Malawi has abundant freshwater resources that take up approximately 20% of the country’s area. (Central Intelligence Agency, 2017).

Administratively, Malawi is divided into three regions, which are further divided into 28 districts. The country has four cities and some town councils, which together with 28 district headquarters and some trading centres make up what are called the urban areas whilst the rest are classified as the rural areas. Approximately 20% of the population live in the urban areas whereas the rest 80% live in the rural areas. In 2015 the population was estimated at 17.22 million (The World Bank, 2015). Each district is divided into traditional authorities (TA), which are ruled by chiefs, these positions are hereditary, and hence the appropriate clans nominate them. A TA is composed of villages, which in turn are made up of households. The village is the smallest unit and is under the leadership of a village headman/woman (Commonwealth Local Government Forum, 2015).

The household survey was carried out in Chiradzulu, which is one of the 28 districts and is in the Southern Region of Malawi. The district area is 767 km² and is divided into 6 TAs. According to the District Commissioner, the district has approximately 787 villages and the population was estimated at over 390 000, Phiri, A, District Commissioner (Personal communication, 9th July, 2015). It is the second most densely populated district in the country second to Likoma Island.

Chiradzulu is one of the poorest districts and in 2007 had 63.5% of the population living below the international poverty line of US$1.25 per day, despite the district being only 25 km from the commercial city of Blantyre. In addition to poverty which results in food insecurity, other challenges in the district included high prevalence of HIV among the adult population, low education levels, lack of infrastructure, markets and job opportunities (Chiradzulu District Assembly, 2007).

Chiradzulu was selected as a case study district because, firstly, from literature search it was one of the districts in which water quality studies were published (Pritchard, Mkandawire and O’Neill, 2007). Secondly, of these districts, Chiradzulu was the poorest. Only one district was selected for study because the available funds for the research were limited.
Figure 3.1: Administrative Map of Malawi showing location of Chiradzulu District

Source: (Nations Online Project, 2017)
3.3 Research design

This thesis employed the interdisciplinary research (IDR) mode, which consisted of techno-economic evaluation and mixed methods research design. The research approach is illustrated in Figure 3.2 and the process is hereinafter discussed.

![Figure 3.2: Schematic representation of the methodology employed in this research](image)

IDR is defined as:

- Quantitative methods
- Techno-economic analysis
- Qualitative methods
- Solar Resource
  - Water Demand
  - WTP
  - Component costs
- Interviews
  - FGDs
  - Observation
- Thematic and Stakeholder Analyses
- Descriptive Statistics
  - Statistical Analyses
- Technical Design
  - Economic Analysis
- Relationships
  - Measures
  - WTP
- Levelised cost of water
  - Payback period
- Themes
  - Charts
  - Case studies
- Sustainable water provision model
“… a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice” (National Academy of Sciences, 2005) (p.2).

The IDR approach was adopted because the nature of the topic is too broad to be adequately addressed by a single discipline; hence, the fields of engineering and technology, social sciences and economics were used. Furthermore, it is problem-focused and addresses issues of social, technical and policy relevance with less emphasis on discipline related outcomes (Tait and Lyall, 2004; National Academy of Sciences, 2005), making it applicable for IDR approach.

Mixed methods were used as the method of inquiry and this method:

“… focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone” (Creswell, Plano Clark and Clark, 2011). (p.5)

Since its origin in the late 1980s, mixed methods has become one of the popular methods in diverse disciplines and applications (Johnson and Onwuegbuzie, 2007; Creswell, Plano Clark and Clark, 2011). However, the method is not meant to replace each one of the methods (quantitative or qualitative) but to capitalize on the strengths and reduce the weakness of each of the methods (Johnson and Onwuegbuzie, 2007). Characteristics of quantitative and qualitative research methods are summarised in Table 3.1. In mixed methods, quantitative and qualitative data can be combined in one of the following three ways (Bryman, 2006; Johnson and Onwuegbuzie, 2007; Creswell, Plano Clark and Clark, 2011):

- concurrently, in which the researcher converges quantitative and qualitative data to provide a comprehensive analysis of a research problem;
- sequentially, which seeks to elaborate or expand the findings of one method with another method; and
- multi-phase combination (combines sequential and/or concurrent).

The mixing can occur during interpretation, data analysis, data collection or at the design level and the data may be emphasized equally or unequally.
### Table 3.1: Characteristics of the Research Approaches

Adapted from: (Tashakkori and Teddlie, 1998; Mack et al., 2005; Creswell, 2013; Yin, 2014; Babbie, 2016)

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose</strong></td>
<td><strong>Purpose</strong></td>
</tr>
<tr>
<td>- Deductive- testing of theory</td>
<td>- Inductive-generating of theory and hypothesis</td>
</tr>
<tr>
<td>- To quantify variation</td>
<td>- To describe variation</td>
</tr>
<tr>
<td>- To predict causal relationships</td>
<td>- To describe and explain relationships</td>
</tr>
<tr>
<td>- To describe characteristics of a population</td>
<td>- To describe individual experiences</td>
</tr>
<tr>
<td>- Can be valid and reliable: largely depends on the measurement device or instrument used</td>
<td>- To describe group norms</td>
</tr>
<tr>
<td>- Can be valid and reliable: largely depends on skill and rigor of the researcher</td>
<td>- Uses semi-structured methods such as in-depth interviews, document review, focus groups, and observation</td>
</tr>
<tr>
<td>- Uses highly structured methods such as questionnaires, surveys, and structured observation</td>
<td>- Open-ended</td>
</tr>
<tr>
<td>- Closed-ended</td>
<td>- Variables are complex, interwoven, and difficult to measure</td>
</tr>
<tr>
<td>- Variables can be identified, and relationships measured</td>
<td>- Textual (obtained from audiotapes, videotapes, and field notes)</td>
</tr>
<tr>
<td>- Numerical (obtained by assigning numerical values to responses)</td>
<td>- More subjective: describes a problem or condition from the point of view of those experiencing it</td>
</tr>
<tr>
<td>- More objective: provides observed effects of a program on a problem or condition (as interpreted by researchers)</td>
<td>- Time expenditure lighter on the planning end and heavier during the analysis phase</td>
</tr>
<tr>
<td>- Time expenditure heavier on the planning phase and lighter on the analysis phase</td>
<td>- More in-depth information on a few cases</td>
</tr>
<tr>
<td>- Less in-depth but more breadth of information across a large number of cases</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Data Collection</th>
<th>Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Uses highly structured methods such as questionnaires, surveys, and structured observation</td>
<td>- Precision - through quantitative and reliable measurement</td>
</tr>
<tr>
<td>- Closed-ended</td>
<td>- Statistical techniques allow for sophisticated analyses</td>
</tr>
<tr>
<td>- Variables can be identified, and relationships measured</td>
<td>- Easy replicated</td>
</tr>
<tr>
<td>- Numerical (obtained by assigning numerical values to responses)</td>
<td>- Allows generalising to broader population</td>
</tr>
<tr>
<td>- More objective: provides observed effects of a program on a problem or condition (as interpreted by researchers)</td>
<td>- Has higher credibility with many people in power</td>
</tr>
<tr>
<td>- Time expenditure heavier on the planning phase and lighter on the analysis phase</td>
<td>- Provides deep, rich and detailed information</td>
</tr>
<tr>
<td>- Less in-depth but more breadth of information across a large number of cases</td>
<td>- The voices of participants and details of experiences are heard, and it may reveal information that would not be identified through pre-determined survey questions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- It fails to take account of people's unique ability to interpret their experiences, construct their own meanings and act on these.</td>
<td>- Inadequate validity and reliability</td>
</tr>
<tr>
<td>- Difficulty in recognizing new and untouched phenomena</td>
<td>- Cannot be replicated to any extent nor can generalisations be made to a wider context than the one studied with any confidence.</td>
</tr>
<tr>
<td>- Larger samples must be studied</td>
<td>- The time required for data collection, analysis and interpretation is lengthy.</td>
</tr>
<tr>
<td>- Knowledge produced might be too abstract and general.</td>
<td>- Issues of anonymity and confidentiality present problems when reporting findings.</td>
</tr>
</tbody>
</table>
The mixed methods design was chosen because with the nature of research problem, it was possible to synthesise complementary quantitative and qualitative results to develop a more complete understanding of the problem (Creswell, Plano Clark and Clark, 2011). Specifically, it allowed for the following: Firstly, it offset the weaknesses and drew on the strengths of both methods. The quantitative method allowed statistical analyses to be carried out for Chiradzulu District, which can be replicated in other districts of the country. The qualitative method allowed for rich and detailed phenomena of water provision in the country to be expressed in a way that could not have been revealed in the quantitative study alone. Secondly, it allowed for triangulation of data, for ensuring validity, credibility, and reliability of the results. Lastly, it provided a more comprehensive account by generating complementary data that was brought together in order to elaborate, enhance, illustrate and clarify on the research objectives (Johnson and Onwuegbuzie, 2007; Creswell, Plano Clark and Clark, 2011; Bryman, 2012). Despite its valuable applications, mixed research methods have some challenges over either quantitative or qualitative alone; such as difficulty for the researcher to acquire experience in both qualitative and quantitative research (design, execution, data collection, analysis, and interpretation), it is time consuming and expensive. However, the advantages outlined in the preceding paragraph outweighed the disadvantages hence for this study; the mixed methods approach was used.

3.3.1 Household survey

3.3.1.1 Introduction

The household survey was carried out to understand the water and energy needs and willingness to pay (WTP) for water in the rural areas of Malawi and thereafter explore sustainable solutions to the water and energy challenges. A mixed-mode survey as described by (Babbie, 2016), consisting of questionnaires, semi-structured interviews, observations and focus group discussions (FGDs) was employed and the household was the unit of analysis and the preferred respondent was the household head. The quantitative methodology was dominant and semi-structured interviews, observations and FGDs provided for triangulation. Triangulation is defined as “the employment of a number of different research techniques, in the belief that a variety of approaches gives the best chance of achieving validity” (Laws, Marcus and Harper, 2003). Specifically, the household survey sought to:

- determine the water and energy requirements of people living in the rural areas of Malawi with case study of Chiradzulu District;
• explore water and energy-related challenges experienced in terms of sustainable development and human well-being; and

• Determine the willingness to pay (WTP) and factors that predict the WTP for water.

### 3.3.1.2 Sampling criteria for household survey

The multi-stage cluster sampling method was used for this research and it was deemed ideal because it is applicable in populations that cannot be easily listed for sampling purposes (Bryman, 2012; Babbie, 2013; Laws, Marcus and Harper, 2003), which was the case for Chiradzulu District. In such cases, where a listing of all eligible individuals is not available, the simple random sampling method cannot be performed. Cluster sampling is also ideal for researchers who do not have enough funding and/or time because cluster surveys are more efficient in terms of costs, transportation and time. The disadvantage of cluster method is that it gives less precise estimates compared to a simple random sample of the same size. However, for this study, its advantages (less costs and time) far outweighed the disadvantages (Czaja, Blair and Blair, 2014).

This research adapted the “30 by 7” two stage cluster sample method developed by WHO, implying that 30 villages and a minimum of 7 households per village were interviewed (Hoshaw-Woodard, 2001). This method is recommended for developing countries because of its simplicity. The first stage of the cluster-sampling unit is usually a geographic area, such as enumeration unit, census tract, or a community; for this research, it was the village. At the second stage, a sample of elements within each of the selected clusters is assessed (frequently households or individuals within households), which in this research was the household.

The map of Chiradzulu District is shown in Figure 3.3, showing the 30 villages that were sampled. Participants were those living in the rural areas of Malawi hence trading centres were excluded because they are classified as the urban area. After getting permission from the district commissioner, to conduct the study in Chiradzulu, Health Surveillance Assistants (HSAs) based at the health care centres were identified as ideal gatekeepers. HSAs are familiar with the villages within the radius of their health centres and are well known by the village headmen and the villagers, hence it was easy to have access to the villages and have them introduce the research team.
3.3.1.3 Data collection instrument for household survey

A questionnaire was chosen as the data collection instrument for this survey and was developed with reference to previous studies identified in the literature review (The World Bank, 1993; Ahmad et al., 2003; WHO/UNICEF, 2006; Adkins, Oppelstrup and Modi, 2012; National Statistical Office, 2012) and guidance from supervisors. The questionnaire had three sections and an appendix. The first section sought information on the socio-economic factors of the household and questions were based on household characteristics such as size of household, income, expenditures, and employment status. The second section was on water access and sought to know about sources of drinking water, quantity collected, challenges, and WTP for both drinking water and water for agriculture. The contingency valuation method (CVM) (Whittington, 1998) was used to estimate households’ WTP and is described in section 2.7.2. The third section was on energy access and asked about sources of energy, challenges, current cost of energy, aspired businesses, and WTP for some of the reported energy needs. Lastly, the appendix was included to allow for calculation of the households’ income, in cases where households did not know their income.
Using guidelines for asking questions from (Bryman, 2012; Fowler, 2014; Babbie, 2016), it was ensured questions were clear, short, and relevant so that respondents would be willing and competent to answer. Double-barrelled questions, biased items and negative terms were avoided. The questionnaire included both open-ended and closed-ended questions. The open-ended questions were later coded according to the frequency of responses to allow for quantitative data analysis.

It was necessary to translate the household questionnaire to the local language (Chichewa); hence, back-translation of the questionnaire as recommended by (Brislin, 1970; Chapman and Carter, 1979) was undertaken by two lecturers at the University of Malawi. A pilot study was carried out at Nkwanda Village, T/A Likoswe, which is one of the villages in the study district. Corrections and adjustments were made to the questionnaire according to the comments and responses from the pilot study. The final household questionnaire is presented in Appendix 3.

3.3.1.4 Administration of the household questionnaire

There are various methods of administering questionnaires, which include post, internet-based, telephone, face to face, and self-administered. The advantages and disadvantages of each method are well documented by (Blaxter, Hughes and Tight, 2006; Babbie, 2016). For this research and with the type of respondents involved, the face-to-face administration by an enumerator was the most feasible method because for people living in the rural areas, access and availability of telephone, internet and personal mailboxes is minimal and rendered these methods almost impossible. High illiteracy levels made self-administered questionnaires unfeasible. Advantages of face-to-face interviews applicable to this survey were:

i. toleration of longer interviews;

ii. provision for validity such as checking the size of container used for collecting water or whether water was covered;

iii. higher completion rate;

iv. elaboration on questions by the enumerator; and

v. Probing for answers by the enumerator

On the other hand, for this research two major disadvantages of face-to-face administration were encountered. Firstly, with no proper roads, access to the rural areas was difficult; this increased the travel costs because a vehicle had to be hired. Secondly, research assistants were required to facilitate the face-to-face administration of the questionnaires and they had to be paid, hence also inflating the research costs.
Five research assistants were employed, and they were all fluent in Chichewa (the local language) and English. All had previous experience as enumerators in similar surveys run by the Departments of Environmental Health and of Environmental Sciences at the University of Malawi. Of these, two had experience as FGDs facilitators and one had experience as data entry clerk. Lecturers from the Environmental Health Department together with the researcher facilitated two days training for the research assistants. The major topics and activities included in the training were adapted from (Fowler, 2014; Babbie, 2016) and included:

i. Background to the survey research and definition of terms;

ii. Roles and responsibilities including effective introduction, good communication skills, appropriate dressing, good first impression, and unbiased probing;

iii. Ensuring confidentiality and privacy of collected data;

iv. Effective interviewing techniques;

v. Discussion over each item on the questionnaire, how to present questions and how to record responses;

vi. Information on where to refer respondents with questions and/or concerns; and

vii. Role-playing practice and a pilot study in the field.

Figure 3.4 shows the pilot study interview with the village headwoman who is facing the four enumerators, with the HSA standing in the background.

Two enumerators (one male and one female) were assigned to a village at a time. An introductory in-depth semi-structured interview was held with the village head to get the background information of each village, available facilities and aspired facilities for their village. Thereafter, questionnaires were administered to the households at their premises. Figure 3.5 illustrates one such interview in progress. Before each interview, the enumerators introduced themselves and made efforts for the respondent to be at ease. The enumerator read, in the local language the information sheet (Appendix 3.2) and the consent form (Appendix 3.3) making sure the participant gave their consent. Though the questionnaire was directed to the head of household, in some instances the head was often together with their spouse. In most cases, the male heads referred some of the questions such as on water and firewood collection to their wives and/or children who were more conversant with such issues.
After the introduction, the enumerator asked questions, as they appeared in the questionnaire in the local language and in the same way for all the respondents. In some instances, the enumerator could probe for incomplete answers in an indirect way. The enumerator recorded the answers for the closed-questions on the questionnaire by selecting from the choice of pre-coded answers. For open-ended questions, the enumerators were trained to record the answers as given by the respondent. At the end of the day, all the completed questionnaires were reviewed to verify whether instructions for completing the questionnaires were followed and that they were legible.
3.3.2 Stakeholder interviews

The qualitative phase of the data collection was carried out from October to December 2015 and involved interviews with the key stakeholders in the energy and water sectors in Malawi. All the interviews were done by the researcher and were held at the stakeholders’ premises. Except for the field visits, all interviews were done in English. These stakeholders were largely based in the cities of Lilongwe and Blantyre. Lilongwe is the capital city of Malawi and the Central Region capital whereas Blantyre is the commercial city and the capital for the Southern Region. The interviews were complemented with four field visits. Purposive sampling method was used to identify the key stakeholders who included government departments, non-governmental organisations (NGOs) and private organisations that are in water, renewable energy and microfinance sectors. In purposive sampling the researcher aims to sample those that are more knowledgeable and relevant to the research questions of the study (Bryman, 2012) and at the same time ensure that there is wide variety of participants. Each organisation was first contacted by phone to ask for the possibility of holding an interview and for them to give the name of the contact to be interviewed. Thereafter, an email with a request letter was sent to the responsible person to arrange on the date, venue and time of interview.

There are several methods of collecting stakeholder views which include FGDs, workshops, phone interviews and semi-structured interviews or a combination of these methods (Reed et al., 2009). The study used in-depth semi-structured interviews, which were found to be cost-effective. FGDs and workshops require bringing stakeholders together which involves transport, accommodation and food among other costs and this study’s budget was not able to cover these costs for all the interviewees.

An interview guide as shown in Appendix 3.4 was prepared in view of the research questions and was used to guide the interviews. The research sought information on the following areas:

i. Organisations’ roles, responsibilities, and experiences in the areas of water provision in the rural areas of Malawi and/or solar PV and micro-finance opportunities;

ii. Description of collaboration with other stakeholders;

iii. Opportunities and barriers to the achievement of water provision (using solar PV); and

iv. Recommendations about sustainable water provision using solar PV.

The researcher was flexible and could follow up on a question or ask questions that were not in the guide. The conversations were recorded by taking down notes and by using a voice recorder, having had obtained permission from the interviewees at the start of the interview. The interviews lasted for 35 to 60 minutes and for those that were not available for a face-to-
face interview, the questions were sent to them by email and the responses returned by email as well.

### 3.3.3 Focus group discussions

These were held to triangulate the data collected from the household survey. Arrangements were made with the village head through the HSA to assemble the group for the following day’s discussion. In total four FGDs from four villages were conducted with: males only group with eight participants (Potani Village), females only group with nine participants (Mataka Village), male and female combination group with 15 participants (Khaoreya Village), and WPC group consisting of males and females with 8 participants (Khumunye Village). The meeting was held at the usual meeting place for the particular village and it was ensured that the atmosphere was relaxed. Figure 3.6 shows the meeting at Mataka village which was held on a flat rock under the shade of a big tree. On average, the FGDs lasted 45 minutes each. The FGDs complemented the questionnaire, therefore the guide questions were on water and energy, similar to the household survey questions. The discussions were recorded using a voice recorder and note-taking as recommended by (Puchta and Potter, 2004; Rabiee, 2004; Babbie, 2016).

![Figure 3.6: Women’s FGD in progress](image)

### 3.3.4 Observations

Direct observations were made throughout the data collection period and recorded in form of photographs and written notes. Observed data were useful in providing additional information on the data collected from the surveys or interviews as recommended by (Kawulich, 2005).
3.4 Data analysis

3.4.1 Household survey data analysis

The household survey data were analysed using (Statistical Package for the Social Sciences) SPSS for Windows Version 23. It is the most widely used computer software for the analysis of quantitative data for social scientists because it has a wide range of statistical capability (Bryman, 2012; Babbie, 2016). The data were coded and entered into the database and was analysed following the procedures illustrated in Figure 3.7 as described by (Leech, Barrett and Morgan, 2011; Field, 2013; Pallant, 2013).

![Flow chart of data analysis process]

Figure 3.7: Flow chart of data analysis process
Source: (Leech, Barrett and Morgan, 2011; Pallant, 2013)

3.4.1.1 Exploratory data analysis

Descriptive statistics were used for data cleaning, summarising, and checking if the variables conformed to the statistical techniques to be used in the analysis. In data cleaning, data were examined for accuracy regarding the codes (checking for missing values, errors in inputting data, and problems with coding); any errors were corrected by crosschecking with the...
questionnaires. Cases with missing data or non-applicable cases, were excluded hence the number of responses, \( n \), may differ in some of the analyses. After data cleaning, 219 questionnaires out of 225 were deemed correct for analysis.

Secondly, the data were summarised using univariate analysis which is the simplest form of quantitative analysis, which is used when only one variable is involved and its purpose is descriptive rather than explanatory (Bryman, 2012). Relevant results were presented as descriptions, frequency distributions, grouped data, measures of central tendency (average, median, and standard deviation), and pie charts and bar charts, to give a pictorial view.

Thirdly, some variables were recoded into a form to enable particular analyses to be carried out; for example, for some analyses, income was recorded from a continuous variable to quartiles and the marital status was collapsed into just two categories representing people ‘in a relationship’ or ‘not in a relationship’. Some categories with fewer representations were collapsed into the ‘other’ category.

Finally, the results of the descriptive statistics revealed that the data were not normally distributed which violated the requirements of the parametric tests. Parametric tests are designed for data that have certain characteristics, such as normal distributions; otherwise, nonparametric test should be used. Hence for this study, nonparametric tests such as \( \chi^2 \)-square, Mann-Whitney \( U \), and Spearman rho were used as these have fewer assumptions (Leech, Barrett and Morgan, 2011; Pallant, 2013).

### 3.4.1.2 Statistical data analysis

The analysis of two variables is called bivariate analysis and is used to explore the relationship between the variables (Bryman, 2012). Specifically, statistical analysis to compare groups (Mann Whitney \( U \) test) and statistical analysis to explore relationships (correlation and regression) were performed and are now described.

Correlation analysis is used to describe the strength and direction of the linear relationship between two variables. Pearson \( r \) is designed for parametric variables whereas Spearman’s rho is designed for use with nonparametric data. A positive correlation indicates that as one variable increases, so does the other, whereas a negative correlation indicates that as one variable increases, the other decreases. The correlation coefficient lies between zero and one. The closer the coefficient is to one, the stronger is the relationship and as the coefficient gets closer to zero, the weaker the relationship (Bryman, 2012). Since the data for this study was nonparametric, spearman’s rho was performed to find the relationship between the income and the socio-economic variables such as household size, water consumption and education.
Regression analysis is a way of predicting an outcome variable from one or more predictor variables. A model is fitted to data and is used to predict values of the dependent variable from one or more independent variables (Field, 2013). When the dependent variable is categorical, it is called logistic regression and when it has only two categories, it is known as binary logistic regression. In this study, binary logistic regression was used to determine the factors that predict WTP for water as detailed in section 4.6.3.

The Mann-Whitney U Test is a nonparametric test used to test for differences between two independent groups on a continuous measure. The test compares medians whereas its equivalent parametric test, the t-test, compares the means of the two groups. This research tested whether males and females differ in terms of their income and WTP for water.

3.4.2 Qualitative data analysis

Qualitative data were analysed using the thematic analysis and stakeholder analysis. Thematic analysis is defined as "... a method for identifying, analysing and reporting patterns (themes) within data" (Braun and Clarke, 2006). It minimally organizes and describes the data set in 'rich' detail and it is suited to a wide range of research interests and theoretical perspectives (Clarke and Braun, 2013). These authors give four advantages of thematic analysis as follows:

- works with a wide range of research questions;
- can be used to analyse different types of data such as data from secondary sources media and transcripts of focus groups or interviews;
- works with large or small data-sets; and
- can be applied to produce data-driven or theory-driven analyses.

Thematic analysis is carried out in six steps, which are illustrated in Figure 3.8. The listed steps are not linear but rather are repeated until the researcher is satisfied with the results.

Familiarisation with the data were achieved by listening to the audio-recorded data for several times and improving the interview notes. Manual coding was used to generate an initial list of items from the data that had a reoccurring pattern and was relevant to the research objectives. This process was repeated by adding, subtracting, combining or splitting potential codes and examining relationships, whilst at the same time looking out for new patterns and issues in the data. The themes were reviewed and named.
Stakeholder analysis was also carried out and is defined as a process of systematically gathering and analysing qualitative information to determine whose interests should be taken into account when developing and/or implementing a policy or program (Schmeer, 1999). The following steps were taken to analyse the stakeholders:

- Identifying relevant stakeholders or stakeholder groups;
- Analysing their perspectives, current vision or arguments;
- Visualising the relationships between the organisation and stakeholders, and the relationships between the different stakeholders; and
- Prioritising stakeholder groups over one another.

The results from the thematic and stakeholder analyses were presented as charts, themes and case studies.

### 3.5 Ethical considerations

Social research should be carried out in ways designed to avoid risk to participants, respondents and interviewers (Fowler, 2014). Since this research involved human participants, ethical approval was granted by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee, Study No: R15-P075 (Appendix 3.5). In Malawi, it was granted by the National Commission for Science and Technology, Protocol No: P.07/15/47.
(Appendix 3.6) and permission to access the villages was obtained from the District Commissioner for Chiradzulu District (Appendix 3.7).

A risk assessment was carried out to ensure the physical, emotional and cultural safety of the researcher and the participants during the fieldwork. The fieldwork was classified to be of low risk by the then School of Electronic, Electrical and Systems Engineering. The requirements of the risk assessment were adhered to which included issues of personal safety, maintaining contact and ensuring that there were both male and female RAs involved in the data collection. Since this research was carried out in a developing country where the norm might be different from that of the western world; particular precaution was taken on issues such as culture sensitivity, language, health risks and working with research assistants as guided by (Laws, Marcus and Harper, 2003; Scheyvens, 2014);

In the field, the Loughborough University code of ethics was followed. The respondents were informed about who was carrying the study, the topic and purpose of the study, procedures that would be used to collect data and what will happen with the results. They were assured that there were no potential risks and that there were no payments for participating in the research. Furthermore, they were told that participation was voluntary, and they were free to withdraw at any time without any penalty. They were also assured of anonymity and confidentiality and this was achieved by making sure the names of participants did not appear on the questionnaire. Each questionnaire was identified by a survey number only. The participants were told that names of villages and institutions would appear in publications and thesis, to which there was no objection. Their consent was obtained before the questionnaire/interview was administered.

### 3.6 Limitations

Four limitations were identified in the data collection phase. The first one was regarding the sampling method that was used for the household survey as described in section 3.3.1.2. The cluster sample method, which was used, gives less precise estimates compared to a simple random sample of the same size. However, because of the way the villages are located it was impossible to do a random sample, if that were attempted it would require more finance and time.

The second limitation was to do with self-reported data in which participants respond with what they think is socially the correct answer (Podsakoff, MacKenzie and Lee, 2003). It was thought that some respondents might have been inclined to give biased information mainly regarding income/wealth for fear of being left out of donations, thinking the results might be used to identify and register the needy. Households in the rural areas are familiar with government or
donor surveys, which are normally taken to register potential recipients of free materials such as fertiliser and / or emergency relief food. Responses were checked by asking the question in a different way, such as the question on income was checked by asking for expenditures, asset ownership, and observations such as type of house. It was also emphasized to the households that this was an academic study.

The third limitation was related to the illiteracy of some of the respondents particularly on questions relating to measurements such as time, income and distance; they might have misreported figures out of ignorance. This was also experienced by Graham et al. (2016) who reported that in determining the time to collect water in SSA, households’ ability to recall water collection was found to be problematic. In the current study, this was checked by using the FGDs, the village head interview and through observations.

The fourth limitation was research fatigue or over research where respondents are tired of responding to questionnaires (Clark, 2008; Finau et al., 2011) which was noted in the pilot study village where some respondents complained that they had participated in many surveys and had never noted any change. Bearing this in mind it was decided to avoid villages where much research had taken place by targeting villages in the remotest areas with the assistance of the HSA.

### 3.7 Techno-economic analysis

#### 3.7.1 Introduction

This section introduces the techno-economic analysis method, which will be further explained in detail in Chapter 5 alongside the results of the analysis. Techno-economic analysis is one of the methods used for evaluating renewable energy for off-grid electrification projects. In this study, the indicator-based technique (Bhattacharyya, 2012) which uses worksheet-based tools and employs life cycle cost analysis (Park, 2011) was employed. Instead of levelized cost of supply as indicated in (Bhattacharyya 2012), the levelized cost of water was calculated.

From the 30 villages that were surveyed, Potani was selected as a case study village to carry out the analysis. Firstly, at the time of the survey the only borehole in the village was not working having had been vandalized by thieves. Secondly, even before being vandalised, the borehole was supplying 191 households, exceeding the government recommendation of 50 households per water point. The borehole remained unrepaird for a long time because repairing it was very costly and almost equivalent to installing a new one. In the meantime, households collected water from the neighbouring villages and supplemented it with water from a nearby river and open wells.
3.7.2 System design

The standalone directly coupled system was chosen for design from amongst the other designs (Chandel, Nagaraju and Chandel, 2015) as presented in section 2.6.3. The main components of this system are the solar PV modules, pump controller, submersible motor-pump set and the water storage tank. The storage tank replaces the use of solar batteries, which often make the system prone to frequent maintenance hence more expensive in the long run. The system design of a SWPS has been described by several authors including (Barlow, McNelis and Derrick, 1993; Argaw, 2004), and consists of the following steps:

Step 1: Calculation of the daily water requirement and storage

The daily water requirement per person is determined from recommendations by the World Health Organisation (WHO, 2011). The daily water requirement for the village is calculated using the population of the community. In cases where PV storage solar batteries are not used, it is usually recommended to store 3-5 days’ water worth in storage tanks to compensate for cloudy days (Argaw, Foster and Ellis, 2003).

Step 2: Determination of water source and the total dynamic head

This involves determining the type of water source, whether groundwater or surface water and whether a treatment method will be required or not. The water source then assists in determining the total dynamic head (TDH). The TDH is defined as the total equivalent vertical distance that the pump must move the water, or the pressure the pump must overcome to move the water to a certain height (Barlow, McNelis and Derrick, 1993; Jenkins, 2014). TDH is illustrated in Chapter 2, Figure 2.13.

Step 3: Determination of the equivalent hydraulic energy

This is determined from the product of the daily water requirement and TDH, as will be illustrated in section 5.2.3.

Step 4: Determination of solar resource and sizing the solar module

The solar irradiation is determined for the location; if the data were not available, it is determined for the nearest weather station. The month with the worst-case combination of solar radiation energy and water demand is generally chosen as the design month, (Argaw, 2004).

Step 5: Determination of the pump size

The motor-pump size is selected using the calculated flow rate (Q), TDH and the manufacturer's pump selection curves. The process is shown in section 5.2.5.
Step 6: Determination of PV array size

The PV array power (in watt-peak, Wp) array size is given by Equation 3.1 (Argaw, 2004; Bouzidi, Haddadi and Belmokhtar, 2009).

\[ P = 1000 \frac{\rho ghV \eta_r}{k G_T \eta_{pv} \eta_s} \]  (3.1)

Where \( \rho \) is the water density, \( g \) is the acceleration due to gravity, \( h \) is the total pumping head (m), \( V \) is the daily mount of water of water required (m\(^3\)), \( \eta_r \) is the array efficiency at 1,000 W/m\(^2\) and 25 \(^\circ\)C, \( G_T \) is the daily solar radiation (kWh/m\(^2\)/day) on the PV array surface, \( \eta_{pv} \) is the efficiency of the PV array under operating conditions and \( \eta_s \) is the subsystem efficiency and \( k = 3 \times 10^6 \) (conversion factor of Joules to kWh).

3.7.3 Economic analysis

The financial viability of the system was assessed using the life cycle cost analysis (LCCA). The LCCA gives the total cost of a project during its lifetime, it considers the capital costs, operating, and maintenance costs, fuel costs, and salvage value as applicable. It is obtained by discounting all the future costs and benefits to the present-day value and added to the present-day investment costs (Argaw, 2004; Park, 2011), to take into account the time value of money. From the LCCA, the levelized cost of water (LCW) is calculated using the Equation 3.2 (Fane, Robinson and White, 2003; Parajuli, Pokharel and Østergaard, 2014).

\[ LCW = \frac{\text{Lifetime Cycle Cost}}{\text{Lifetime water production}} = \frac{\sum_{t=0}^{T} \frac{(C_t + O_t + M_t - S_t)}{(1 + r)^t}}{\sum_{t=0}^{T} \frac{Q_t}{(1 + r)^t}} \]  (3.2)

Where:

- \( T \) is the life of project in years; and \( t \) is for year;
- \( C_t \) is the net capital cost of project for \( t \) in US$;
- \( r \) is the discount rate for \( t \) (%);
- \( O_t \) and \( M_t \) are the sum of all yearly operation and maintenance costs for \( t \);
- \( S_t \) is the salvage value and is the net worth of the system in the final year; and
- \( Q_t \) is the lifetime water production.
The payback period of the system was also calculated. The costs of the components were obtained from local entrepreneurs and checked against those from other countries as detailed in section 5.3.2. The LCW was compared with that of previous studies and with the current cost of water and the WTP.

Sensitivity analysis, as detailed in section 5.3.3 was used to account for risk and uncertainty. It identifies the input parameters that have the greatest impact on a specific measure of economic evaluation (Short, Packey and Holt, 1995). To test sensitivity, a base case scenario whereby the net present value was set equal to zero was selected and the input parameters were increased or decreased in increments of 10%.

3.7.4 Cross-subsidising the cost of water

The research developed a model whereby the cost of water was cross-subsidised with the cost of basic energy services, for charging mobile phones and solar PV rechargeable lanterns. As demonstrated in section 5.4.6, a charging system was designed alongside provision of water at an additional cost and would be used as a charging kiosk. Using the designed model, the variation in LCW was explored.

3.8 Chapter summary

This chapter discussed the research design and methodology used for this study. It explains how the interdisciplinary research employed the mixed methods research design, which consisted of a household survey, field visits, FGDs, and semi structured-interviews. The chapter further discussed the data collection instrument, data collection and data analysis methods, ethical issues and limitations of the study. The quantitative data were analysed using SPSS software and the qualitative data were analysed using thematic analysis and stakeholder analysis. In this chapter, the methodology for techno-economic evaluation is introduced, and will further be discussed in Chapter 5, alongside the calculations and results. The results of the research are presented in the next three chapters: Chapter 4 presents the results of the household survey, Chapter 5 presents the results of the techno-economic analysis and chapter 6 presents the results of stakeholder analysis.
4 Household Water and Energy Needs Analysis

4.1 Introduction

This chapter presents the results of the household survey carried out in Malawi in August and September 2015, in 30 selected villages of Chiradzulu District. The overall aim of the research was to develop a planning and investment decision-support model for sustainable water provision in the rural areas of Malawi based upon renewable energy sources. The location of the district and the villages are shown on the maps in Chapter 3 in Figure 3.1 and Figure 3.3, respectively. The aim of the household survey was to address the second objective of the study, which was to assess the water and energy provision, regarding access, opportunities, challenges and willingness to pay for water with respect to socioeconomic and demographic characteristics of rural communities in Malawi. Data were collected (as discussed in detail in Chapter 3) using a structured questionnaire and was complemented and verified by a triangulation method utilising focus group discussions (FGDs), semi-structured interviews with village heads and observations (photographs and written notes). In addition to presenting the results, this chapter also analyses the findings and compares them with previous research. The chapter concludes with a summary and discussion. The applicable results are used in the techno-economic analysis for drinking water provision presented in Chapter 5.

4.2 Demographic and socio-economic characteristics of respondents

The questionnaire was administered to household heads from 30 selected rural villages pooled from all the six Traditional Authorities of Chiradzulu District. In total, 219 valid responses were obtained (the complete list of the villages is shown in Appendix 4.1. The demographic characteristics of the households are summarised in Table 4.1 and they help the reader in understanding the community under study in addition to assisting in determining how the characteristics of the community would respond to a water provision intervention. The results for household size, head of household, gender, marital status, occupation, education, income will be discussed in the following sections and their significance regarding willingness to pay for water were discussed in detail in section 2.7.3. Table 4.2 shows village characteristics for 11 selected villages obtained from interviews with village heads. These village characteristics were also used to triangulate household survey findings.
Table 4.1: Demographic data of the Chiradzulu rural households’ survey

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of villages</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>No of Respondents (Household Heads)</td>
<td>219</td>
<td>100</td>
</tr>
<tr>
<td>Age of Household Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 to 20 years</td>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td>21 to 59 years</td>
<td>168</td>
<td>76.7</td>
</tr>
<tr>
<td>60 and above</td>
<td>40</td>
<td>18.3</td>
</tr>
<tr>
<td>Don’t Know</td>
<td>6</td>
<td>2.7</td>
</tr>
<tr>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 people</td>
<td>22</td>
<td>10.0</td>
</tr>
<tr>
<td>3-5 people</td>
<td>125</td>
<td>57.1</td>
</tr>
<tr>
<td>&gt;6 people</td>
<td>72</td>
<td>32.9</td>
</tr>
<tr>
<td>Mean Household Size</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Religion of Household Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christian</td>
<td>189</td>
<td>86.3</td>
</tr>
<tr>
<td>Muslim</td>
<td>30</td>
<td>13.7</td>
</tr>
<tr>
<td>Type of House</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mud walls/grass roof</td>
<td>64</td>
<td>29.2</td>
</tr>
<tr>
<td>Brick walls/grass roof or Mud walls/iron roof</td>
<td>60</td>
<td>27.3</td>
</tr>
<tr>
<td>Brick walls/iron roof</td>
<td>95</td>
<td>43.4</td>
</tr>
<tr>
<td>Household Asset Ownership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>157</td>
<td>71.7</td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>127</td>
<td>58.0</td>
</tr>
<tr>
<td>Radio</td>
<td>99</td>
<td>45.2</td>
</tr>
<tr>
<td>Bicycle</td>
<td>98</td>
<td>44.7</td>
</tr>
<tr>
<td>Solar Home System</td>
<td>14</td>
<td>6.39</td>
</tr>
<tr>
<td>Bank Account</td>
<td>13</td>
<td>5.9</td>
</tr>
<tr>
<td>TV</td>
<td>13</td>
<td>5.9</td>
</tr>
<tr>
<td>Treadle Pump</td>
<td>6</td>
<td>2.7</td>
</tr>
<tr>
<td>Motor Vehicle</td>
<td>2</td>
<td>0.9</td>
</tr>
</tbody>
</table>

4.2.1 Household size

Table 4.1 shows that the mean household size is 4.8 people which is slightly higher than the national rural household size of 4.7 people (NSO, 2010), which should be acceptable considering that in the previous censuses, households sizes got bigger with time and also varied from region to region and district to district (National Statistical Office, 2008). Household size is believed to have an impact on the general welfare of the family for instance how much income is earned and spent, how resources such as food are shared, how much water is used, and distribution of productivity and labour (Tchale, 2009).
Table 4.2: Village characteristics for 12 selected villages

<table>
<thead>
<tr>
<th>No</th>
<th>Village</th>
<th>HHs</th>
<th>Available Facilities</th>
<th>Facilities Needed</th>
<th>Crops</th>
<th>Livestock</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kanyong’o</td>
<td>200</td>
<td>2 Water points, Nursery School, 2 Grocery shops, 2 VSLs, Road, river</td>
<td>Loan, Boreholes, Nursery, Bridge Primary School, Agribusiness support</td>
<td>Maize, cassava, groundnuts, beans, cow</td>
<td>Chicken, goats, doves, pigs</td>
</tr>
<tr>
<td>2</td>
<td>Khumunye</td>
<td>48</td>
<td>Water point, 1 Hawker, Road, Dambo</td>
<td>Nursery school, Clinic, Electricity Irrigation System</td>
<td>Pigeon peas, vegetables, peas</td>
<td>Pigs, cattle</td>
</tr>
<tr>
<td>3</td>
<td>Potani</td>
<td>191</td>
<td>1 Water point, Church, Hawker, 2 VSL, River</td>
<td>Markets for selling produce</td>
<td>Pigeon pea, vegetables</td>
<td>Chicken</td>
</tr>
<tr>
<td>4</td>
<td>Kenani</td>
<td>49</td>
<td>2 water points, Nursery School, Primary School Church, 2 Hawkers, VSL, Road, river</td>
<td>Solar systems Water Reserve Irrigation System Maize mill</td>
<td>Pigeon pea, vegetables, finger millet</td>
<td>Goats, chicken</td>
</tr>
<tr>
<td>5</td>
<td>Mlukla</td>
<td>146</td>
<td>4 Water points, 1 Nursery school, 3 Hawkers, 2 rivers</td>
<td>Bridge, Forest reserve Boreholes</td>
<td>Maize, vegetables, sugarcane</td>
<td>Pigs</td>
</tr>
<tr>
<td>6</td>
<td>Salihera</td>
<td>120</td>
<td>2 water points, VSL, Nursery School, Mobile Network, Church, Hawker</td>
<td>Road, Maize Mill, Food (experiencing famine)</td>
<td>Maize, sweet potato, soya, groundnuts</td>
<td>Chicken</td>
</tr>
<tr>
<td>7</td>
<td>Maone</td>
<td>280</td>
<td>5 water points, Nursery school, 3 Churches, clinic, Road, 5 Hawkers, 4 VSLs, NGOs</td>
<td>Electricity, Primary School, Maize Mill Hall</td>
<td>Maize, pigeon pea, sugarcane, sweet potato cassava</td>
<td>Goats, chicken, pigs</td>
</tr>
<tr>
<td>8</td>
<td>Chapweteka</td>
<td>65</td>
<td>1 Water point, Road, Church, 3 Hawkers, Mobile network, VSL,</td>
<td>Borehole (water is insufficient), Nursery School, Police Unit, solar PV loans</td>
<td>Maize, pigeon pea, millet</td>
<td>Pigs, goats, chicken, doves, dairy cows</td>
</tr>
<tr>
<td>9</td>
<td>Imedi</td>
<td>116</td>
<td>2 water points, VSL, Nursery school, 3 churches, Road, 4 Hawkers, Market, Church</td>
<td>Borehole, Primary School, Bridges, Help for orphans, Electricity</td>
<td>Maize, pigeon pea, vegetables</td>
<td>Cattle, goats, ducks, pigs</td>
</tr>
<tr>
<td>10</td>
<td>Mandota</td>
<td>85</td>
<td>Water point, Nursery School, Hawker, Mobile network, Road</td>
<td>Borehole, Nursery school teachers, Phone network Bridge</td>
<td>Maize, beans vegetables, pigeon pea</td>
<td>Goats, Dove, duck, chicken, rabbits</td>
</tr>
<tr>
<td>11</td>
<td>Ngumwiche</td>
<td>320</td>
<td>2 Water points, Primary School, Church</td>
<td>Ambulance, Clinic, Teachers, Boreholes, Secondary School</td>
<td>Maize, beans, pigeon pea, vegetables</td>
<td>Goats, chicken, pigs</td>
</tr>
</tbody>
</table>
4.2.2 Gender and marital status of head of household

Figure 4.1 shows the gender and marital status of the household heads. There are more male-headed households 159(72.6%) than female-headed ones 59(26.9%). These findings are comparable to the national data in the Malawi Demographic and Health Survey (MDHS) (NSO, 2010) in which 72% are male-headed households and 28% are female-headed. The majority of the female heads were not married (they were single, widowed, or divorced) 52(23.74%), whereas only 1(0.46%) of males was not married. In Malawi and other developing countries, female-headed households are more disadvantaged than male-headed ones, more vulnerable to poverty and usually not included in decision-making roles (FAO, 1999; GOM, 2010).

![Figure 4.1: Gender vs marital status of the household heads, n=219](image)

4.2.3 Educational qualification

The educational qualifications of the head of household is illustrated in the bar chart of Figure 4.2 which shows that more than a fifth 47(21.5%) of the respondents are illiterate whilst less than a fifth 39(17.8%) have 12 years of education or over. The bar chart also illustrates that males are more educated than females; for instance, only 2(0.91%) females had 10 or more years of education as compared to 37(17%) males. Low illiteracy levels are associated with high incidences of poverty and derailment of sustainable development. (Tchale, 2009) showed that education is important in farming communities because educated farmers are likely to take risks and therefore more willing to try out new technologies that may enhance agricultural...
productivity. In addition, they easily understand instructions and assimilate new technologies. For the illiterate population, it implies that vigorous awareness campaigns and training would be required for the introduction of new interventions because high illiteracy levels have a huge contributing factor to how the people would be able to engage and assimilate change. In chapter 6, it is reported that a common problem with illiterate communities is that they were slow to grasp the need for a water system and hence caused delay in the implementation.

Figure 4.2: Educational qualification vs gender of the household heads, n=219

4.2.4 Main occupation

As illustrated in the pie chart of Figure 4.3 the main occupation of the household head is subsistence farming and the popular subsistence crops grown in the district are maize, beans, and pigeon peas. For casual labour, people work in other’s gardens and do other menial work in the surrounding areas, nearest trading centres or in the city of Blantyre, which is not very far from the district. The business types included selling farm produce, livestock, sugarcane, horticultural crops (such as tomatoes and vegetables), food items which is popular with women who sell traditional snacks (mandasi, zitumbuwa, kanyenya) and beer brewing, shop ownership, and few are in full time employment as teachers, health centre staff and as guards in the nearby city of Blantyre. The source of income and livelihoods of the households clearly
centre on agriculture which is expected because for Malawi, agriculture accounts for about 36% of GDP, 87% of total employment and supplies more than 65% of the manufacturing sector’s raw material requirements (GoM, 2002). Their dependence on agriculture provides an opportunity to apply water pumping using renewable energy for irrigation (see section 4.5), since some of them are already involved in agriculture-related businesses or occupations.

![Figure 4.3: Main occupation of the household head, n=219](image)

If they were to have electricity, the households aspired to have a variety of income generation activities such as charging of mobile phones and car batteries, salon, barbershop, sale of miscellaneous cold or frozen drinks and foods, chicken and egg production, and baking among others. Though they did not mention agro-processing, this could be a viable business for an agricultural community. However, some of the village headmen mentioned the need for maize milling machines, irrigation systems, electricity, and solar home systems, among other needs as shown in Table 4.2. The households were willing to have training on business and farm practices, access to loans not necessarily in cash but could be in goods such as individual solar home systems, community solar water pumping systems, food, and school fees assistance.

### 4.2.5 Income

The households' incomes are very low as illustrated by the income and expenditure quartiles in Table 4.3. It was found essential to collect both income and expenditure data to validate the amount given for the households' income. From the data, the reported incomes are slightly low for lower quartile. The data shows that 55 households (25%) have a monthly income of approximately US$8 and only another 55 households (25%) have a monthly income of more than US$30, which is approximately US$1 per household per day. However, these figures may
not reflect their actual income very well because some of their day-to-day transactions are not monetised. In addition, most of the households have irregular incomes and in such cases their monthly income was estimated from annual produce sales, business sales or casual labour engagements, and errors might have occurred in the estimation. The household income is significant since it would establish how much the households would be able to pay for services, such as water provision using solar PV in the context of this study.

**Table 4.3: Monthly income and expenditure quartiles for the households**

<table>
<thead>
<tr>
<th>Quartile</th>
<th>Income (US$)</th>
<th>Expenditure US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>8.15</td>
<td>8.66</td>
</tr>
<tr>
<td>Median</td>
<td>14.99</td>
<td>13.50</td>
</tr>
<tr>
<td>Upper</td>
<td>30.90</td>
<td>23.10</td>
</tr>
</tbody>
</table>

Table 4.1 showed the type of house and household assets each household owns, and are used to understand the economic status of the households. Of interest to note is that though the mobile phone is a recent invention, it is widely owned by 127 (58%) households coming second to land ownership. The rapid diffusion of the mobile phone in SSA has leapfrogged the landline and exceeded expectation bearing in mind that some of the people who own the mobile phone live on less than US$1 per day. In poorer countries, the mobile phone provides opportunities for disseminating agricultural price information, monitoring health care, digital money transactions such as sending/receiving money and paying for services among others (Aker and Mbiti, 2010; World Bank, 2013; Hampshire et al., 2015). With no reliable postal services, landlines nor banks, it is an essential service for the rural areas.

Bivariate analysis, using Spearman’s correlation analysis (see section 3.4.1.2), was conducted to determine the relationship between income and selected socio-economic variables. The correlation analysis results are shown in Table 4.4 which shows that all the variables (household size, education, and consumption) are weakly correlated with income at either the 0.05 level of significance (* $p<0.05$) or at the 0.01 level of significance (** $p<0.01$). The strength of the relationship is interpreted as: small $r = 0.1$ to 0.29, medium $r = 0.3$ to 0.49 and large $r = 0.5$ to 1.0 (Cohen 1988) in (Pallant, 2013).
Table 4.4: Spearman’s correlation of income and socio-economic variables

<table>
<thead>
<tr>
<th></th>
<th>Income</th>
<th>Household Size</th>
<th>Education</th>
<th>Water Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household Size</td>
<td>0.160*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>0.289**</td>
<td>0.013</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Water Consumption</td>
<td>0.281**</td>
<td>0.463**</td>
<td>0.093</td>
<td>1</td>
</tr>
</tbody>
</table>

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

A Mann Whitney U test (described in section 3.4.1.2) was applied to compare the income levels of the males and females; an examination of the findings in Table 4.5 shows a statistically significant difference ($p = 0.047$). The results demonstrate that the males have higher median ranking compared to the females. This is common in the rural areas of agricultural developing countries and may be attributed to the low level of education and low access to inputs for females (Tchale, 2009; Ndiritu, Kassie and Shiferaw, 2014).

Table 4.5: The Mann-Whitney Rank-Sum of gender vs income

<table>
<thead>
<tr>
<th>Gender</th>
<th>n</th>
<th>Median (US$)</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>156</td>
<td>15.67</td>
<td>17221.50</td>
<td>3448.500</td>
<td>-1.984</td>
<td>0.047</td>
</tr>
<tr>
<td>Female</td>
<td>54</td>
<td>12.50</td>
<td>4933.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>210</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Only 13 households (5.9%) have bank accounts because most households do not have an identity document required to open an account. Besides, others might not have the surplus income for savings. Most of the households, hence, have resorted to joining Village Savings and Loans (VSL) groups, popularly known as “Banki mukhonde”. A VSL group has approximately 15 members and in most cases membership are women only who belong to the VSLs groups on behalf of their husbands or on their own behalf. The members meet weekly for giving in their contributions, and for getting or repaying loans. A member can contribute anything from US$0.19 to US$3.85 per week. A loan must be repaid in one month and the interest on the loans is 20% per month. This interest rate is lower than that of loan sharks who charge interest rates of 50% to 100%. If a member fails to repay the loan, they can pay only the interest every month until they are able to repay the capital. If a member is unable to repay the loan, their property is confiscated until they can redeem it, but such cases
were rare. At the end of the year, the members share the capital plus dividends accordingly, and start the cycle all over in the following year. They reported that VSL groups have been handy to them in such ways as emergencies, food, school fees for children, fertiliser and pesticides, building houses roofed with iron sheets, capital for starting a business, rentals for a field, and purchasing livestock. For a study in Northern Malawi it was found that VSLs improved food security and strengthened household income indicators (Ksoll et al., 2016). The VSLs are seen as an alternative to solving the limited access to credit and financing among poor households with no collateral to use if they are to borrow from formal credit institutions (Ksoll et al., 2016; Mwansakilwa et al., 2017). Hence, they would make a possible platform for micro-financing organisations to distribute funds for diffusion of RETs because as discussed in section 6.3.2.3, the micro financing organisations find it easier to work through already established groups. Micro financing is one of the options for financing RETs (Bazilian et al., 2012) though it has some associated risks such as low credit-worthiness of recipients, high non-recovery of energy equipment cost, no proper regulatory arrangements for the sector, misappropriation of consumer money and poor quality of services (Bhattacharyya, 2013).

4.3 Drinking water access

The households were asked about their main source of drinking water, who collects water, time taken to collect water and water management issues. The results are now reported and discussed.

4.3.1 Main source of drinking water

Figure 4.4 shows that the main source of drinking water for 199 households (90.87%) is boreholes and 13(6%) still collect drinking water from unprotected sources, which include rivers and unprotected wells and springs. In the “other” category, sources included GFSs, and protected springs and wells. Comparatively the national data shows that among households in rural areas, 72% obtain their water from boreholes and 15% still collect water from unimproved sources (National Statistical Office and ICF, 2017). For Sub-Saharan Africa only 68% of the population have access to improved drinking water sources (WHO & UNICEF, 2015). In addition to drinking, the water from boreholes is also used for bathing and washing clothes; there are purpose-built washing areas at each borehole though some WPCs forbid washing at the borehole for hygienic reasons and these households do so at the rivers or streams. This was also the case in a study by (Van-Houweling, 2016).
The Goma recommends 250 people or 50 households per handpump (Chavula, 2012) as also reported in Chapter 6; though the design population of the pump is more. From the village heads interviews, results showed that in many instances the recommended number of households per borehole was exceeded (see Table 4.2). For instance, before being vandalised the borehole at Potani village was serving 191 households, which is almost four times the recommended limit of 50 households per borehole. Following the vandalism, the households are now collecting water from neighbouring villages or from rivers, laying pressure on the boreholes of the neighbouring villages and hence rendering queuing and long distance inevitable. It is believed that exceeding the capacity of the boreholes makes them more prone to breakdowns (Fisher et al., 2015). In other villages, the water points were nearly adequate; for example, Maone village had five water points supplying 280 households, averaging 56 households per water point. This lack of equity is also discussed by (Stoupy and Sugden, 2003) who found that there was lack of equity in the distribution of boreholes in Salima and Mulanje Districts in Malawi. They discovered that water points were concentrated among some enumeration areas, or along roadsides or paths. Lack of equity was caused by various problems such as inadequate information, community’s educational level, lack of collaboration by different implementers and lack of access roads, among other reasons (Gutierrez, 2007). Lack of equity also happens because there are multiple ways in which a community may obtain a water point such as from government, NGOs, religious organisations, politicians and other individual donors. Also, funds may be released at the wrong time for example in the wet season when the roads are impassable or when the water table is high; such that the drillers may relocate the borehole to whatever location they wish so that they do not miss out on the payment (Gutierrez, 2007). The existence of some of these issues was also raised by the stakeholders interviewed for this study and are discussed in Chapter 6.
4.3.2 Who funded the water source?

As shown in Figure 4.5 the government and Non-Governmental Organisations (NGOs) funded the construction of most of water sources, showing that they are the major stakeholders in water provision in the rural areas. The NGOs also work in other areas such as livestock distribution, maize meal distribution, orphan care, road repair and training on farming methods and nutrition. In 2014/2015 rainy season, some parts of the district were affected by floods hence some people had new houses built for them by the NGOs. However, it was not possible for the NGOs to reach out to all the villages equally.

![Figure 4.5: Funding sources](image)

4.3.3 Who collects water?

The results of the survey show that the main water collectors are women 175(79.9%) and girls 41(18.7%); and only 3(1.4%) males collect water. The women and girls carry the water on their heads in 20-40 litre buckets. The results, though on the higher side are consistent with others who show that in many of the developing countries the physical and time burden of water collection falls upon women and girls (Blagbrough, 2001; WHO & UNICEF, 2011, 2015; Graham et al., 2016). Reference to the physical burden was mentioned in the FGDs that sometimes the handpump felt very hard to operate and needed pumping very hard in order to extract water. However, because of being accustomed to it, the women might not have thought the physical burden of water collection to be a problem.

Through FGDs, it was learnt that traditionally there are chores that are specific to each gender and others that can be done by both genders. Domestic chores such as cleaning, cooking, washing, taking care of babies, collecting water and firewood, are deemed women’s jobs, whereas males are expected to do jobs that bring income for the household such as tending the gardens, employment, casual work, business, and building structures at the home. Both men and women go to the fields for cultivation and tending of crops but after they come back
home, women continue working but the men have time for leisure. Children help in the chores appropriate to their age. Similar findings are reported by (Van-Houweling, 2016) who further assert that women spend most of their day in contact with water in activities such as washing clothes, bathing, cooking, cleaning dishes, and collecting water. The women’s income generating activities such as pottery making, gardening, brewing, and cooking food for the market also centre on water. She further reports that in her study, water access did not change the gender roles. Hence, water interventions may not be able to change the gender roles but must be sensitive to women and girls and be able to lessen the physical burden of collecting water.

4.3.4 Time taken to collect water

Figure 4.6 shows that the majority of the households, 125(57%) collect water more than four times per day and Figure 4.7 shows that the majority of households, 130(63%) exceed 30 minutes per round trip of water collection. Under these circumstances, a great amount of time is spent collecting water. These results are higher than the national data which shows that 47% of rural households spend 30 minutes or more to obtain their drinking water (National Statistical Office and ICF, 2017). Basic access is considered to be achieved where up to 20 litres per capita per day is available within one kilometre or 30 minutes per round trip (Howard and Bartram, 2003; WHO, 2011). According to the WHO, data from 35 household surveys showed that 18% of the population in Sub-Saharan Africa relies on an improved drinking water source that is more than 30 minutes away (WHO & UNICEF, 2011). Besides, in a more recent study it is reported that in 14 countries in Sub-Saharan Africa more than a quarter of the population takes longer than 30 minutes to make one water collection round trip (WHO & UNICEF, 2015). In addition to being a gender issue, the time taken to collect water can be viewed from the health perspective because it determines whether a household can obtain enough water for drinking, food preparation and personal hygiene. If the total time taken per round trip exceeds 30 minutes, people tend to collect less water, thus compromising their basic drinking water needs and hence their health (Howard and Bartram, 2003; Hunter and Wang, 2010; WHO & UNICEF, 2011).
It is apparent that women and girls spend a lot of their time collecting water. They are deprived of time, which could be used for carrying out such things as education income-generation activities, growing food, caring for their families or for leisure. On the contrary, (Van-Houweling, 2016), found that women do not use the extra time to initiate new income-generating activities or to take on new roles but they spend more time in their existing agricultural, domestic, and social activities. In the current study, several households 42(19.2%) reported that children had been late and absent from school because of water collection. At Mataka Village FGD it was reported that if a child is absent the parents are required to pay a fine, hence for that reason their children did not miss school. In reflections from previous research, collecting water could therefore be one of the contributing factors to girls’ deficiency in education (Chinyoka and Naidu, 2010). Queuing and low yield rather than distance apparently increased the time spent collecting water. Accordingly, more water points with
reasonable yields would reduce the time taken to collect water and go a long way towards improving the welfare of women and girls. It may not be possible to change the tradition of who collects water, but it could be possible to construct more water points, which would minimise the time and physical burden of collecting water.

4.3.5 Water quantity, storage and household management

The median amount of water used was 120 litres per household per day, which approximately translates to 25 litres per person per day. Comparatively (GOM, 2011) estimates that the water use for rural areas households is 27 litres per person per day. There are different levels of access recommended by the WHO but the basic access recommendation is 20 litres per person per day with laundry being done elsewhere (WHO, 2011). In the current research, it was noted that households that were engaged in home-based income generating activities used water from the borehole with some of them requiring large quantities of water such as in beer brewing. Such families used up to half a tonne per household per day. The amount of water used specifically for income generating activities was not investigated, but this would be an interesting area for further research. The histogram in Figure 4.8 shows the number of households and amount of water collected by each household per day.

![Figure 4.8: Number of households and water consumption per day](image)

Regarding water storage methods, all the households reported that they stored their drinking water in covered containers (buckets, jerry cans, clay pots) whereas water for other domestic purposes could be left uncovered; spot checks by the research assistants verified this to be
accurate. Research shows that apart from water source, the water management process such as transportation storage, and general sanitation and hygiene practices can also introduce pathogens in the drinking water (Swerdlow et al., 1997; Masangwi et al., 2009). In a study of Lungwena rural community in Malawi, (Taulo, Mkakosya, & Kululanga, 2008) found that stored water was more contaminated than source water due to environmental sanitation and also water management practices such as finger dipping, covering method, mixing of fresh water with old water and non-use of the two-cup\(^1\) drinking system among other issues. Hence, education on water management of water is an important component of water supply. In Malawi, educating the households on water management and quality is usually done before construction of a new borehole and during the whole life cycle of the project as discussed in Chapter 6. The village heads and HSAs, through informal discussions, indicated that they carry out health awareness meetings in the villages on regular basis.

### 4.3.6 Management of water points

The government requirement is that each community appoints a WPC of 10 members consisting of both males and females, who are elected by the households to manage the operation and maintenance of the water point. Over 92% of the households reported having knowledge of the presence of a WPC in their respective villages. They reported the roles of the WPC to include collection of contributions, ensuring clean surroundings at the water point, security, maintenance and repair or referring those repairs they are unable to carry out to the area mechanics. The households complained that the WPC neglected some of their duties particularly accountability with money, which in some cases led to people giving grudgingly or not contributing at all, leading to having no money for repairs when needed. In her study (Chowns, 2014), reports that sometimes the village chiefs abuse their power and use the money for personal needs. The communities are able to pay for small repairs but the major ones remain un repaired as also alluded to by (Chisenga, 2014) who found that the handpumps in most of her study areas were non-functional. For the major repairs, they often seek for assistance from well-wishers who include businesspersons, relatives in town or politicians, particularly during campaign period. Regardless of family size or quantity of water collected, each household pays the same amount of money and it seems they are content with that arrangement. When to contribute varies from village to village, some contribute when the borehole is broken, others once a year that is soon after the harvest, others quarterly and yet others once a month. It was reported by the participants that most of the households contributed, some had to be forced to do so

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\(^1\) One cup is used for drawing water from the bucket and the other one for drinking to avoid contamination
and a few did not contribute. Contribution (or tariff) was found to determine the sustainability or functionality of a handpump (Chowns, 2014; Fisher et al., 2015).

4.4 Challenges associated with water provision

The respondents were asked to state if they experienced any of the stated challenges associated with water provision on a 5-point Likert scale where 1 was strongly disagree and 5 strongly agree; their responses are illustrated in the stacked chart of Figure 4.9 and discussed in the subsequent sections. Other challenges that were not included in the Likert scale question but were in the other parts of the questionnaire and in the FGDs will also be discussed.

![Figure 4.9: Households perception on severity of challenges, n=219](image)

**4.4.1 Queuing and low yield**

According to the households’ responses, the leading challenge in the provision of water in Chiradzulu district is queuing and one such queue is shown in Figure 4.10. Queuing is followed by low yield and these challenges are the probable causes for the long time spent collecting water. These two challenges are very closely related hence are discussed alongside. From FGDs, it was established that one reason for queuing was high population,
implying the number of people being served from a single water point exceeds the recommended number. The second reason for queuing was low yield from the boreholes, particularly in the dry season. For instance, at one of the boreholes in Khaoreya village, the households wait until the afternoon for the borehole to produce water. They stated that the borehole was shallow, and the handpump was fitted on a hand-dug well. The women in the study area complained of quarrels and scrambling for water when there are queues. When collecting water from neighbouring villages, the other women are sometimes hostile towards them. The verbal abuse and quarrels have been reported to cause psychological stress on women (Stevenson et al., 2012; Sommer et al., 2014).

Figure 4.10: Queuing for water

Low yield or drying up is associated with the construction method of the borehole. In his study (Harvey, 2004), showed that the likelihood of borehole failure increased by a factor of six when drilling occurred during the wet season, and discovered a strong correlation between monthly precipitation and respective failure rates for boreholes drilled in each month. This is because during the wet season the water table is higher than in the dry season. The potential for borehole failure also increased significantly when the initial yield was below the guideline value of 10 litres/min. He recommends drilling in the dry season and making sure the initial yield is above the guideline. This may imply that non-functionality may be caused by poor drilling, siting and construction workmanship. According to (Anscombe, 2011) the low yield occurrence is frequently related to shallow drilling depth which is often caused by the contractors' inability (or reluctance) to go deeper and fully penetrate the aquifer. This in turn can be related to a very narrow drilling diameter coupled with poor drilling technique and/or poor equipment.
Further to that (Baumann and Danert, 2008) report that there is a lack of hydro geologists in the country such that drilling supervision is undertaken by communities who are incompetent. These findings allude to a need for monitoring the contractors so that they follow guidelines for adequate water provision from the boreholes. Lack of enough human resources is also reported in section 6.3.3.1 and lack of monitoring is discussed in section 6.3.3.2.

4.4.2 Distance

Though in earlier literature distance is often cited as a major problem in water collection in developing countries (The World Bank, 1993; Blagbrough, 2001), it was not reported as a major problem in this study. Approximately 33(15%) of the respondents indicated distance as a challenge in the Likert scale question. In a separate question, households were asked if water supply was sufficient and those who thought water was insufficient (n=53) were asked an open-ended question why they thought so. Of these, only 4(1.8%) mentioned distance as a challenge. There is a disparity in the two questions, because in the first question distance was given as an option whereas in the second they had to state the challenges themselves. Probably the households had become used to the distance and it apparently appeared to be the norm to them. For most of those affected with long distance, it was because they were collecting water from neighbouring villages since their borehole was non-functional. In other cases, it was because some of the respondents’ homes were further away from their village’s centralised water point. Thus, it would be recommended for larger villages to have more than one water-point or to have a system that provides more than one water standpoint.

4.4.3 Lack of access

Of the respondents, 166(75.8%) reported that water from their current water source was sufficient; the rest 53(24.2%) thought water for their households was not enough. These households gave the following reasons for the insufficiency: 40(18.26%) indicated high population and therefore single borehole was used for many people, 9(4.1%) indicated few collecting buckets and 4(1.8%) indicated long distance. The results imply large number of people per borehole was one of the major problems and another possible reason for queuing. From interviews with village heads (see Table 4.2) and from FGDs, it was also reported that in some of the villages the boreholes were not able to meet water needs of the growing population. In Karonga, high population density was reported as one of the reasons for water problems (Namadzunda, 2015). And further (WHO & UNICEF, 2011), reports that population growth, together with urbanization; economic development and climate change put pressure on water resources. The respondents were asked for any recommendations regarding water supply in their village; and 190(87%) requested for the increase in the number of water points.
and 1(0.5%) requested for information on the available water treatment methods. It is apparent that there is a problem of insufficient water access.

### 4.4.4 Contamination and water quality

From the Likert scale question, contamination of drinking water was reported as a minor problem. Concerning water treatment, 174(79.4%) of the respondents did not treat their water, 40(18.4%) used the chlorination method and 5(2.2%) boiled their water. Comparatively, the national data shows that 67% households do not treat their drinking water and 20% add bleach/chlorine (National Statistical Office and ICF, 2017). Figure 4.11 shows the reasons provided by the households in the current research for not treating their water. Reasons in the “other” category included that they did not know how to treat, the HSA did not distribute the chlorine and they did not know where to buy chlorine. Some households reported that they treat their water only in the rainy season. For a study in Pakistan, (Khan et al., 2010) found that 40% of households were not treating their drinking water, and the rest treated their water using the following methods: 25% boiling, 10% chlorine tablets, 15% ordinary filters and 10% electric filters.

![Figure 4.11: Reason for not treating water](image)

The households in the study area stated that the taste of the water was generally good, but turbidity was a common problem in the rainy season. Though the majority of the respondents thought they were used to the water or that the water was safe, providing safe water should be a consideration because a previous study in Chiradzulu showed that water from shallow wells was heavily contaminated with coliforms and the problem was more severe in the rainy season (Pritchard, Mkandawire and O’Neill, 2008). Possible solutions are to provide deep boreholes, or those that have sustainable purification systems. Deeper groundwater resources of more than 20 m are said to be more reliable and have lower vulnerability to
Salinity was reported to be a problem by a few of the people. A borehole in Kanyong’o village (illustrated in Figure 4.12) was abandoned because of salinity. Saline water was also reported at Ngumwiche Village. Previous researchers (Pritchard, Mkandawire and O’Neill, 2007; Taylor et al., 2012; Mapoma and Xie, 2014) have not documented issues of salinity in Chiradzulu District. Further concerns about salinity in the country are discussed in section 6.3.1.2.

Figure 4.12: Abandoned borehole at Kanyong’o Village

4.4.5 Incidence of diarrhoea

It is estimated 88% of diarrhoeal deaths worldwide are attributable to unsafe water, inadequate sanitation and poor hygiene. The incidence of diarrhoea is therefore often used as a proxy to determine the water quality (Prüss et al., 2002; Fewtrell et al., 2005). Nearly a fifth of households, in the study area 41(19%) reported to experiencing an incidence of diarrhoea in the six months prior to the household survey. During FGDs, the participants affirmed that children did get sick from diarrhoea. Comparatively, the national data reports a 17.5% prevalence of diarrhoea (National Statistical Office and ICF, 2017) and a study in Chikhwawa District (Masangwi et al., 2009) reports a higher diarrhoeal prevalence ranging from 59% to 78% in the households of the four communities they studied. In the Chiradzulu Socioeconomic Profile, it is reported that cholera and diarrhoea were prevalent in the district (Chiradzulu District Assembly, 2007). According to the village heads, diarrhoea was observed to be
declining along the years because of vigilant health campaigns by the district through the HSAs. Comparatively, for a study in Bangladesh (Ahmad et al., 2003), found that 16% of households reported cases of diarrhoea in the six months prior to their study. The presence of diarrhoea indicates the need to provide safe water to the households, though other interventions are also required.

4.4.6 Theft and vandalism

Theft and vandalism is widespread in the district and borehole parts, livestock, produce and other items can be stolen. Some households go to the extent of keeping their livestock in their houses at night regardless of the dangers of house sharing with livestock. Theft and vandalism of water point parts in Malawi has been mentioned in studies by (Kleemeier, 2000; Chisenga, 2014; Chowns, 2014). In gravity water supplies, (Kleemeier, 2000) observes that stealing of pipes to make hoes was one of the main causes of failure of rural piped-water systems. Similarly, (Chowns, 2014) notes that theft and vandalism are the cause of nearly two-thirds of the non-functionality in boreholes.

The FGDs participants felt that the police were not vigilant and many a time they released the suspects without charge. The study by (Chowns, 2014), observes that ‘High incidence of theft and vandalism may suggest two things: low sense of ownership, and weak rule of law’(p.150), implying there is possibly lack of upholding the law in the country. To curb theft some villages, have chains and locks for the boreholes. In one village, they had the added measure of a concrete block as shown in Figure 4.13. A study on security of water systems for Malawi, (RWSN, 2014) reports that villagers hire watchmen or organize patrol of community police to guard the systems during the night and some NGOs designed and implemented various technical solutions to protect the pumps from theft and vandalism.

In recent years, as discussed in Chapter 6, it was learnt that for solar PV, if proper security measures are put in place the problem of theft and vandalism could be ended. The common methods used for preventing solar PV theft are bolting the solar modules to steel structures and employing security guards. These methods were also used in Kenyan refugee camps (Kraehenbuehl, Ibanez and Burt, 2015) and by the interviewees in Chapter 6 (Int9, WASH NGO and Int21, entrepreneur) The incidence of theft implies that for any new system that would be installed, there has to be adequate security, more so those that incorporate solar PV.
4.4.7 Non-functionality of boreholes

One of the major challenges in rural water supplies of developing countries is non-functional boreholes, as was also the case in this study. For instance, in one of the villages (Khaoreya Village), out of the four boreholes, only one was working appropriately. When a borehole is broken and there is no alternative borehole, the households get water from neighbouring villages, which in many cases are at longer distances and causes overcrowding. The women reported scrambling and quarrels to have taken place and sometimes households resort to collecting water at night to avoid the congestions. The women reported that when they are too tired to go to the other village or the neighbouring villages are hostile towards them as they sometimes do; they collect water from unprotected sources such as rivers. For a study in Ethiopia Stevenson et al. (2012) alleges that women experienced emotional distress when they are involved in verbal abuse, or other violence whilst standing in water queues or when there is risk of accident in the process of collecting water. Figure 4.14 shows women collecting water from a broken elephant pump at Mlukla Village in Chiradzulu, which puts the women at risk of falling. They could not use the pump handle because it was broken, instead, they are using lifting buckets, which are also a potential source of water contamination. In the same figure, can be seen the 20-litre (left) and 40-litre (right) buckets that they use to collect water as was discussed in section 4.3.3.

Figure 4.13: Concrete block built over handpump to protect from theft
Non-functionality of handpumps is a common issue in developing countries. In rural Sub-Saharan Africa, an average of 36% of handpumps is estimated to be non-operational at any given time, and in some countries, it is estimated that more than 60% of handpumps are non-operational (Harvey, 2004; Baraki and Brent, 2013; Fisher et al., 2015). Technologies such as play-pumps\(^2\) first installed in the country in 2009 were discontinued because of high operational and maintenance costs as reported by one of the interviewees in Chapter 6 (Int16, Donor). (Harvey, 2008) further reports that the reasons for such low levels of rural water supply sustainability are multifaceted and include limited demand, lack of affordability or acceptability among communities, limited sustainability of community management structures, inadequate supply chains for equipment and spare parts, insufficient government support, and environmental issues. Chapter 6 discusses some of these issues that were raised by interviewees.

### 4.4.8 Other challenges

In some developing countries, sexual harassment and physical abuse are often cited as some of the challenges faced by women when collecting water (Blagbrough, 2001; Palamuleni, 2002; Sommer et al., 2014). However, this was not the case in this research though, Sommer et al. (2014) argue that sexual violence being a sensitive topic, might go unreported. However,

\(^2\) The Play-Pump is a system that uses the energy created by children playing on a merry-go-round to operate a water pump.
one person mentioned physical attack and wild animals as possible challenges, but it has never occurred before. Published research for Malawi was scarce but the media reports of bartering of sex with water in Karonga District in the Northern Region of the country (Namadzunda, 2015). It could be an isolated case, but significant.

4.5 Water for agriculture

Most of the households in Chiradzulu rely on rain-fed agriculture and only a few households apply traditional irrigation methods on small pieces of land, which is also the case at national level. The number of livestock for the households was small, they were watered from the boreholes, and larger livestock drank from the rivers and streams. This was in agreement with one of the stakeholder interviewees report (Int4, Government). A few households practise irrigation and cultivate their crops in a dimba\(^3\), which is located in the dambo\(^4\) area or along the river. According to FGDs, not everyone owns a dimba, which depends on one’s motivation, stamina and availability of suitable land (dambo land or land near river), suitability of crop with type of soil, and seasonal timing. Other important factors are market availability and accessibility to those markets. Currently the households sell their crops at the nearby trading centres or to vendors who come to them or they take their produce to the nearby city of Blantyre. The rain-fed crops grown are tobacco, maize, pigeon peas, beans, popcorn, and sweet potatoes. Irrigation crops, which are mainly for income generation, are tomato, sugarcane, mustard, bean leaves, onions, green maize, cassava, eggplants, bananas, and cabbage. Reported methods of water abstraction were watering cans/buckets and treadle pumps, with only 6(1.4\%) of the households from the study sample owning a treadle pump. These irrigation methods are labour intensive, which limits the size of land that can be planted and hence the quantity of produce. Having access to irrigation would lessen the burden of hand or treadle-pump watering and have the potential to increase produce and income. Hence, a less labour-intensive method of irrigation would be desirable.

4.6 Willingness and ability to pay for water

4.6.1 Willingness to pay for water

The willingness to pay was established using the CVM method, which is discussed in section 2.7.2. The emphasis in this study was on water for drinking though water for irrigation was also investigated. In this research, the respondents were asked how much they would be

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3 Dimba is a dry season field irrigated with water from dambo area or river
4 Dambos are wetlands, are seasonally water-logged and retain residual moisture during dry seasons
willing to pay for improved water services obtained from pumping using solar PV; the water would be readily available all the time in quality and quantity. The majority of the households [208(95%)] were willing to pay for water. The few that were unwilling said they were too poor/old to pay or had their own source of water. In terms of irrigation water, if they were to have easily accessible irrigation water, 160(73%) of the households were willing to pay. Table 4.6 shows the monthly amount of money they are currently paying for drinking water, the WTP amount for drinking water and the WTP amount for irrigation water. Income, expenditure and water consumption are included for perspective. The histograms in Figure 4.15 and Figure 4.16, which illustrate the difference between WTP amounts for drinking water and for irrigation water, complement this table.

Table 4.6: Income, current contribution, WTP for water and amount of water collected

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income (US$/month)</td>
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<td>27.74</td>
<td>14.98</td>
<td>34.39</td>
<td>0.33</td>
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<td>Expenditure (US$/month)</td>
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<td>13.46</td>
<td>17.90</td>
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</tr>
<tr>
<td>Consumption (litres/day)</td>
<td>219</td>
<td>130.50</td>
<td>120.00</td>
<td>81.51</td>
<td>20.00</td>
<td>500.00</td>
</tr>
<tr>
<td>Current Drinking Payment</td>
<td>201</td>
<td>0.29</td>
<td>0.19</td>
<td>0.20</td>
<td>0.04</td>
<td>0.96</td>
</tr>
<tr>
<td>WTP_Drinking (US$/month)</td>
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<td>1.08</td>
<td>0.38</td>
<td>1.85</td>
<td>0.10</td>
<td>13.46</td>
</tr>
<tr>
<td>WTP_Irrigation (US$/month)</td>
<td>159</td>
<td>1.99</td>
<td>0.96</td>
<td>2.64</td>
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<td>15.38</td>
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</tbody>
</table>

It is interesting to note that the households were willing to pay more for irrigation water as compared to drinking water; medians of US$0.96 and US$0.38, respectively. This is significant because unlike for drinking water for which they are already paying some contribution; they are currently not paying anything (in monetary terms) for irrigation water. Apparently, unlike drinking water, irrigation water gives them an income and they probably perceive this benefit. In addition, the low amounts that they are currently paying for drinking water might have had an influence on their willingness to pay. A study in Kenya (Sharma, 1997) reports that households were willing to pay more if they also used the domestic water for productive uses such as a vegetable garden.

From the FGDs, the households’ consensus was monthly payments though a few proposed paying per bucket as is the case with the trading centres at which water was charged at US$0.019 per 20-litre bucket. From the households’ current median consumption of (120 litres per household per day; water cost would be equivalent to US$3.42 per household per month. Comparatively, the households are paying US$0.19 per household per month. For both drinking and irrigation water, the FGDs indicated that they were willing to discuss further if this
initiative was to be implemented and are open to reconsider their WTP after being presented with the actual design and payment procedures of the SWPS.

Figure 4.15: Histogram showing WTP for Drinking Water

Figure 4.16: Histogram showing WTP for irrigation water
4.6.2 Ability to pay for water

Affordability or ability to pay (ATP) for water is determined by the ratio of the amount paid for water to income. An ATP of 5% is generally assumed as the maximum acceptable ATP that a household should pay for water (Whittington, 1998). The households in the study area had a median ATP of 1.26%. This implies that the current amount they are paying is less than their maximum acceptable ATP. For Lao PDR (Lopaying, 2004) found out that the ATP is greater when traditional water sources involve greater opportunity cost such as longer walking distance to get water or longer time for water collection. In Bangladesh the ATP for a public stand post was found to be approximately 0.7% and 1.7% for the non-poor and the poor households respectively with an average of 1.1% (Ahmad et al., 2003), illustrating that poor households pay a larger proportion of their income than the non-poor ones.

4.6.3 Factors predicting willingness to pay for water

Binary multiple logistic regression was carried out to investigate the factors that predict WTP for water. In order to facilitate this regression procedure, the variables were recoded into 'dummy' variables (Howitt and Cramer, 2005; Field, 2013; Pallant, 2013) as in Table 4.7 which shows the name, description and coding of each variable.

Table 4.7: Coding of variables for WTP for water

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Variable Description</th>
<th>Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WTPDri</td>
<td>Willing to pay US$0.38 or more for drinking water</td>
<td>Yes=1, No=0</td>
</tr>
<tr>
<td>WTPIrr</td>
<td>Willing to pay US$0.96 or more for irrigation water</td>
<td>Yes=1, No=0</td>
</tr>
<tr>
<td>Independent Variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td>Average income per month</td>
<td>Continuous</td>
</tr>
<tr>
<td>HHSize</td>
<td>Size of household</td>
<td>Discrete</td>
</tr>
<tr>
<td>Education</td>
<td>Completed Primary Education</td>
<td>Yes=1, No=0</td>
</tr>
<tr>
<td>Gender</td>
<td>Sex of household head</td>
<td>Male=1, Female=0</td>
</tr>
<tr>
<td>Occupation</td>
<td>Formal Employment</td>
<td>Yes=1, No=0</td>
</tr>
<tr>
<td>Time</td>
<td>Spends less than 30 mins per water trip</td>
<td>Yes=1, No=0</td>
</tr>
</tbody>
</table>
The results of the significant models for drinking and irrigation water are summarized in Table 4.8, which show that for this study, the only predictor of WTP for drinking water is education and the predictors for irrigation water are income and gender. These results are compared with similar studies shown in Table 4.9 which were carried out in rural areas of developing countries from selected countries of Latin America, Africa, and South Asia (The World Bank, 1993), Bangladesh (Ahmad et al., 2003), and Haiti (Whittington et al., 1990).

The results of the present study indicate that for drinking water education is the only significant predictor of willingness to pay, which agrees with all the other three studies. Educated households heads are perceived to be more aware of the health benefits of water and their opportunity cost for time spent collecting water is higher, hence they would be willing to pay more for improved water services (The World Bank, 1993).

**Table 4.8: Results of logistic regression predicting WTP**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTP Drinking</td>
<td>Education</td>
<td>-0.860</td>
<td>0.383</td>
<td>5.035</td>
<td>1</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>1.680</td>
<td>0.328</td>
<td>26.157</td>
<td>1</td>
<td>0.000</td>
</tr>
<tr>
<td>WTP Irrigation</td>
<td>Income</td>
<td>0.000026</td>
<td>0.000</td>
<td>5.555</td>
<td>1</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-0.817</td>
<td>0.415</td>
<td>3.869</td>
<td>1</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>0.151</td>
<td>0.222</td>
<td>0.463</td>
<td>1</td>
<td>0.496</td>
</tr>
</tbody>
</table>

**Table 4.9: Comparison with other studies on predictors of WTP for drinking water**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Current Study</th>
<th>The World Bank</th>
<th>Ahmad</th>
<th>Whittington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>ns</td>
<td>sig</td>
<td>sig</td>
<td>sig</td>
</tr>
<tr>
<td>Education</td>
<td>sig</td>
<td>sig</td>
<td>sig</td>
<td>sig</td>
</tr>
<tr>
<td>Gender</td>
<td>ns</td>
<td>sig</td>
<td>n/a</td>
<td>mixed</td>
</tr>
<tr>
<td>Occupation</td>
<td>ns</td>
<td>mixed</td>
<td>sig</td>
<td>ns</td>
</tr>
<tr>
<td>Household size</td>
<td>ns</td>
<td>ns</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Distance</td>
<td>ns</td>
<td>sig</td>
<td>n/a</td>
<td>sig</td>
</tr>
</tbody>
</table>

*sig=significant, ns=not significant, n/a=not applicable*

In the present study, income was not a predictor of willingness to pay for drinking water and one possible reason could be that the majority of the households were male-headed, and the males might not have been able to understand the burden of collecting water hence would not appreciate the need to pay. Incomes of the minority female-headed households were lower...
than their male counterparts as discussed in section 4.2.5 and hence the women’s WTP fraction would probably be smaller. The World Bank study suggests that households’ income, although often important, depends on other factors such as the present and proposed water supplies. For Lao PDR (Lopaying, 2004) found that significance of income depended on how much a particular town was paying at the time of the study. This suggests the household in the current study might also have been influenced by what they were currently paying.

The World Bank found out that gender was significant, but the direction of significance was not clear depending on the culture of the respondents. For the Haiti study (Whittington et al., 1990) the results were mixed and depended on whether the type of connection was public or private. For the current study, a Mann-Whitney U test was conducted to test whether males and females differ in their WTP for water and the results are summarized in Table 4.10. The results show that there is no significant difference (p=0.183) between males’ and females’ WTP for drinking water. However, there is a significant difference (p=0.018) between males’ and females’ WTP for irrigation water, with males willing to pay more than females. A study in Lao PDR (Lopaying, 2004) found that the women’s WTP for drinking water was less than the males’.

Table 4.10: The Mann-Whitney Rank-Sum of gender vs WTP

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median</th>
<th>Sum of Ranks</th>
<th>Mann-Whitney U</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WTP Drinking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>153</td>
<td>.58</td>
<td>107.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>54</td>
<td>.38</td>
<td>94.85</td>
<td>3637</td>
<td>-1.331</td>
<td>.183</td>
</tr>
<tr>
<td>Total</td>
<td>207</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WTP Irrigation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>123</td>
<td>.96</td>
<td>84.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>36</td>
<td>.58</td>
<td>64.26</td>
<td>1648</td>
<td>-2.359</td>
<td>.018</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Those in formal occupations are perceived to be willing to pay more for water as confirmed by the Bangladesh study (Ahmad et al., 2003). For the World Bank study, the results were mixed and depended on other factors regarding the employment. Distance was not significant, apparently because it was not a major issue in the present study area (see section 4.4.2). Household size was not significant in both studies in which it was tested (including the current study).

Further research is recommended for the factors that specifically predict the willingness to pay for irrigation water such as farm size, distance to market, type of crop and type of water source, among others (Tang, Nan and Liu, 2013; Namyenya, Sserunkuuma and Bagamba, 2014) that were not tested in the current study.
4.7 Energy access

The energy component was carried out to assess the households’ energy access types, costs, challenges and opportunities. Energy access was included to evaluate possible synergies with using solar PV for additional purposes other than just water. Available data on energy access is at national level in the census reports and the Malawi Demographic and Health Survey (MDHS) reports (National Statistical Office, 2010; NSO, 2011; National Statistical Office and ICF, 2017). This study specifically sought to find out current energy access for the households from the rural areas of Chiradzulu District.

4.7.1 Energy types

The percentage of households that reported any use of each of the energy sources are summarised in Figure 4.17.

![Figure 4.17: Percentage of households who reported any use of energy source](image)

Figure 4.17: Percentage of households who reported any use of energy source

The results show that the most commonly used energy sources by households in Chiradzulu are firewood which is used by 213(97%) households, non-rechargeable dry cell batteries used by 158(72%) households and crop residues used by 140(64%) households. Animal dung and
diesel generators are rarely used, and though the grid lines passed through some of the surveyed areas grid electricity was not used at all because of unavailability of electricity services in the rural areas of Malawi. This is a reflection of the national data of which, in 2010, 9% of households in the country had access to electricity, of which the proportion was higher among households in urban areas (35%) than in rural areas (4%) (NSO, 2011). The rural area figures are much lower for grid electricity (GoM, 2015). LPG was also not used which is not surprising since at national level households also rarely use LPG. A study was carried out on 10 Millennium Villages in SSA (Adkins, Oppelstrup and Modi, 2012) and one of the 10 villages was Mwandama in Malawi. Comparatively, the most commonly used energy types by the households across all the 10 villages were fuelwood, which was used by an average of 99%, kerosene (commonly known as paraffin in Malawi) was used by 86%, non-rechargeable dry cell batteries by 69% and crop residue by 47%.

Overall, only 32(14.6%) households in the current study reported that they were satisfied with their current sources of energy. The rest indicated the reasons as shown in Table 4.11.

Table 4.11: Reasons for dissatisfaction with current source of energy

<table>
<thead>
<tr>
<th>Reason for Dissatisfaction</th>
<th>Number (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-rechargeable Dry Cell batteries are expensive</td>
<td>131(59.8%)</td>
</tr>
<tr>
<td>Scarcity of firewood</td>
<td>123(56.2%)</td>
</tr>
<tr>
<td>Lack of optional sources of energy</td>
<td>26(11.9%)</td>
</tr>
<tr>
<td>Long distance to phone charging</td>
<td>20(9.1%)</td>
</tr>
<tr>
<td>Paraffin is expensive</td>
<td>16(7.3%)</td>
</tr>
<tr>
<td>Insufficient power from solar PV</td>
<td>8(3.7%)</td>
</tr>
<tr>
<td>Candles are expensive</td>
<td>5(2.3%)</td>
</tr>
</tbody>
</table>

4.7.2 Cost of energy

The cost of energy is summarised in Table 4.12, which shows the median costs per household per month of US$0.28, US$0.55, US$0.80, and US$2.77 for charging mobile phone, lighting, radio and firewood, respectively. The cost of water is also included in the table for comparison and shows that water represents the least amount paid for services by the households. For water, the households are paying 1.96% of their overall expenditure whereas for lighting alone, the households are paying 5.66%. (Gradl and Knobloch, 2011) state that low income

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5 The Millennium Villages Project was a demonstration project aimed at proving that its integrated approach to rural development can be used to achieve the MDGs
households pay an average of 9% of their overall expenditure on energy and they further argue that energy in form of kerosene or candles is far more expensive than that from the grid. Hence, these households would be willing to pay if electricity were to be available. From the FGDs, the households showed interest in solar PV; they asked costs of items and from where they could buy solar PV products. For charging mobile phone, lighting, radio power and firewood, altogether the households in the current study were paying an average of approximately 40% of their income. Though shocking it might fall within assumptions given by (Gradl and Knobloch, 2011) who report that low income households with an annual income of up to $500 spend an average of $148 per year on energy, which is approximately 30% of their income.

Table 4.12: Cost of energy per household per month

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Income (US$)</td>
<td>214</td>
<td>20.01</td>
<td>10.81</td>
<td>24.81</td>
<td>0.24</td>
<td>140.80</td>
</tr>
<tr>
<td>Expenditure (US$)</td>
<td>214</td>
<td>13.47</td>
<td>9.71</td>
<td>12.92</td>
<td>0.35</td>
<td>97.09</td>
</tr>
<tr>
<td>Cost of Firewood (US$)</td>
<td>65</td>
<td>3.49</td>
<td>2.77</td>
<td>2.47</td>
<td>0.21</td>
<td>13.87</td>
</tr>
<tr>
<td>Firewood Roundtrip (Hrs)</td>
<td>157</td>
<td>2.31</td>
<td>2.00</td>
<td>1.65</td>
<td>0.20</td>
<td>10.00</td>
</tr>
<tr>
<td>Cost of Lighting Energy(US$)</td>
<td>206</td>
<td>0.72</td>
<td>0.55</td>
<td>0.78</td>
<td>0.28</td>
<td>5.55</td>
</tr>
<tr>
<td>Current Cost for Phone Charging (US$)</td>
<td>115</td>
<td>0.41</td>
<td>0.28</td>
<td>0.29</td>
<td>0.06</td>
<td>2.08</td>
</tr>
<tr>
<td>Distance to Charging Place (km)</td>
<td>119</td>
<td>3.28</td>
<td>2.50</td>
<td>2.78</td>
<td>0.10</td>
<td>20.00</td>
</tr>
<tr>
<td>Cost of Batteries for Radio (US$)</td>
<td>88</td>
<td>1.07</td>
<td>0.80</td>
<td>0.91</td>
<td>0.14</td>
<td>6.24</td>
</tr>
<tr>
<td>Cost of Other Energy Sources (US$)</td>
<td>6</td>
<td>1.70</td>
<td>0.59</td>
<td>1.96</td>
<td>0.28</td>
<td>4.85</td>
</tr>
<tr>
<td>Cost of Water (US$)</td>
<td>201</td>
<td>0.29</td>
<td>0.19</td>
<td>0.20</td>
<td>0.04</td>
<td>0.96</td>
</tr>
</tbody>
</table>

4.7.3 Main energy source for cooking

Biomass is used for cooking by 100% of households in the rural areas of Chiradzulu, and is used in the form of firewood 204(93%), crop residues 13(6%) and charcoal 2(1%). These findings are similar to the MDHS report (NSO, 2011) in which 98% of all households use biomass for cooking, with 100% and 90% households from rural and urban areas, respectively. The dependency on biomass for cooking has been reported in (GoM, 2003) in which the
contribution of biomass to the country’s total energy mix was at 93% and in 2015 reduced to only 85.6% (GoM, 2015).

For the current research, households indicated their main source of firewood as follows: 150(69%) collected from the forests and gardens, 46(21%) purchased and the rest 14(6%) collected from their own woodlots. For the respondents who reported buying firewood (n=65), the median was US$2.77 per month. Firewood was mostly used in an open fire, which is an inefficient method of use. Crop residues, though overall in the second place, were the most used fuel for cooking during and soon after the harvest season since they are available in abundance at that time. Charcoal is rarely used and at national level, it is used by 12% of urban households and only 4% of rural households (NSO, 2011). Like water collection, firewood is mainly collected by women who spend an average of 2.3 hrs and up to 11 hrs per round trip and they also carry the firewood on their heads.

The reported challenges associated with firewood collection included scarcity of firewood, injuries from tripping or thorns piercing their feet because they may not have shoes, long distance to collect firewood, wild animal/insects, and lack of money to buy a gate pass to allow them to collect firewood from a government reserve forest. Reported problems related to cooking were that crop residues produced loose ashes that easily flew around and fell in the food, and firewood became wet in the rainy season making it difficult to burn. Though firewood use causes smoke, which is a health hazard, surprisingly the respondents did not mention it. Probably they take it as the norm. The other reason could be that they are not aware that smoke produced from firewood when cooking is also a health hazard. It is reported that acute respiratory infections in children and chronic obstructive pulmonary disease in women are associated with indoor biomass smoke (Torres-Duque et al., 2008). For a study in Bangladesh (Practical Action, 2016), women did not perceive significant risks to health from their current stoves, rather they valued the extent to which smoke helped to repel insects. In Chiradzulu, the methods of firewood procurement are still not sustainable and only a few people have set up their own woodlots. From observation, deforestation was visibly evident in the district. With the growing population, the future of firewood sustainability is uncertain.

4.7.4 Main energy source for lighting

As shown in Figure 4.18, the main energy source for lighting is non-rechargeable dry cell battery LED torches followed by paraffin lamps and then solar PV lamp, the ‘other’ category included candles, biomass (straw/grass/firewood), solar home system and rechargeable car battery. In the 2008 census (NSO, 2010), 92.6% of households in rural areas used paraffin and the rest used other sources such as candles, electricity and biomass. In the Millennium Villages study (Adkins, Oppelstrup and Modi, 2012), the most commonly used energy source
for lighting by the households of Mwandama Village in Malawi was kerosene, which was reported as the primary or secondary energy source by 97% of the households, followed by candles, at 57%, ‘other’ sources at 11% and electricity at 2%. Clearly, in the present study the use of non-rechargeable battery torches for lighting has surpassed the use of paraffin. A study by (Business Innovation Facility, 2014) also report a shift from paraffin lamps to non-rechargeable battery-powered torches. In the current study, for those who reported the cost of their lighting energy ($n=206$) the median cost was US$0.55 per household per month.

Figure 4.18: Main energy source for lighting

On average, a torch uses two non-rechargeable batteries and each battery cost US$0.21. The non-rechargeable batteries can last from 1 week to 1 month depending on usage. From the FGDs, paraffin, which was the second most used choice for lighting, is popular with the older generation whereas battery torches are popular with the younger generation. Paraffin costs US$1.11/litre and 1 litre lasts up to one and a half months, also depending on usage. Paraffin in also sold in smaller amounts for people who cannot afford larger amounts though it becomes more expensive in the long-run. Accidental fires were a big threat to using paraffin and the FGDs reported examples of people whose property was destroyed from paraffin accidents. If they have no money, the households reported to have to do with no lighting or the lighting is only used for selected tasks such as preparing for bed, and by making sure, they carry out the essential tasks whilst it is still daylight. The non-rechargeable dry cell batteries used in torches are also the main source of energy for radio and on average; a radio used three batteries, which lasted from one week to one month. The households thought the batteries were expensive. In addition, they lacked proper disposal methods for the non-rechargeable batteries. Replacing the paraffin and non-rechargeable battery energy sources with solar PV sources has shown to decrease the lighting energy costs for households by up to 87.5% (Adkins et al., 2010).
4.7.5 Main energy source for mobile phone charging

The 127(58%) households who owned mobile phones reported the following methods of phone charging, as a percentage of all households: elsewhere at a fee 113(51.6%), own solar PV 11(5%) and elsewhere at no fee 5(2.3%). For those who took their phones elsewhere for charging, they had to travel distances of 1 to 20 km. For those who reported their mobile phone charging cost \( n=115 \), the median cost per month was US$0.28. The phones had to be charged two to three times per week at a cost of US$0.06 to US$0.07 per charge. The households complained that because of congestion at the charging place, sometimes phones were not fully charged. Some respondents alleged car batteries and inverters, which some business people used, had damaging effect on their phones. Also in the rainy season, distances to phone charging became longer, because some roads became impassable and they had to use alternative routes. For the Millennium Villages study (Adkins, Oppelstrup and Modi, 2012), the methods of mobile phone charging were home chargers, commercial charger and community charging stations which were located at average distances of 1.5 to 52.5 km across the 10 villages of their study. The authors allege that the distance to charging phones will determine whether people used their phone or not.

4.7.6 Knowledge on renewable energy sources

It is generally believed that knowledge on RETs helps to drive the technology and knowledgeable people are more acceptable to the technology (Reddy and Painuly, 2004; Luthra et al., 2015). Lack of awareness is often cited as one of the major barriers to the deployment of RETs. The respondents were aware of the following renewable energy sources: solar PV 203(92.7%), hydro 184(84%), wind 35(16%) and biogas 16(7.3%). However, just being aware is not enough but they need more information on cost and what the technologies are able to achieve (Kunen et al., 2015). Popular sources of getting information on renewable energy sources were radio 157(71.7%) followed by word of mouth 153(69.9%). The less popular methods were: demonstration project 49(22.4%), village meeting 27(12.3%), at school 11(5%), at religious place 8(3.7%), and TV 3(1.4%). The results point out that the most effective way of communicating is through radio and word of mouth, hence the need for continued effort of having information broadcast on the radio for effective delivery to the people living in rural areas. Other methods may also continue to be used.

4.8 Discussion and chapter summary

The household survey has identified the water and energy needs for people living in the rural areas of Chiradzulu District in Malawi. The results add to, as well as confirm, existing data
from previous studies. The major findings relevant to this study and possible opportunities are summarised in Table 4.13.

**Table 4.13: Summary of key findings and opportunities for intervention**

<table>
<thead>
<tr>
<th>Findings</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low incomes</td>
<td>Explore irrigation water to enhance income-generating activities and improve incomes.</td>
</tr>
<tr>
<td>Low literacy levels particularly in women</td>
<td>Education is a significant predictor of willingness to pay. Income is correlated to education. Stakeholders should ensure education for the citizens. Dissemination of knowledge to continue through word of mouth and radio which are effective in the district, not only for water/energy issues but for all-round socioeconomic development of the country and breaking the cycle of poverty.</td>
</tr>
<tr>
<td>Inadequate access Queuing</td>
<td>Increase water access Make the boreholes deep enough (at least more than 20 m) Long-term goals would be distribution of water to individual houses/compounds.</td>
</tr>
<tr>
<td>Low yield</td>
<td>Construct more water points Bring water points closer to the homes so that women and girls have no/less drudgery, hence provide them time to attend school or productive activities</td>
</tr>
<tr>
<td>Women and girls spend much of their time collecting water</td>
<td>Ensure a financial management system is in place Ensure operation and maintenance structures are agreed upon</td>
</tr>
<tr>
<td>Non-functional boreholes</td>
<td>Ensure the water points are well secured. Educate the people</td>
</tr>
<tr>
<td>Theft and vandalism</td>
<td>Ensure the water points are well secured. Educate the people</td>
</tr>
<tr>
<td>Labour intensive irrigation methods</td>
<td>Promote small-scale irrigation by designing suitable irrigation systems which can contribute to food security and income</td>
</tr>
<tr>
<td>Households were willing to pay more for irrigation water</td>
<td>Implies probability of payback for irrigation water is high Introduce mechanisms such as soft loan policies or private enterprises that would promote RETs for water pumping in the rural households</td>
</tr>
<tr>
<td>Use of dry cell non-rechargeable battery for torches and radio</td>
<td>Introduce parallel charging systems with the solar PV water provision in order to use LED rechargeable lanterns Safe disposal of batteries</td>
</tr>
<tr>
<td>Use of dry cell non-rechargeable battery for torches and radio Mobile phone charging at long distances</td>
<td>Introduce parallel charging systems with the solar PV water provision in order to use LED rechargeable lanterns Safe disposal of batteries</td>
</tr>
<tr>
<td>Biomass remains main energy source for cooking but becoming scarce</td>
<td>Continue to educate on sustainable use of biomass (efficient stoves, use of own woodlots, tree planting and others)</td>
</tr>
</tbody>
</table>

The study found out that the biggest challenge regarding drinking water provision in Chiradzulu District was lack of access, which was evidenced by exceeding the number of households per borehole and queuing for water. Lack of access is apparently caused by high population and
non-functionality (complete failure, low yield or partly functioning). This implies that there is need for more boreholes that are well designed to provide better yields and be able to meet the water demands of the growing population. As for irrigation, the households use watering cans, and a few have treadle pumps which are both labour intensive and don’t allow for cultivation of larger plots because of the heavy labour involved. Solar water pumping as discussed in Chapter 2 has the potential to meet the water needs for drinking and irrigation water. This study proposes the design of a solar-powered water pumping system to provide water for drinking and for agriculture to address the emerging challenges from this survey.

Although the households are willing to pay for both drinking and irrigation water, their ability to pay is low and is compromised by their incomes. The study found out that in the rural areas of Chiradzulu, incomes are low and illiteracy levels are still high, with women less educated and having lower incomes than men. The study also found out that the households are willing to pay more for irrigation water than for drinking water, which indicates that they realise the importance of irrigation water. On one hand, water for irrigation can enhance food security whilst on the other it augments generation of income. However, in addition to provision of water, the households would also need farm inputs, training in agriculture business and availability of adequate markets. Hence, proper planning, design and impartation of knowledge on how provision of water can generate income are necessary. Though this present research determines the households' WTP and ATP, it does not guarantee that the households will pay, as that would need further engagement with them. However, the WTP amount acts as a guideline for policy and decision makers.

In terms of lighting energy, it was found that non-rechargeable battery torches have superseded the use of paraffin though the older generation still prefer the use of paraffin. Batteries are also used for powering radios. However, batteries have challenges of cost such that the households sometimes forego lighting and radio listening. The importance of lighting in enhancing education and income generation was discussed and highlighted in Chapter 2 whereas from the household survey results radio was found to be the main mode of information dissemination, which highlights its importance in educating the masses. As a drawback to the lighting methods, it was observed that households do not have proper disposal methods for the batteries whilst paraffin is a health hazard.

The majority of households travel elsewhere to charge their mobile phones at a fee, with some of them travelling up to 20 km. Hence, from the survey there arises an obvious role for solar PV to recharge batteries in torches and for use in other devices requiring very low power. Solar PV can eliminate the need to travel a long distance to have a phone charged. One way to solve the challenge of meeting the costs for drinking water is cross-subsidising water cost with the household energy use, particularly rechargeable solar lanterns, phone charging, and radio
charging. In so doing these energy services will be offered at a more affordable cost and convenient distance and at the same time subsidizing the cost of water.

From the results of the household survey, the primary driver in terms of drinking water is to supply adequate water to the growing population. Reducing water-linked diseases such as diarrhoea becomes a secondary goal. Water provision on its own cannot prevent diseases, it also needs the inclusion of good hygiene practices. Therefore, the project implementers should continue sensitisation of good water management.

Furthermore, results of the household survey provide a knowledge base regarding water and energy use and an estimation of the households’ WTP for improved drinking water access and quality, and irrigation water for food security and income generation. The data can serve as a basis to better identify the proper technological choice and the level of service to be provided for developing appropriate policies for cost effectiveness and sustainability of better water-provision systems using solar PV for the rural areas of Malawi. This study is unique in that it addresses both the needs for energy and water in one study. Similar studies can be carried in other parts of the country to confirm or add on the results of this study. Particularly in this research, the results are used in the techno-economic analysis to model a water provision system using solar PV for a case study village in the rural areas of Malawi. The analysis is presented in the next chapter, Chapter 5.
5 Techno-economic Analysis for Solar PV Water Pumping System

5.1 Introduction

This chapter presents and discusses the techno-economic analysis that was carried out for a Solar PV Water Pumping System (SWPS) for Potani Village, in Chiradzulu District. This was achieved by designing the system and carrying out an economic analysis employing the life cycle cost analysis (LCCA), which takes into account the time value of money over the entire project life cycle (Argaw, 2004; Park, 2011). The life cycle cost (LCC) and the annual demand of water supplied over the lifecycle were used to calculate the levelized cost of water (LCW) (Fane, Robinson and White, 2003). Sensitivity analysis was carried out to account for risk and uncertainty of the system. The LCW was compared to what the households are currently paying and to what they are willing to pay. The chapter further calculates the payback period under various scenarios. Financing of the system was modelled by cross-subsidising the cost of water with cost of charging handheld lanterns and mobile phones, which was incorporated in the SWPS to provide basic but necessary energy services. The chapter concludes with a discussion and summary.

5.2 Design for a SWPS for drinking water

The standalone directly coupled SWPS was designed and it employs tanks for storage of water rather than storing energy in batteries. Batteries often make the systems prone to frequent maintenance hence become expensive in the long-run. In addition to continuous supply of water, when the sun is not shining, the tanks redistribute the water using gravity. The main components of this system are the PV modules, pump controller, submersible motor-pump set and the water storage tank as illustrated in Figure 5.1 (Sahin and Rehman, 2012; Chandel, Nagaraju and Chandel, 2015; Sontake and Kalamkar, 2016). The related parts of the system include the structures for the tank, PV modules, wiring, balance of system, pipes and taps. The designed system has a single collection point with four taps but at an extra cost, a distribution system could be added.
5.2.1 Step 1: Calculation of the daily water requirement and storage

The WHO recommends 20 litres per person per day within 1 km (or within 30 min round trip) for domestic water supply for the basic access category. It is assumed that laundry would be carried out elsewhere (WHO, 2011). This research adopted the WHO basic access category with the similar assumption that laundry would be carried out at the river or shallow wells. As can be seen in the map of Figure 3.3 in Chapter 3, rivers and streams are abundant in Chiradzulu. Using the WHO recommendation and results from the household survey about the average number of people per household and the number of households in Potani village, the village water requirement was approximated to 18,336 litres as illustrated in the calculation in Table 5.1. Considering population growth, 10% is added and the daily water requirement is approximated to 20 m$^3$. Water demand was assumed to be the same for all months of the year (Ramos and Ramos, 2009). To compensate for cloudy days, this study designed for two days’ worth water storage though less or more days may be required depending on the availability of solar irradiation, alternative water sources, geographical location, and other factors (Barlow, McNelis and Derrick, 1993; Argaw, Foster and Ellis, 2003; Argaw, 2004). However, (Argaw, Foster and Ellis, 2003) warns against storing water for many days because it can form a breeding ground for microorganisms, or begin to smell, depending on the local climate.
### Table 5.1: Calculation for water requirement for Potani Village

<table>
<thead>
<tr>
<th>Water requirement per person per day (litres) (a)</th>
<th>No of households (b)</th>
<th>No of people per household (c)</th>
<th>No of people in the village (d=b x c)</th>
<th>Village water requirement per day (litres) (e=a x d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>191</td>
<td>4.8</td>
<td>917</td>
<td>18,336</td>
</tr>
</tbody>
</table>

### 5.2.2 Step 2: Determination of the water source and the total dynamic head

As discussed in Chapter 2, groundwater and surface water resources are abundant in Malawi and are believed to be generally adequate. If the necessary siting precautions (see section 2.5.4) have been followed, groundwater is usually relatively safe to drink with no treatment, though disinfection may be necessary; whereas surface water always requires expensive treatment (Argaw, 2004). In addition, groundwater is in proximity to the communities' dwellings, thus groundwater was preferred for this study, assuming that adequate groundwater yield will be available for the village. Water will be pumped from the ground and stored in an elevated tank to provide for gravity-fed distribution.

In Chapter 6, the expert interviewees reported that the recommended minimum depth for deep wells in Malawi is 20 m and most of the deep boreholes are in the range of 20 to 60 m, with an average of 45 m, which is consistent with relevant literature (Baumann and Furey, 2013; Furey, 2014). Previous research carried out in Chiradzulu (Pritchard, Mkandawire and O’Neill, 2007) found out that AFRIDEV pumps of 7 and 7.5 m depth, elephant pumps of 6, 8 and 9 m and MALDA pumps of 4 and 6 m. However, AFRIDEV pumps are supposed to be fitted on deep wells. Deeper groundwater resources of more than 20 m are said to be more reliable and have lower vulnerability to contamination (Bonsor, MacDonald and Calow, 2010; Howard, Charles and Pond, 2010; MacDonald et al., 2011). Tanks are usually located as close as possible to the boreholes and elevated at 2 to 6 m. With this information, the TDH for Potani village was estimated to be 60 m. However, this figure is indicative hence the actual dimensions would be confirmed after well drilling and testing have been completed. TDH is defined in section 3.7.2.

### 5.2.3 Step 3: Determination of the hydraulic equivalent energy

The equivalent hydraulic energy, $E_h$, is defined as the product of head and volume of water delivered per day or year with units of m$^4$ (Odeh, Yohanis and Norton, 2006a). For this study, it is calculated as shown in Equation. 5.1 (Argaw, 2004; Odeh, Yohanis and Norton, 2006a):

$$E_h = V \times TDH = 20 \text{ m}^3 \times 60 \text{ m} = 1,200 \text{ m}^4$$  \hfill (5.1)

where
• $V$ is water output volume ($m^3$); and

• $TDH$ (m) is the total dynamic head.

$E_h$ is used because it encompasses both water volume and pumping head components and makes it possible to compare systems with different TDH and volumes. For a particular borehole, $E_h$ may vary from month to month depending on variation in water levels or water demand. It is useful when selecting and designing a system. For instance, (Argaw, 2004) recommends that for hydraulic loads of less than 250 $m^4$, handpumps should be used. Similarly, (Cloutier and Rowley, 2011) recommended the use of handpumps for small sparsely populated communities. In their study, (Odeh, Yohanis and Norton, 2006a) found out that SWPS are more economical than diesel pumping systems for $E_h$ below 5,750 $m^4/day$ at 21.6 MJ/$m^2/day$ average insolation, after which for larger applications diesel pumping system became more economic.

In recent years the value of $E_h$ might not be used because there has been considerable advancement and improvement in PV efficiency and reduction in PV prices (Chandel, Nagaraju and Chandel, 2015; Kazem et al., 2015). (IRENA, 2016b) reports that the levelized cost of energy for solar PV fell 58% from 2010 to 2015, making it increasingly competitive at utility scale. Besides, diesel applications may not be feasible for remote locations of developing countries because of scarcity of diesel and maintenance personnel (Argaw, 2004; Al-Smairan, 2012; Chandel, Nagaraju and Chandel, 2015). In section 5.4.4 it will be noted that the largest SWPS from the presented literature had an $E_h$ of 10,000 $m^4/day$ (Sahin and Rehman, 2012). Thus, it can be suggested that SWPS should be recommended on a case-by-case basis.

### 5.2.4 Step 4: Determination of solar irradiation

Malawi has relatively high solar irradiation; the Malawi Energy Policy (GoM, 2003) states the average daily solar irradiation of 6 kWh/$m^2/day$. A more recent comprehensive study for Malawi’s solar irradiation was carried out by the World Bank (Suri et al., 2015), and the results are illustrated by the map in Figure 5.2. The map shows that the highest global horizontal irradiation (GHI) is in the northern and central part of the Northern Region of the country where peak average daily totals is 6.0 kWh/$m^2$ with yearly total of at least 2,190 kWh/$m^2$. The report further compares monthly averages of daily values of GHI and shows that the highest lasts for five months from August to December. Figure 5.3 shows the GHI long-term average, average, minima and maxima of daily totals for a period of 21 years for seven selected sites. The report further explains that the sites have similar geographical characteristics hence small variability.
between them suggesting that all sites will experience similar performance of solar PV power systems.

Figure 5.2: GHI long term averages of daily/yearly totals for Malawi

Source: (Suri et al., 2015)
The geographical coordinates of Potani village are latitude -15.727° and longitude 35.1° at 634 m above sea level. Site specific data for the village was not available and from the seven selected sites in the World Bank report, the nearest one is Blantyre, which is approximately 25 km away, and has an average minimum of 4.24 kWh/m²/day in June/July, maximum of 6.49 kWh/m²/day, in October and yearly average of 5.43 kWh/m²/day.

Data for Potani village from the NASA's Atmospheric Science Data Centre (NASA, 2015) indicates a minimum of 4.34 kWh/m²/day in June, maximum of 6.49 kWh/m²/day in October, and a yearly average of 5.38 kWh/m²/day, as illustrated in Figure 5.4. The data were provided for monthly average radiation incident on a horizontal surface over a 22-year period. With no data specifically available for Potani village and since it was beyond the scope of this study to set up a system to measure the data, the NASA data were found adequate for this study’s analysis because it was close to that of the nearest city of Blantyre (compare the data in Figures 5.2, 5.3 and 5.4). To maximise the solar resource, the solar modules would be tilted to the North with a tilt angle corresponding to the site latitude (Argaw, 2004).

In his study for the feasibility of solar PV grid-tied energy system for Nigeria, (Adaramola, 2014) used data from NASA and (Zalengera, 2015) established that the measured data for Likoma Island in Malawi compared well with the NASA data. Unavailability of various types of data in Malawi was one of the challenges raised by the stakeholders in section 6.3.1.3. For India (Luthra et al., 2015), also cites unavailability of solar irradiation data as one of the barriers to RETs adoption.
The month with the worst-case combination of solar radiation energy and water demand is generally chosen as the design month. Such systems will provide the required volume of water in months where the least sunlight is available, and produce above the required demand in the months with greater solar insolation (Argaw, 2004). Studies by Barlow, McNelis and Derrick (1993) and Al-Smairan (2012), suggest that water demand varies seasonally such that the dry months which have the highest GHI are the months in which the water demand is high and vice versa hence the demand is matched with the available power. In line with these authors, this research thus used the annual average daily irradiation of 5.38 kWh/m²/day rather than the minimum just as other researchers such as (Odeh, Yohanis and Norton, 2006a; Abu-Aligh, 2011) have used. Barlow et al. (1993) further argue that people adapt to the pumping conditions and that it is more preferable to have less water for a short period of the year rather than having no water at all.

5.2.5 Step 5: Determination of the pump size

The motor-pump size is estimated and selected by using the flow rate (Q) and the TDH. The Q for Potani Village was calculated as shown in Equation. 5.2 (Shehadeh, 2015).

\[
Q = \frac{\text{Daily water requirement}}{\text{Average daily solar insolation}} = \frac{20\text{m}^3}{5.38\text{kWh/m}^2} = 3.72\text{m}^3/\text{hr}
\]

\[
= 1.03 \text{litres/s}
\]

In section 2.5.3, it was discussed that the aquifers in Malawi can produce a yield of over 1 litre/s and hence would be adequate for the calculated flow rate. Using the calculated Q, TDH and the manufacturer’s pump selection curves, the Grundfos submersible pump-motor
SQFlex 3A-10 and SQFlex 2.5-2, met the calculated Q and TDH criteria. The performance curves for these pumps are shown in appendix 5.1 and both have ratings of 30-300V DC, 1.4 kW and 8.4 A. The Grundfos supplier in the country had the SQFlex 2.5-2 readily available and they have experience with the model, hence it was selected for the analysis.

5.2.6 Step 6: Determination of solar array size

The module sizing design procedure was adapted from (Argaw, 2004; Chandel, Nagaraju and Chandel, 2015). The PV array power (in watt-peak, Wp) is given by Equation 5.3 (Argaw, 2004; Bouzidi, 2009; Al-Smairan, 2012):

\[ P = 1000 \frac{\rho ghV \eta_r}{k G_T \eta_{pv} \eta_s} \]  

(5.3)

where, \( \rho \) is the water density (kg/ m\(^3\)), \( g \) is the acceleration due to gravity (g/m\(^2\)), \( h \) is TDH (m), \( V \) is the daily amount of water required (m\(^3\)), \( G_T \) is the daily solar irradiation (kWh/m\(^2\)/day) on the PV array surface, \( \eta_{pv} \) is the efficiency of the PV array under operating conditions and \( \eta_s \) is the subsystem efficiency, \( \eta_r \) is the array efficiency at 1000 W/m\(^2\) and 25\(^\circ\)C, and \( k = 3 \times 10^6 \) (conversion factor of Joules to kWh). In the absence of field data, the generally accepted values are used and Equation 5.3 simplifies to Equation 5.4.

\[ P = \frac{\rho ghV}{G_T FE} \]  

(5.4)

where, \( F \) is the array mismatch factor and is the ratio of the power output of the PV array under operating condition to its power output at the maximum power point. Typical values of \( F \) are 0.85-0.90. \( E \) is the daily subsystem efficiency and has typical values of 0.2-0.6 (Al-Smairan, 2012). For this study, values of 0.85 and 0.5 were used for \( F \) and \( E \), respectively.

The amount of water pumped per day, in m\(^3\) is given by Equation 5.5:

\[ V = \frac{P G_T EF}{\rho ghH} \]  

(5.5)

5.3 Economic analysis

5.3.1 Payback period

Both the simple payback period (SPB) and the discounted payback period (DPB) were calculated for the system. SPB is the number of years necessary to recover the project cost of an investment under consideration and allows for a quick assessment of the duration during
which an investor’s capital is at risk. DPB, on the other hand is the number of years necessary to recover the project cost of an investment while accounting for the time value of money (Short, Packey and Holt, 1995; Fuller and Petersen, 1996). SPB is calculated using Equation 5.6 and DPB using Equation 5.7 (Winkler et al., 1990; Park, 2011).

\[
SPB \text{ (yrs)} = \frac{\text{Cost of installed system}}{\text{Net annual cash inflow}} \tag{5.6}
\]

\[
DPB \text{ (yrs)} = \frac{-\ln[1 - ((r)(PVA)/PMT)]}{\ln(1 + r)} \tag{5.7}
\]

Where,

- \(PVA\) is present value of annuity,
- \(PMT\) is the repayment amount and
- \(r\) is the discount rate.

### 5.3.2 Life cycle cost analysis

The life cycle cost analysis (LCCA) method is used to evaluate the financial viability of a system and it gives the total cost of a project during its lifetime and considers the life cycle costs (LCC), namely capital costs, operating and maintenance costs, fuel costs, and salvage value. It is obtained by discounting all the future costs and benefits to the present-day value and added to the present-day investment costs (Short, Packey and Holt, 1995; Argaw, 2004), to account for the time value of money. From the LCC, the levelized cost of water (LCW) is calculated using equation 5.8 (Fane, Robinson and White, 2003; Parajuli, Pokharel and Østergaard, 2014).

\[
LCW = \frac{LCC}{Lifetime \ water \ production} = \frac{\sum_{t=0}^{T} (C_t + O_t + M_t - S_t)}{(1 + r)^t} \frac{\sum_{t=0}^{T} Q_t}{\sum_{t=0}^{T} (1 + r)^t} \tag{5.8}
\]

Where:

- \(T\) is the life of project in years; and \(t\) is for year \(t\);
- \(C_t\) is the net capital cost of project for \(t\) in US$, and includes capital expenses for equipment, system design, and installation costs (Chandrasekar and Kandpal, 2005; Odeh, Yohanis and Norton, 2006b);
• \( r \) is the discount rate for \( t \) (%);

• \( O_t \) and \( M_t \) are the sum of all yearly scheduled operation and maintenance costs for \( t \), which is the cost of all repair and equipment replacement cost expected over the life of the system; and

• \( S_t \), is the salvage value and is the net worth of the system in the final year.

The LCCA for Potani village was based on the following parameters and assumptions:

a. **Capital Costs**: Quotations for costs of system components, well drilling, labour, transport and administration were obtained from several commercial suppliers Malawi. These were validated with costs from Kenya, Blanchard, R, Lecturer (Personal communication, 31st March 2017), from LORENTZ, an international supplier, Honey, A, Head of Marketing (Personal communication, 7th April 2017) and from Water Mission, the only international NGO that is involved in SWPS in Malawi, Longwe, B. (Personal communication, 27th February 2017).

The costs consisted of the following:

• Design power was 1.43 kWp and consisted of 7 Solar World modules of 225 W each;

• Grundfos SQF 3A-10 submersible motor-pump as discussed in section 5.2.5;

• Balance of system which consisted of pump controller, cables, piping, connecters and other accessories;

• Storages tanks and stands, including taps and pipes, the stands to also be used for the solar modules' support;

• Well drilling; and

• Labour, transport and administration.

b. **Period**: Having had no access to documented study on SWPSs in Malawi, this study adopted a lifetime of 20 years with a replacement for the pump in the 10th year. It is generally recommended for PV panels to be replaced after a period of 20 to 30 years, whereas the motor-pump may be replaced after 5-10 years. Several authors (Ghoneim, 2006; Khatib, 2010; Abu-Aligh, 2011; Cloutier and Rowley, 2011) have used a time period of 20 years whilst other have used 25 years(Sahin and Rehman, 2012).

c. **Operation and maintenance costs (O&M)**: For a solar project these are usually taken as 2% of capital costs (Short, Packey and Holt, 1995; Al-Smairan, 2012), and assumed
constant throughout the lifetime of the project and the pump would be replaced in the 10\textsuperscript{th} year. The O&M costs have been considered to be 1\% of capital cost because it is assumed that the community would carry out most of these costs such as cleaning and inspection for cracks and damage of the solar modules, trimming trees to prevent shadows and providing security. Other costs such as inspection of electrical components and replacement of taps would need some basic technical expertise.

d. \textbf{Discount rate (DR):} This depends on the type of analysis such as personal, business investment, or social DR (Doshi, D'Souza and Nguyen, 2013). For government or NGO funded projects, authors such as (Short, Packey and Holt, 1995; Branker, Pathak and Pearce, 2011) recommend the use of an appropriate social DR other than the market rate because of the social benefits provided by public projects. The DR is at the discretion of the evaluator. The high DR used by the private sector do not capture the long-term social benefits but enable them to maximize the short term profits (Branker, Pathak and Pearce, 2011). Assuming the system to be a social enterprise, a social DR of 10\% was used (ESCOM, 2014). However, private enterprises may use higher rates since Malawi's economy is volatile, with high inflation and interest rates with inflation rate currently at 20\% (Reserve Bank of Malawi, 2017) and the base lending interest rate can reach a maximum of 42.88\% (Press Corporation Limited, 2015).

e. \textbf{Salvage costs:} These were assumed to be zero as some authors have used (Branker, Pathak and Pearce, 2011; Cloutier and Rowley, 2011).

5.3.3 \textbf{Sensitivity analysis}

This was carried out to account for uncertainty and risk particularly to identify the input parameters that have the greatest impact on a specific measure of economic evaluation and at the same time determine how variability in the input value affects the economic measure (Short, Packey and Holt, 1995). See section 2.6.5.

According to (Odeh, Yohanis and Norton, 2006a), the parameters that affect water unit cost in order of priority are system productivity, capital investment, interest rate and operating cost. For this study, sensitivity analysis was carried for the NPV (or LCC) and the LCW against input variables of capital cost, discount rate, O&M and monthly contribution. Only the analysis of the NPV is reported because the parameter effects on NPV and LCW were similar. To test sensitivity, a base case scenario whereby the NPV was equal to zero was selected and the input parameters were increased or decreased in increments of \pm 10 \% up to 50 \%. The parameters are shown in Table 5.2, which also states the possible causes of variation.
Table 5.2: Sensitivity analysis input parameters and possible causes

Adapted from: (Chandrasekar and Kandpal, 2005; Odeh, Yohanis and Norton, 2006b) and researcher’s study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Possible causes for variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>Component prices, distance from city, subsidies, soft loans, exemption or reduction of excise duty</td>
</tr>
<tr>
<td>Tariff</td>
<td>Education, income, gender</td>
</tr>
<tr>
<td>DR</td>
<td>Market situation, loan interest, inflation rate, subsidies</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>Labour cost, wages, component lifetime</td>
</tr>
</tbody>
</table>

In this study, system productivity was not tested because for a specific location and community there is little control on it. System productivity is determined by the irradiation, water availability, water demand, system optimization, and TDH among other things (Odeh, Yohanis and Norton, 2006a).

5.4 Results

Using the design and economic analysis steps discussed in section 5.2 and 5.3, a SWPS was designed for Potani village and an economic analysis was carried out. The results of the study are now presented, discussed and compared to those from previous research.

5.4.1 Input parameters

The main design input parameters for the SWPS are summarised in Table 5.3 and the choice off values were discussed in sections 5.2 and 5.3.

5.4.2 System costs

The modelled total cost of the system was US$18,600 and the percentage cost contribution of each item of the system is shown in Table 5.4 and illustrated in Figure 5.5. At an extra cost of US$3,000, a purification system designed by Water Mission can be added. See Appendix 6.2.b.
Table 5.3: Technical parameters used in the evaluation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water requirement per day (m³)</td>
<td>20</td>
</tr>
<tr>
<td>Water storage tanks size (m³)</td>
<td>40</td>
</tr>
<tr>
<td>Monthly average irradiance (kwh/m³/day)</td>
<td>5.38</td>
</tr>
<tr>
<td>TDH (m)</td>
<td>60</td>
</tr>
<tr>
<td>PV Module Power (kWp)</td>
<td>1.43</td>
</tr>
<tr>
<td>Lifetime of PV module (years)</td>
<td>20</td>
</tr>
<tr>
<td>Life time of submersible pump (years)</td>
<td>10</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>1% of capital cost</td>
</tr>
<tr>
<td>DR (%)</td>
<td>10</td>
</tr>
<tr>
<td>Salvage value (US$)</td>
<td>0</td>
</tr>
<tr>
<td>Highest quantity of water delivered per day (m³)</td>
<td>24 (October)</td>
</tr>
<tr>
<td>Lowest quantity of Water delivered per day (m³)</td>
<td>16 (June)</td>
</tr>
</tbody>
</table>

Table 5.4: Cost of system components

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (US$)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage and distribution</td>
<td>8,250</td>
<td>44</td>
</tr>
<tr>
<td>Well drilling</td>
<td>3,000</td>
<td>16</td>
</tr>
<tr>
<td>Pump</td>
<td>2,400</td>
<td>13</td>
</tr>
<tr>
<td>Labour, transport, administration</td>
<td>2,645</td>
<td>14</td>
</tr>
<tr>
<td>Solar modules</td>
<td>1,575</td>
<td>8</td>
</tr>
<tr>
<td>Balance of system</td>
<td>1,000</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>18,600</td>
<td>100</td>
</tr>
</tbody>
</table>
Comparatively, Water Missions stated that their basic system cost approximately US$25,000. Costs of systems by other selected authors will be discussed in section 5.4.4 alongside the cost of water. The major costs of the system are associated with storage and distribution followed by well drilling whereas the solar modules account for only 8% of the costs.

High capital costs are usually associated with the cost of solar modules, but in this study, it shows that the civil works are the major costs. The other reason for the high cost of the civil works is that the cost of stands for the tanks which doubles up as the stand for the solar modules are included in the civil works rather than the solar modules. To reduce the storage costs, it may be considered to reduce the days of autonomy, but this would require monitoring of a practical system under Malawi’s irradiation conditions and hence set up corresponding standards for Malawi.

Comparatively, a borehole fitted with a handpump costs US$8,000 as reported by interviewees in Chapter 6. A single borehole is recommended to supply 250 people (or 50 households). On the other hand, at an extra cost of US$11,000 (or at 2.3 times the borehole cost), the SWPS can supply up to four times as many people (households). This would appear to indicate that the SWPS is more cost-effective than the borehole.

Possible long-term goals would be distribution of water to individual houses/compounds for those who can afford because amongst the households in the survey, there were others who were willing to pay much more than others.
5.4.3 Quantity of water pumped

The volume of water pumped over each of the 12 months is shown in Figure 5.6 and the annual total is approximately equal to 2,701 m³. Since the average irradiation was used for design, there are four months (April, May, June, and July) in which the volume of water pumped is below the required amount of 18.3 m³ per day. The least amount of 16 m³ is in June; followed by July with 17 m³. These are cold months and generally, less water is used as compared to the dry months from September to November. In the dry months there would be excess energy/water which could be used for other purposes.

5.4.4 Cost of water

The LCW for the designed system was calculated and found to be US$0.34/m³. This falls within results of other authors within the last ten years (Ramos and Ramos, 2009; Bouzidi, 2011; Cloutier and Rowley, 2011; Al-Smailan, 2012; Sahin and Rehman, 2012) as illustrated in Table 5.5. Costs are shown in US dollars for comparison purposes.

The LCW from other studies range from US$0.03 /m³ to US$1.14/m³. Alternatively, the systems can be compared using the hydraulic energy cost, which gives slightly different ranking as shown in the same table. The variations in the cost of water can be explained by several reasons. Firstly, the exclusion or inclusion of costs such as drilling and storage. Secondly, the location of study, which determines among other things, the solar irradiation, cost of components, water quantity, TDH, and DR. Thirdly, the lifetime of the system and finally, the values used for O&M costs.

The lowest LCW of US$0.024 is stated by (Sahin and Rehman, 2012) and in their design, the inclusion of drilling and water storage costs is not mentioned. Their system cost is highest of all authors’ and largest capacity, probably the economies of scale have played a part in reducing the LCW. For their best system they were pumping approximately 240 m³ per day (90,000 m³ per annum), whereas the rest of the authors pumped between 1 m³ to 60 m³ per day. The hydraulic load equivalent cost is US$6.66/m⁴ and is second cheapest. The LCW for (Bouzidi, 2011; Al-Smailan, 2012) are lower than the current study and they do not mention the drilling costs. For the (Cloutier and Rowley, 2011) study, the cost of water for the 20 m³ and 30 m³ systems is higher than in the current study and they included drilling costs, however, instead of tank storage, they used solar battery storage.
Figure 5.6: Average amount of water pumped per day in each month

Table 5.5: Cost of water comparison with other studies

<table>
<thead>
<tr>
<th>Author</th>
<th>Array size (kWp)</th>
<th>TDH (m)</th>
<th>Water demand (m$^3$)</th>
<th>Cost of system (US$)</th>
<th>LCW (US$/m$^3$)</th>
<th>Hydraulic energy, $E_h$, (m$^4$)</th>
<th>$E_h$ Cost (US$/m^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahin and Rehman- Nejran (2012)</td>
<td>-</td>
<td>50</td>
<td>240</td>
<td>79,920</td>
<td>0.024</td>
<td>12,000</td>
<td>6.66</td>
</tr>
<tr>
<td>Sahin and Rehman- Dhahran (2012)</td>
<td>-</td>
<td>50</td>
<td>200</td>
<td>79,920</td>
<td>0.027</td>
<td>10,000</td>
<td>7.99</td>
</tr>
<tr>
<td>Bouzidi (2011)</td>
<td>-</td>
<td>45</td>
<td>60</td>
<td>24,450</td>
<td>0.14</td>
<td>2,420</td>
<td>10.1</td>
</tr>
<tr>
<td>Al-Smairan (2012)</td>
<td>5.94</td>
<td>70</td>
<td>45</td>
<td>20,790</td>
<td>0.20</td>
<td>3,150</td>
<td>6.6</td>
</tr>
<tr>
<td>Current Study</td>
<td>1.43</td>
<td>60</td>
<td>20</td>
<td>18,600</td>
<td>0.34</td>
<td>1,200</td>
<td>15.5</td>
</tr>
<tr>
<td>Cloutier &amp; Rowley - 20 m$^3$ (2011)</td>
<td>1.68</td>
<td>40</td>
<td>20</td>
<td>28,000</td>
<td>0.68</td>
<td>800</td>
<td>35.0</td>
</tr>
<tr>
<td>Raturi (2011)</td>
<td>6.4</td>
<td>100</td>
<td>26</td>
<td>43,300</td>
<td>0.70</td>
<td>2,600</td>
<td>16.7</td>
</tr>
<tr>
<td>Cloutier &amp; Rowley - 30 m$^3$ (2011)</td>
<td>2.52</td>
<td>40</td>
<td>30</td>
<td>38,700</td>
<td>0.87</td>
<td>1,200</td>
<td>32.3</td>
</tr>
<tr>
<td>Ramos &amp; Ramos (2009)</td>
<td>0.195</td>
<td>110</td>
<td>1</td>
<td>3,200</td>
<td>1.14</td>
<td>100</td>
<td>32.0</td>
</tr>
<tr>
<td>Malawi Kiosk (2015)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.92</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Though (Ramos and Ramos, 2009; Raturi, 2011) did not include the drilling and water storage costs, they have the highest costs. For (Ramos and Ramos, 2009) possibly because they
designed for a small system of 1 m³ and economies of scale might have played part. The cost of the current design was also compared to cost of water from water kiosks supplied by the city’s Waterboard, which are the popular method of water delivery in the low-income urban areas of Malawi. As shown in Table 5.5, the designed system was found to be cheaper than the kiosk water. All the above studies are silent on whether a water purification method was used.

5.4.5 Sensitivity analysis results

The results of the sensitivity analysis are illustrated in the line graphs of Figure 5.7 and tornado chart of Figure 5.8.

The line graph allows for rate of variation to be visualised whereas the tornado chart allows the magnitudes to be easily differentiated. The results show that the monthly contribution (or tariff) has the most impact on NPV. For an acceptable return on investment, a positive high NPV is desirable.

Capital cost which include the costs of solar modules, motor-pump set, water tanks, structures, transport and drilling came second. In Malawi, there is exemption on duty but not on value added tax and currently there are no subsidies on renewables. Also discussed are the high transport to the rural areas and drilling costs, which are increased by the poor road infrastructures. Furthermore, lack of entrepreneurs closer to the rural areas is also a contributing factor. There are several ways of meeting the capital costs in rural areas of developing countries such as cash, micro-finance, fiscal instruments, grants, and subsidy, among others (Bhattacharyya, 2013; Mainali et al., 2014). To make renewable technologies affordable for its customers in Bangladesh, Grameen Shakti offers them micro-credit assistance rather than providing any direct grants or subsidies. That way ownership and financial commitment is instilled in the communities (IEA, 2008). Similar innovations may be explored for Malawi.

Factors that influence the DR are loan interest rate, and inflation. It is recommended for such projects to have access to soft (low interest) loans. Alternatively, private organizations may offer interest-free loans as corporate social responsibility. O&M costs had the least effect on NPV, which is expected for SWPS particularly if genuine components that do not fail easily have been used. The main maintenance issues and recurring cost issues are the cleaning of the modules, security to protect against vandalism and breakdown of water distribution systems. For security, it is recommended that the modules be close to dwelling houses. Where that is not possible, security guards and/or members of the community should alternate in guarding the system at night as done by the Tiyanjane community discussed in section 6.5.
5.4.6 Payback period and comparison of LCW with WTP

For comparison purpose, the designed cost of water per cubic metre was converted to its equivalent average monthly payment because the households paid based on a fixed monthly contribution. The amount of water per household per month was calculated using the
designed quantity per annum as illustrated in Table 5.6. The table shows that each household will have an average of 3.14 m$^3$ per month. The LCW is US$0.34/m$^3$ and multiplying with the quantity of water per household gives the designed cost of water to be US$1.08 per household per month.

**Table 5.6: Calculating the quantity of water per household**

<table>
<thead>
<tr>
<th>Quantity of water per annum (m$^3$) (a)</th>
<th>No of households (b)</th>
<th>Quantity of water per household per annum (m$^3$) (c=a/b)</th>
<th>Quantity of water per household per month (m$^3$) (d= c/12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7201</td>
<td>191</td>
<td>37.7</td>
<td>3.14</td>
</tr>
</tbody>
</table>

The LCW is compared to various costs as shown in Table 5.7. The table also shows the payback periods, which will be discussed later in the section. The results show that the LCW is approximately six times the current households' payment and three times their median WTP. Medians were used for the main comparisons because for nonparametric data, which was the case with this study, medians must be used rather than means as explained in section 3.4.1.1. Also shown in the table is the maximum acceptable ATP (which is defined as 5% of monthly income), and the mean WTP, which interestingly is equal to the designed cost. The findings of this study established the WTP for the people living in the rural areas of Malawi.

**Table 5.7: Designed LCW compared with WTP amounts**

<table>
<thead>
<tr>
<th>Description of contribution</th>
<th>Amount (US$)</th>
<th>SPB (Yrs.)</th>
<th>DPB (Yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed cost per m$^3$</td>
<td>0.34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Designed cost per household per month equivalent</td>
<td>1.08</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Current median payment per household per month</td>
<td>0.19</td>
<td>&gt;40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Median WTP per household per month</td>
<td>0.38</td>
<td>30</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Maximum acceptable ATP (5% of income) per household per month</td>
<td>0.75</td>
<td>14</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Mean WTP per household per month</td>
<td>1.08</td>
<td>8</td>
<td>20</td>
</tr>
</tbody>
</table>

Another way of encouraging payment is paying according to usage. Currently, the flat monthly fee payment model is largely in use though it disadvantages households who use less water such as small families; whereas those who use more water such as large families, and those using it for income generation activities are at an advantage. For instance, water usage ranged from 20-500 litres per household per day; the household collecting 500 litres was engaged in traditional beer brewing. For fair use, a payment based on quantity used may be prescribed
such as has been practised by Water Missions in one of their models discussed in section 6.4.5. On the other hand, paying according to use may disadvantage the very poor families who may not always have readily available cash. In their study, (WaterAid, 2012) witnessed that if the poor communities appreciate the services and have proper structures in place, they can afford to pay higher amounts. Hence, with proper planning and consultation, a solution can be designed regarding paying for water by the rural households. However, for the WaterAid study it was for a peri-urban area. For this study it has yet to be established whether those in the rural areas would actually pay what they indicated that they would be willing to pay.

Table 5.7 also shows the simple payback period and the discounted payback period for each amount. The results illustrate that the households would not be able to payback for the system using the current payment or the median WTP within its lifetime. A payback period of less than four years is reported for a water pumping system for an academic institution in India (Jamil, Anees and Rizwan, 2012). For an urban area in Malawi, this is also a possibility considering that at a Kiosk water is at an equivalent cost of US$1.92/m³, which is 10 times the currently payment. Other studies (Mahmoud and el Nather, 2003; Pande et al., 2003; Espericueta, Pronaf and Juárez, 2004) state payback period of around six years for systems used for agriculture and livestock purposes; which is expected since the water was used for income-generation. For income-generating irrigated agriculture to be successful, the households have to undergo intensive engagement and training (see sections 6.3.1.3 and 6.6.5).

5.4.7 Cross-subsidising cost of water

From the previous section, it is apparent that the households may not be able to meet the cost of water using their income alone; thus, a model to aid financing the cost of water was developed. In the model, the cost of water is subsidised with the cost of some basic energy services. From the household study, it was found out that lighting and phone charging are essential services and currently required energy solutions. From literature, phone and lantern charging is a viable business in the rural areas of developing countries (Collings, 2011; Almeida and Brito, 2015) which some of the households from the survey aspired. With no grid connection, solar PV makes an attractive source of electric power to provide these basic energy needs. Thus, a charging kiosk for phones and lantern charger was incorporated in the water system at an estimated extra cost of US$2,000 based on studies by (Collings, 2011; Almeida and Brito, 2015; Iland and Belding, 2016). The kiosk consisted of a solar storage battery, PV module, controller, inverter and charging stations. With the added kiosk, the cost of the whole system became US$20,600 and the new cost of water became US$0.38/m³.
which translated to US$1.19 per household per month. The capital cost for the lanterns is not included in the analysis. The households would be paying their current monthly median contributions for water, and lighting and mobile phone charging (to be called energy revenue) from the findings in Chapter 4, which are shown again in Table 5.8.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of lighting energy (US$/month)</td>
<td>0.72</td>
<td>0.55</td>
<td>0.78</td>
<td>0.28</td>
<td>5.55</td>
</tr>
<tr>
<td>Current cost for phone charging (US$/month)</td>
<td>0.41</td>
<td>0.28</td>
<td>0.29</td>
<td>0.06</td>
<td>2.08</td>
</tr>
<tr>
<td>Distance to charging place (km)</td>
<td>3.28</td>
<td>2.50</td>
<td>2.78</td>
<td>0.10</td>
<td>20.00</td>
</tr>
<tr>
<td>WTP for charging phone (US$/month)</td>
<td>0.44</td>
<td>0.28</td>
<td>0.38</td>
<td>0.03</td>
<td>2.08</td>
</tr>
<tr>
<td>Cost of batteries for radio (US$/month)</td>
<td>1.07</td>
<td>0.80</td>
<td>0.91</td>
<td>0.14</td>
<td>6.24</td>
</tr>
<tr>
<td>Current water cost (US$/month)</td>
<td>0.29</td>
<td>0.19</td>
<td>0.20</td>
<td>0.04</td>
<td>0.96</td>
</tr>
<tr>
<td>WTP for water (US$/month)</td>
<td>1.08</td>
<td>0.38</td>
<td>1.85</td>
<td>0.10</td>
<td>13.46</td>
</tr>
</tbody>
</table>

The results for breakeven cost of water over the 20-year period, with and without revenues are shown in Table 5.9. If the households were to pay their current contribution for water only, the breakeven cost of water is US$1.19 per household per month. In the second scenario, the households would be paying their current median cost of water and energy revenues. The break-even cost of water is reduced from US$1.19 to US$0.49 per household per month. This is a considerable reduction in that the breakeven cost is now less than the maximum acceptable ATP of US$0.75 per household per month.

Considering that households are likely to pay more for energy than water, in the third scenario, the households would be paying their current median cost of water and their current mean energy costs revenues. The break-even cost of water is reduced from US$1.19 to US$0.25 per household per month, which is only US$0.06, more than what they are currently paying. Apparently, energy revenues would be easier to pay since the households would be paying what they require, other than for water of which they pay fixed amount (currently). Not all villages might have such a system hence people from neighbouring villages may use the system and increase the number of people charging their phones. In addition, the distance to mobile phone charging would be reduced hence they would be motivated to have their phones charged. However, this arrangement would also need engagement and training to change their mind-set from what they are used to doing.
Table 5.9: Breakeven water cost with and without energy revenues

<table>
<thead>
<tr>
<th>Payment Scenario</th>
<th>Cost per household per month (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed cost without energy revenues</td>
<td>1.19</td>
</tr>
<tr>
<td>Breakeven cost with median energy revenues</td>
<td>0.49</td>
</tr>
<tr>
<td>Breakeven cost with mean energy revenues</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The payback period for the various payment scenarios are shown in Table 5.10. These results show that with more innovative enterprises, the break-even amount can be reduced further. However, it may be accompanied by small increases in the capital cost.

Table 5.10: Selected payment scenario illustrating payback period

<table>
<thead>
<tr>
<th>Payment Scenario</th>
<th>Water cost per HH (US$)</th>
<th>Energy revenue for village (US$)</th>
<th>SPB (Yrs.)</th>
<th>DPB (Yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed cost</td>
<td>1.19</td>
<td>-</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Current median water contribution</td>
<td>0.19</td>
<td>-</td>
<td>&gt;40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Current water + energy revenues medians</td>
<td>0.19</td>
<td>134.2</td>
<td>30</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Water WTP + median energy revenues</td>
<td>0.38</td>
<td>134.2</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Current water + mean energy revenues</td>
<td>0.19</td>
<td>180.46</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>WTP + mean energy revenues</td>
<td>0.38</td>
<td>180.46</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

Community based systems were found to have failed in management of money (Chowns, 2014). Hence, it is recommended that this system should be run as a business giving part ownership to people who are interested to run a business from the village rather than having the volunteering WPC. The entrepreneurs can be rotated after a certain period and would require training in running the business and the communities on understanding the arrangement.

In section 6.3.2.3 and section 6.5.5, the NGO stakeholders reported that agreed payments with households vary from US$0.48 to US$0.78 per household per month. Though it was not verified whether the communities actually pay, these amounts are higher than the findings from the household survey. If these figures were entered in the model, payback period would be much shorter. It is then surprising that the communities are not able to pay for O&M costs on the current handpumps. One possibility is as mentioned by other researchers (Chowns, 2014) and the FGDs that the collected money is usually mismanaged. One way is to help manage finances is to make changes in the current management model. The presence of a
microfinance organisation or other similar organisation would be required to assist them to reinvest the contributions. Furthermore, mobile money secure payment can be utilised as discussed by other authors (Aker and Mbiti, 2010; World Bank, 2013; Hampshire et al., 2015).

5.5 Discussion and chapter summary

In this chapter, a techno-economic analysis was carried out by designing a SWPS and carrying out an economic analysis, which calculates the LCW and sensitivity analysis. The results have been validated by comparison with those from existing literature. Unlike previous studies which only present the LCW or determined the WTP, this research synthesised the two costs in order to calculate the breakeven cost for different scenarios. In addition, the study will further synthesise these findings with those of stakeholder’s, which are presented in Chapter 6.

The modelled cost of the system was US$18,600 and the LCW was US$0.34/m³, which is equivalent to US$1.08 per household per month. Currently, the households are paying a median of US$0.19 per household per month, and are willing to pay a median of US$0.38 per household per month, which are both clearly far much less than the LCW. From the sensitivity analysis, the tariff and capital cost were found to have the most impact on NPV and the cost of water.

Advantages of this system over the handpump are:

- Cost-effectiveness because a handpump is recommended for 50 households and costs US$8,000 whereas, the designed system would be able to adequately meet the water needs of the 191 households at approximately 2.3 times the cost of the handpump;
- Meeting the water demand of the population;
- Reduction of the manual labour due to pumping;
- Lessening contamination because of the depth;
- Reduction of queuing time and lessening of the stress associated with queuing as there is provision of multiple taps, hence time savings; and
- Meeting their energy needs simultaneously with the water needs because of the added kiosk. Results of this study show that cross-subsidizing the cost of water with the cost of lantern and mobile phone charging reduced the breakeven monthly contribution for water by over half.

The main disadvantage of the system is the high capital cost, which would be unaffordable for the rural communities who have low incomes. The sensitivity analysis results showed that the
monthly contribution followed by the capital cost have the most impact on NPV. In view of these results, suggested ways of reducing the capital cost are:

- Provision of interest free loans; and
- Reduction/removal of taxes on SWPS devices.

Furthermore, this research has highlighted that provision for water in developing countries goes beyond the technical design, but there are social aspects that must be considered as well. These are discussed in the next chapter.

Further work needs to be done to quantify resources that are available in the country such as solar irradiation, groundwater, and wind among others. Unavailability of long-term meteorological data with a small time-step is cited as one of the challenges in SWPS design (Muhsen, Khatib and Nagi, 2017). The data could be used for academic research and implementation of systems. It is recommended that in order to make improvements in the design, further research should be undertaken to investigate the long-term technical and economic field performance of SWPS and their return on investment after several years of owning and operating such systems. It is also recommended that a techno-economic analysis be carried out specifically for irrigation water.

In addition to this, sustainability depends on WTP, income and available, income generating activities, among other factors. This study is the first step towards techno-economic feasibility studies for SWPS for a Malawian rural village. The present findings might be useful to policymakers and investors because the study can easily be adapted to other parts of the country. The design is not a one size fits all as it depends on location and community, which would determine water demand, water resource availability and renewable energy resource availability, among other parameters. Hence, it is recommended to design each system depending on the variables and requirements of a particular location and community, which can be accomplished by carrying out a baseline study to determine factors for the location under consideration. Also for future research, it is recommended to carry out performance analysis on a practical system covering the technical, social and technical aspects. The next chapter presents and discusses the results of the stakeholder analysis.
6 Findings from Stakeholder Interviews

6.1 Introduction

This chapter describes the results of the qualitative evaluation that was conducted in order to explore stakeholders’ roles, responsibilities, activities, relationships, challenges and opportunities relating to water provision in the rural areas of Malawi. The research sought to gain a richer and deeper understanding of the process and issues involved from the point of view of stakeholders that are currently involved or would be potentially involved in providing water using solar PV. Data were obtained through a combination of methods, which comprised in-depth interviews, questionnaires, and field visits to four solar PV water-pumping projects, two for drinking water and two for irrigation. The interviews were conducted using some core interview guide questions designed to elicit information that would be used to address the specific objectives of the study. The qualitative analysis findings give a comprehensive assessment of the interviewees’ perceptions from different sectors and levels.

The complete list of organisations included government representatives, non-governmental organisations (NGOs), donors, entrepreneurs, and micro-finance organisations and is provided in appendix 6.1. The list also provides the interviewee codes that have been used to identify their affiliation in the voice quotes of this chapter. Section 6.2 describes roles and responsibilities of stakeholders. Section 6.3 describes the challenges from the stakeholders’ point of view. Sections 6.4 and 6.5 describe the practical experiences of solar PV water pumping systems (SWPS) with case studies for drinking and irrigation water respectively. The chapter ends with a discussion and summary presented in section 6.6.

6.2 Stakeholders identification, roles and responsibilities

Organisations that are involved in providing drinking water may also provide hygiene and sanitation services, such as covering drinking water, two-cup system of drinking water, hand washing, latrine use, dish rack usage, waste management, and menstrual hygiene management, among other activities. These activities are of importance because potable water provision alone cannot prevent disease but must be accompanied by sanitation and hygiene. The organisations carry out their work in communities, schools, health facilities, markets, and other public areas; but this research sought information about their involvement in the context of rural households. In addition to WASH services, some of these organisations also worked on capacity building, governance, environmental management such as afforestation and policy and advocacy issues related to the WASH sector.
Interviewees were asked to identify the main stakeholders they interact with and to describe their roles and responsibilities and these findings are summarised in Table 6.1. Similar findings are reported by (Baumann and Danert, 2008; Chowns, 2014). Interviewees felt that almost all the government ministries had the potential to be involved in water issues but singled out the following as the most significant ones:

- Agriculture, Irrigation and Water Development;
- Health,
- Finance and Economic Development;
- Education, Science and Technology;
- Natural Resources, Energy and Mining; and
- Local Government

At national level, the Malawi Government is represented by the ministries, whereas at local level the ministries are represented by the District Councils, each district having a District Coordinating Team in which each ministry is supposed to be represented. However, it was noted that not all sectors are represented for reasons such as shortage of human resources and the lack of policy structure for some ministries. For instance the water sector (and others) was decentralised and is represented at the district level whereas the energy sector is not represented (GoM, 1998; Commonwealth Local Government Forum, 2015). District councils are the link between the donors, NGOs and communities. The comment below demonstrates this observation:

“I would say the main stakeholder link is with the Districts Councils, so projects should not be implemented without that coordination with the district…normally what happens in terms of planning is… it is done with the conjunction of the district… in effect the district provides their plan of where the needs are… we work directly with the districts and where the projects are implemented by an NGO we expect the NGO to work with the district” (Int18, Donor)

NGOs could be at either international level, national level or local level. Communities, who are the main recipients, are represented by the Traditional Authorities (Chiefs), village headmen, area or village development committees, WPCs and the water users who are households, with the chiefs playing the most significant role in the process because they are the point of contact. Entrepreneurs include the RETs companies, and borehole contractors. At lower levels, they are represented by borehole spare parts shops and borehole area mechanics.
Table 6.1: Stakeholder roles and responsibilities

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Roles and Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government (National)</td>
<td>Formulate policy&lt;br&gt;Enforce policy&lt;br&gt;Financing</td>
</tr>
<tr>
<td>Local Government (District Council)</td>
<td>Planning for district&lt;br&gt;Identify needs&lt;br&gt;Coordination of NGO and Communities&lt;br&gt;Mobilisation&lt;br&gt;Monitoring (WPC, boreholes drilling, water quality)&lt;br&gt;Technical support e.g. major repairs</td>
</tr>
<tr>
<td>Donors</td>
<td>Proposal guidelines&lt;br&gt;Verify sites&lt;br&gt;Training&lt;br&gt;Financing&lt;br&gt;Procure equipment&lt;br&gt;Skills &amp; expertise&lt;br&gt;Monitoring</td>
</tr>
<tr>
<td>NGOs</td>
<td>Sensitisation &amp; mobilisation&lt;br&gt;Identify community, contractors &amp; suppliers&lt;br&gt;Train WPC&lt;br&gt;Monitoring &amp; handover</td>
</tr>
<tr>
<td>Community</td>
<td>State needs &amp; commitment&lt;br&gt;Siting of water points&lt;br&gt;Elect WPC&lt;br&gt;Offer materials &amp; non-skilled labour&lt;br&gt;Monthly contributions&lt;br&gt;Security of system&lt;br&gt;Operation &amp; maintenance</td>
</tr>
<tr>
<td>Private Sector (Entrepreneurs, Contractors)</td>
<td>Feasibility study&lt;br&gt;Design &amp; construction&lt;br&gt;Expertise&lt;br&gt;Skilled labour&lt;br&gt;Maintenance</td>
</tr>
<tr>
<td>Microfinance Organisations</td>
<td>Funding&lt;br&gt;Training</td>
</tr>
<tr>
<td>Media</td>
<td>Informing&lt;br&gt;Awareness&lt;br&gt;Accountability</td>
</tr>
<tr>
<td>Academia</td>
<td>Knowledge impartation&lt;br&gt;Research and development&lt;br&gt;Expertise</td>
</tr>
<tr>
<td>Politicians (MPs &amp; Councillors)</td>
<td>Lobbying &amp; advocacy&lt;br&gt;Legislature</td>
</tr>
</tbody>
</table>

From the interviewees' descriptions and from the literature (Bryson, 2004; Reed et al., 2009), the stakeholders' level of power and interest were deduced, as presented in a matrix in Table 6.2.
### Table 6.2: Power vs interest matrix for SWPS in Malawi, researcher’s ranking

Matrix adapted from: (Bryson, 2004; Reed et al., 2009)

<table>
<thead>
<tr>
<th>POWER \ INTEREST</th>
<th>Subjects - Keep Informed</th>
<th>Key players - Keep Satisfied</th>
<th>The Crowd - Monitor</th>
<th>Context setters - Manage Closely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td></td>
<td>National Government</td>
<td>Media</td>
<td>Micro-finance</td>
</tr>
<tr>
<td>Local NGOs</td>
<td></td>
<td>Donors</td>
<td>Academia/Researchers</td>
<td>Private sector (entrepreneurs/contractors)</td>
</tr>
<tr>
<td>Politician</td>
<td></td>
<td>International NGOs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Crowd</td>
<td></td>
<td>District Council</td>
<td></td>
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<tr>
<td>The Crowd</td>
<td></td>
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<td></td>
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</tbody>
</table>

The stakeholders in each of the four boxes are described as follows:

i. **High power/high interest stakeholders, referred to as ‘key players’:** These have both the power and interest and are the key players and are supposed to be fully involved. Effort should be made to keep them satisfied with the project progress and results. They are the ones who have the decision-making power, budgetary power, and/or resource power. In addition, they can cause the most disruption for a project if they are not informed or their expectations are not managed.

ii. **High power/low interest stakeholders also referred to as ‘the context setters’:** These stakeholders must have their expectations and needs understood and managed. They have the power to cause significant disruptions to the project; however, they do not have substantial interest.

iii. **Low power/high interest stakeholders referred to as ‘subjects’:** These stakeholders need to be kept informed and they are the ones who provide background information, user requirements, and non-functional requirements. They should be provided the opportunity to give some input, though their input may not always be applied. However, if they carefully managed they can be effective promoters of the project solution by building interest and help ensure adoption. They may gain power by forming alliances with other stakeholders.

iv. **Low power/low interest stakeholders referred to as ‘the crowd’:** They have little need to engage or consider them in much detail. These stakeholders have only to be monitored but they can sometimes have valuable information from a requirements perspective. Their lack of interest can make it difficult to appropriate stakeholder to engage with or identify their knowledge.
It should be noted that these classifications are dynamic and may vary depending on time and the stage of the project.

6.3 Emerging themes

The second method of analysis was thematic analysis in which the findings from the stakeholders are presented as themes and subthemes. The choice of themes and subthemes was guided by the literature, study objectives and some of the themes evolved during the analysis. Similar themes are discussed by other authors (Reddy and Painuly, 2004; Gutierrez, 2007; Chowns, 2015; Luthra et al., 2015; Gabriel, 2016). To facilitate discussion, the subthemes were grouped under three main themes as are illustrated in Figure 6.1. The subthemes could fall under more than one main theme or overlap; thus, they were placed under a main theme which was assumed would be convenient to facilitate discussion. Thereafter the findings are presented and analysed under the water, energy or a combination of the two sectors.

![Figure 6.1: Major themes from the qualitative study](image)

6.3.1 Institutional, policy and regulatory issues

Five subthemes were classified under institutional and regulatory issues as illustrated in Figure 6.2. These included policy formulation, lack of research and development, lack of information and awareness, lack of coordination and political interference.
6.3.1.1 Policy formulation

Interviewees felt that the main stakeholder regarding policy is the government and through the relevant ministries and departments, it is responsible for setting up, directing and revising policies and regulations and ensuring that they are enforced. The donors and NGOs mentioned that they follow the current government standards for water provision in the rural areas namely use of AFRIDEV pumps for deep wells (20 to 60 m), MALDA pumps for shallow wells (less than 20 m), and where the technology would be appropriate they install gravity fed systems or spring protection systems. On the contrary, AFRIDEV pumps were reported to be fitted on boreholes of as low as 7 m (Pritchard, Mkandawire and O'Neill, 2007). Each water point is recommended to supply 250 people within a radius of 500 m. One interviewee explained as follows:

“We use the government standards… AFRIDEV pumps for deep wells which are supposed to be 20 m to 60 m and MALDA pumps for shallow wells…the Ministry is responsible for standards and development of the designs for the pumps and for the boreholes themselves…” (Int17, Donor)

The AFRIDEV is one of the most used pumps in the world (Baumann and Furey, 2013) and both the AFRIDEV and MALDA pumps are less vulnerable to corrosion. They can last for over 20 years though they need frequent maintenance because of their fast wearing parts (rubbers,
bearings, chains, bushes, pivots, pins) that need replacement in 2-5 year periods and the medium wearing parts (pipes and rods) that need 5-10-year replacement periods (Baumann and Furey, 2013; Furey, 2014)

It was apparent that the stakeholders thought that the government should also direct what sources of energy to use:

“We are not compelled to make a choice on what source of power to use [for irrigation project], but will use any source of power that the government specifies, whether solar or other” (Int5, Government Project)

On lack of regulations (Chipofya, Kainja and Botha, 2009) mention that the lack of regulation facilities on Shire River exacerbates the problems associated with poor resource management in the country. In addition there was a general feeling that the government is using old policies and in some instances policies do not exist at all and where they do exist they are not enforced and there are no punitive measures for the offenders (Chipofya, Kainja and Botha, 2012).

It was reported that though the government promotes RETs in other applications such as lighting, there are no specific policies, toolkits, or deliberate structures regarding SWPS. In India, (Chandel, Nagaraju and Chandel, 2015) reports that the government provided guidelines to the manufactures of PV panels and approved technical specification for SWPS. The interviewees felt policies to strategize how solar water pumping is going to be implemented should be in place and for an all-inclusive policy; the government should work with all relevant stakeholders, as the comments below illustrate:

“The Malawi Government is the major stakeholder, they have a role to play…they are the policy holders they have to direct policy if they want the uptake of renewable energy to increase… the policy has to deliberately state that…and use the government structure to promote renewable energy” (Int11, WASH NGO).

“You have to have a policy and a strategy of how it’s going to be implemented…and government needs to work with stakeholders” (Int9, WASH NGO).

Similarly, whilst working with decision-makers and financiers around the world, Practical Action has identified two critical barriers to achieving meaningful and universal access to energy. The first one is not being up-to-date with technological innovations in renewable energy and the second one is lacking clear guidance as summarised below:

“The second, and more fundamental barrier, is that no clear and usable guidance exists for energy planners about how to meaningfully incorporate new technologies, the voices of the energy-poor, or a service-focussed understanding
Some of the interviewees indicated that if the government were to put in place standards for SWPS for drinking water they are willing to adhere to them. The interviewees were positive and welcoming about solar water pumping, but felt there is need for sensitization and research:

“It's not a bad idea, as we go… I think that's an improved level of service… I mean when you do [install] a solar supply system you don't expect the people to do this [gestures water pumping action] …you expect people opening the taps… and benefit women and girls who bear the burden of collecting water… we don't have to stay at the same level of service…” (Int17, Donor).

“For community approach the standard is that the boreholes have a handpump… those standards come from government but again there are gaps I think it's something that needs to be improved… I think there needs to be a cost benefit analysis when we are talking about an alternative system…” (Int18, Donor).

(Practical Action, 2016) suggests that donors and national governments should include either the participation of end-users, or the specific market, finance, and policy requirements of holistic energy access service-provision. Currently there is no comprehensive record of RE documentation, and the Department of Energy Affairs was in the process of developing a Renewable Energy Strategy for Malawi and also revising the energy policy of 2003:

“There are plans to develop a renewable energy strategy. It is therefore hoped that this will contain reliable information on renewable energy” (Int1, Government Department).

The government also reported through the interviewee (Int1, Government) that it is working with international donors and organisations in several projects. Among them is The Malawi Renewable Energy Acceleration Programme, which is evaluating wind mapping for Malawi and the funding formulation of SE4ALL Investment Prospectus and Action Agenda for Malawi.

6.3.1.2 Limited research and development

Interviewees felt that the academia and researchers in the country are not active in research and development (R&D) other than research for academic purposes. They felt the results of academic research are published in journals that are not accessible in Malawi and the findings are not widely disseminated and applied in Malawi. They felt researchers and academicians should be in the forefront of spearheading research that addresses the problems on the ground rather than abstract problems. (Luthra et al., 2015) also reports that lack of (R&D) is a barrier to the adoption of RETs. Several interviewees mentioned that they do interact with the
academia, but they felt the interaction should be improved. Interviewees raised the need for solutions to water provision for the hilly areas and saline water. Salinity is a problem in some parts of the country which resulted in boreholes being abandoned, waste of resources, or households resorting to collecting drinking water from unsafe sources (Monjerezi and Ngongondo, 2012; Grimason et al., 2013). In Karonga salinity was reported as one of the reasons for abandonment of boreholes (Namadzunda, 2015). The phenomenon was thought to be complex because there were areas in close proximity that were affected differently. The comment below illustrates the salinity issue:

“One of the biggest challenges is water quality in terms of the chemical composition…so you would spend four million Kwacha [US$7,700] to drill a well and then you find that the water is saline and not edible [drinkable] to people” (Int10. WASH NGO)

One of the interviewees mentioned that they are researching on ways to find out if it would be possible to seal out the water closer to the surface, which was thought to be saline whereas the water at great depths was thought to be non-saline. This concept is also alluded to by (Howard, Charles and Pond, 2010), who suggests that sinking deeper boreholes that are separated from shallower aquifers by ‘aquicludes’ offers a potential solution but cautions that it would change the cost-effectiveness of the borehole.

Interviewees also recommended research on more sustainable drinking water systems other than the AFRIDEV and MALDA handpumps which were reported to be prone to frequent breakdowns as also documented by Baumann and Furey (2013). In terms of water abstraction, the interviewees pointed out that though there is enough water from the lakes, rivers and underground, there is lack of adequate water harvesting technologies.

6.3.1.3 Lack of information and awareness

The interviewees reported that there are low levels of information acquisition and access and lack of sharing amongst stakeholders. They reported that the government lacks an information updating and management system, both for energy and water sectors. For example, information about number of boreholes and PV installations in the country. They thought that if such databases are available, then they are not shared with the relevant stakeholders. However, in selecting which area to construct new boreholes, the water providers did get information from the government through the District Councils, for example regarding communities that had low access to water (or sanitation). Similarly, in her research in Malawi, Chowns (2014) found that information in the districts of her research was lacking and she recommended that a live water point database be prepared. In addition, inadequate information was reported to cause lack of equity in water points (Gutierrez, 2007). In the draft
energy policy, scarcity of data is mentioned as one of the major drawbacks in the compilation of the energy mix projections (GoM, 2015).

Awareness and knowledge in the various sectors were also thought to be lacking to the citizens as explained by interviews in the following quotes:

“There is low citizen awareness on their rights to water sanitation and hygiene and because of that they are not effectively engaged in demanding for access to water” (Int8, WASH NGO).

“There is limited knowledge in operation and maintenance of the systems [irrigation] among the smallholder farmers” Int6, Government Department”.

“But the challenges are one [Firstly]; the farmers do not have the knowledge to do it on their own and secondly is that the whole business of farming is just left to a farmer who doesn’t put calculations to it” (Int22, Entrepreneur)

The interviewees reported that the private sector is now catching up on solar water pumping particularly for irrigation, though most of the others and the general citizens were not aware of what RETs can achieve. The interviewees recommended that the government in conjunction with other stakeholders must do more on awareness and sensitization on all the capabilities of RETs.

“There is lack of sensitisation…the government has to work on sensitisation, people should know what are the benefits what are the disadvantages and what do they stand to gain if they go solar” (Int15-Microfinance NGO)

“People have not been sensitised to this, it’s one of the issues we are innovating on” (Int8, WASH NGO)

In their report Scott et al. (2016), concur and report that awareness of solar products in Malawi is low and is coupled with negative reputation hence evidence on the benefits of solar would improve technology uptake. This is obviously the case in other developing countries; in their study about challenges in Sub-Saharan Africa, Mohammed et al. (2013) reveal that most energy investors have no proper knowledge of renewable energy development because of lack of adequate information regarding financial and technical prospects. Practical Action (2016) also agree and report that decision-makers are not up-to-date with technological innovations in renewable energy, hence the available opportunities are disregarded due to misperceptions of the quality and appropriateness of these technologies. Similarly, (Kunen et al., 2015) found that the key barriers to increased commercialization of SWPSs for irrigation are not technological but instead centre around the education of the farmers who lack information on cost, performance, installation, and maintenance of the systems.
Related to this is the negative attitude of the people, which is caused by lack of knowledge, information and awareness. Interviewees thought that the people’s mentality and mind-set is that the government, donors or NGOs should be obligated to provide free services and materials because they have been free from time immemorial. Along the same lines, they think water is supposed to be offered by the government free of charge as one interviewee expressed:

“People are not used to paying for services…people want to get free things and what have you…” Int15, Microfinance NGO

Expectation for free water has also been reported as a reason for low willingness to pay for water (Kayaga, Calvert and Sansom, 2003; Fonjong and Fokum, 2017). For a study in Malawi on solar lighting products, Scott et al. (2016) refers to it as “aid culture” in which they report that households expected to receive solar PV goods for free. This was further intensified by politicians who promise free goods during campaigns supposedly on behalf of the government.

Another attitude is dependency on rain-fed agriculture. The people have a mind-set to have one planting cycle per year during the rainy season. Related to that is what types of crops to grow and what type of activities to use for generating income as discussed in section 6.5.5. Mohammed et al. (2013) notes that awareness is interchangeable with education, and that most of the people in the Sub-Saharan region are illiterate. In their study they found illiteracy derailed development particularly, application of RETs. However, with proper consultations and engagement as discussed in the case study in section 6.4.1, it could be possible to change the mind-set of the people but could take long periods. As reported in section 4.2.3, over a fifth of the household heads in the household surveys were illiterate signifying the need for intensive engagement and awareness.

Interviewees also reported that striking groundwater was a very complex issue and became more complex with lack of appropriate data. They recommended the mapping of the current boreholes regarding their spatial position, working status such as broken, semi-dry or dry boreholes, and water availability such as the presence of the aquifers and rivers and quality of water. Such information could be presented in a Management Information System such as GIS application which upon the entering a geographical location of any area in Malawi, would be able to tell the status of water in a particular area. In addition, the reporting of non-functional boreholes could also be in a real-time application. The data would be useful for planning and implementing water projects and make savings on initiating a project where there is no water availability. In addition, it would ensure that non-functional boreholes are known and repaired. This suggestion is an important issue for consideration for further research and work.
6.3.1.4 Lack of Coordination

Coordination and harmonisation was an issue mentioned from several perspectives, firstly regarding lack of coordination amongst the stakeholders such as coordination of NGOs amongst themselves, coordination with the development partners and coordination with the government. Secondly, lack of coordination within relevant policies and lastly coordination between the government ministries. Interviewees also acknowledged that water is a multi-sectoral commodity hence the water ministry cannot do everything on its own and would benefit from the assistance of the private sector and industries. Poor coordination in Malawi is also reported as a major challenge in Goma (2012b) and Goma (2013). Several comments were made by respondents to reinforce the issue as follows:

“Let me just talk of something which is very key... the issue of coordination you know the issue of sector wide approach ... you know that water or WASH is a multi-sectoral commodity in terms that the Ministry of Agriculture on its own cannot do much, you know they need the Ministry of Health, Ministry of Local Government, the emphasis is that it’s better to improve the coordination nearer to where the services are being provided” (Int17, Donor).

“The other problem is coordination among the NGOs...some organisations will just go in the community and use other organisations materials...there is no policing and we cannot deal with each other...” (Int9, WASH NGO).

From the interviews, it was noted that the Department of Irrigation has embarked on several irrigation projects using solar PV, which however the Department of Energy was not aware of or if they were aware, they overlooked mentioning them during the interview. For Kenya, Practical Action (2016) reports that the Kenyan SE4All Action Agendas also recognised a lack of coordination between ministries and lack of comprehensive planning in their energy sector. Following that, they recommended the need for the Kenyan Ministry of Energy to cooperate with the Ministry of Water regarding water pumping which could bring benefits to the Ministry of Agriculture regarding food security and processing of subsistence crops.

The interviewees thought lack of coordination caused disparity in the distribution of boreholes and on the other hand duplication of projects. From his study Gutierrez (2007), was in agreement. Several comments were made regarding the impacts of lack of coordination, such as the ones below:

“We saw lots of disparities, where most of the water points were piled up in one area of the district at the expense of the communities...you find that this village with 1,000 people has got one or two facilities, the next village with 1,000 people has got four to eight facilities...or sometimes to make it worse still, this has got...
eight, the next one has got zero…suffice to say is that lack of coordination of investment is one key element that leads to that unequitable provision of services” (Int8, WASH NGO).

In addition, lack of coordination was thought to affect the non-functionality of boreholes as mentioned below:

“Connected with that [ownership] is the reporting side when infrastructure has a problem you find that it’s been non-functional for some time, but no one is aware…it’s never been reported …or the people who are in that community …they didn’t know who to report to…” (Int18, Donor).

It was reported that individual NGOs had invested much in the water provision system but there was no information on how much the NGOs have collectively put in the system, with each organisation keeping their own information to themselves. This was also witnessed in Zambia a neighbouring country for Malawi, where the government was unable to capture donor disbursements in government accounting systems, making it difficult to plan and monitor overall expenditure Gutierrez et al. (2004,) in Gutierrez (2007). In some cases this happens because governments that operate decentralised forms of administration, do not have well established mutual agreements between central and local governments to support actual plans, programs and actions (Mohammed, Mustafa and Bashir, 2013).

In addition, the interviewees felt there was no harmonisation/coordination of policies for instance between the irrigation sector and the environmental policy, which cause some problems such as siltation reported in the following instance:

“For example, we are promoting irrigation and sometimes irrigation is being done in river banks, if you use a treadle pump how far away can you extract water…it could be 5, 10 metres but the environment policy provides for a 20-m buffer zone from the river’s course, that area is not supposed to be cultivatable land to avoid impacts such as siltation” (Int8, WASH NGO).

Not only does siltation affect drinking water but it also affects the generation capacity of electricity which is done on one of the major rivers in the country (Phiri, 2009). On issues of water resources management Chipofya et al. (2009), also found that policies were inadequate in that they conflict each other instead of complementing one another. They recommended harmonisation of policies in the country and with those of the region. Though the NGOs acknowledged some interaction and assisting one another in specific projects, there is still lack of coordination amongst them. The Water and Environmental Sanitation Network (WESNET), was formed and started operating in 2012 to be an umbrella organisation. It was reported that it has not reached most parts of the country. However, there was hope that the
organisations would solve some of the coordination issues. This implies integrated planning across ministries may help solve the problem of coordination. (Practical Action, 2016) also recommended the need to restructure the sectors clearly and harmonise policies.

6.3.1.5 Political interference

Politics was thought to play a role in the provision of water as several stakeholders reported that politicians interfere with water provision amongst other services in the country. Two of the interviewees’ organisations from the current study had their establishment aligned to a political party and one of them reported the following:

“Our organisation dates back to 2004 and so when it first came it was just an organisation that came in to attend to some emergency on the water shortages when that other government was in power … that was when late Ethel Mutharika [former first lady] was there and she is the one who used it as a political campaign sort of thing… so they installed pumps from up North in Chitipa down to Nsanje in the South” (Int9, WASH NGO).

Kamwamba-Mtethwa (2016) reports that one way of acquiring a free treadle pump or a motorised pump was by one’s political affiliation. In some instances, politicians gave free renewable energy products to households apparently as a campaigning tool (Zalengera et al., 2014) or promised other free services such as water (Harvey, 2007). These authors acknowledged that though it is a good gesture, it does not promote sustainability and ownership. Similarly, in a study of rural water supplies in Malawi, Baumann and Danert (2008), report that water is used as a campaign tool. Politicians promise the electorate new boreholes and/or free water. They further note that sometimes it is used to invite people to a religious affiliation. This practice affects willingness to pay and negates taking responsibility for the water points because the communities had been promised that water would be free. It is further reported that sometimes construction is substandard because it is made hastily in order to fulfil political requests. In the energy sector, Zalengera et al. (2014), similarly observed that standards may be compromised when dealing with issues affecting people’s political alignment because there was high likelihood that systems where hastily certified to gain political milestones. Political interference is also present in the urban areas of Malawi where political interests were found to influence the management of water kiosks (Jimu, 2008).

Expounding on that, Gutierrez (2007) notes that in Malawi the water sector challenges are not only technical, but are also political because of the peculiar forms of power relations that have emerged within institutional and political environments. For Zambia, he observed that there was great variance between authorised provision and actual spending for water in the
country's budget, and one of the suggested reasons was the exercising of political discretion in actual funding releases, corruption or diverting to elsewhere or other budgets.

6.3.2 Economic issues

The economic subthemes are illustrated in Figure 6.3. These include high capital cost, high inflation and interest rates, lack of finances, and corruption.

Financial and economic limitations are identified as a major barrier to the deployment of renewable energy in developing countries (Reddy and Painuly, 2004; Amigun, Sigamoney and von Blottnitz, 2008; Luthra et al., 2015). These also appeared crucial for the development of SWPS in Malawi as well and the interviewees asserted that the financial hurdle is one of the most important challenges.

![Figure 6.3: Subthemes under Economical issues](image)

6.3.2.1 High capital cost

Interviewees reported that a major drawback of solar powered systems is the high initial capital cost, which they thought was exacerbated by the absence of RETs manufacturing companies in the country. All RETs products and accessories must be imported and this puts a strain on the availability of foreign exchange in the country. Projects may sometimes be delayed due to lack of foreign exchange. This leads to having low rate of return for the entrepreneurs and
hence fewer entrepreneurs venturing in the business. To the customers it means that high quality products have high cost and are therefore unaffordable to most people. Whilst the entrepreneurs applauded the government on the import tax waiver on solar modules, they felt the waiver should be extended to other RETs. The interviewees suggested that the government should explore ways of funding mechanism so that the households pay back over several years. One entrepreneur had this to say about the households’ possibility to pay back loans:

“The ability for the rural farmers to buy using their own cash is not there but the ability would be possible if there are financing institutions for them to repay. That one I can challenge you that it is possible. In our case, we have tried it with our 7.5 kW system we are irrigating 10 hectares. Within two years of four seasons of growing we have already recovered our money...so for the rural farmers since they would be paying for other costs we can put the payback at five years...” (Int22, Entrepreneur).

From literature, payback periods of 2.5 to 6 years were reported for SWPS (Section 2.6.3). In addition, the interviewees recommended that government should consider the manufacturing or assembly of basic RETs in the short term, to make them cheaper. To accelerate irrigation in Kenya and Nepal, portable SWPS have been introduced at lower costs for smallholder farmers (Kunen et al., 2015).

6.3.2.2 High inflation and interest rates

Related to high capital cost, the interviewees felt the financial environment was not conducive to investments because it is characterized by high inflation, hence high interest rates. Lending rates by financing organisations are high and there is generally low consumer spending. The economic environment is also characterised with exchange rate fluctuations and during the year of this study, 2015, the country experienced a sharp depreciation of the Malawi Kwacha. Currently the inflation rate is at 20% and the base lending interest rate is at a minimum of 33.6% and maximum of 42.88%. This suggests very high and unbearable rates for the citizens (Press Corporation Limited, 2015; Reserve Bank of Malawi, 2017). The general public and entrepreneurs are unable to get loans to fund their requirements for fear of the high interests. Similarly, Scott et al. (2016) reports that currency fluctuations together with high VAT rates pose a great risk to solar companies in Malawi. Mohammed et al. (2013) affirms that this is a common challenge in Sub-Saharan Africa and asserts that interest rates are high such that investors are not willing to embark on the high risk involved.
6.3.2.3 Lack of finances

Lack of finances is reported as one of the main challenges in the water sector in Malawi (GoM, 2013). The interviewees reported that the majority of the people in the rural areas have low income, which was also apparent in the households’ survey findings in Chapter 4. Most of the interviewees indicated that the communities they worked with were willing to pay for water, though their lack of finances might be a deterrent. In addition, they pointed out that if the water provision service were better, people would try their best to pay something even if it means to cover for only operation and maintenance costs.

“We agree with the community at the onset that the tariff should cover for operation and maintenance over the lifecycle of the pump but now we are working with the district that the tariff should also cover the cost of replacement of the handpump...The tariff varies from community to community depending on population and for the communities that we work with now it ranges from K250 to K400 [US$0.48 to 0.78] per household per month...In our experience willingness to pay depends on the awareness campaigns that we conduct before we install a borehole and we tell them the importance of contributing...we find that communities are always willing to pay they may struggle for some months but ...we advise them that during the harvest season they may pay off for the whole year...” (Int11, WASH NGO).

“What I know is, if the service is better than what people are used to; people will always try their best to pay... “(Int17, Donor).

Factors that affect willingness to pay are discussed in section 4.6; to these can be added political interference (section 5.2.2.6), lack of ownership (section 5.2.4.5), and accountability with money (section 4.3.6).

However, the interviewees thought the government could offer loans or subsidies, similar to what the government gives out in other sectors. For instance, programmes such as the farm input subsidy programme or building houses for people in the rural areas. In their study Scott et al. (2016) recommends the engagement of microfinance institutions for the distribution of solar lights to increase awareness and build trust for mobile money benefits and to promote a faster uptake among the population. On the other hand, the financing organisations in the current study mentioned that sometimes it becomes difficult to give loans because the country has no identification documents for the citizens (only a few of those in the rural areas can afford/would need a passport and drivers licence) hence it becomes difficult to trace people that have defaulted. They however find it easier to work with groups, and they do give loans
to groups for other purposes. The VSLs groups that are present in the villages would be ideal for disbursement of the loans.

Lack of finances was also experienced by the government, such that the interviewees reported that the government allocates little funding to the ministries. Hence, the ministries are not able to carry out their budgeted plans. In agreement, Gutierrez (2007) notes that the corresponding funds allocated do not match the projects identified for funding. Although WASH is a very critical sector, it is only allocated very little as reported by the interviewees:

“One other thing which is important is the issue of finances …you know when you look at the funding for the WASH sector has always been very low on average about 2 to 3% per year we are talking of the national budget…” (Int17, Donor).

“Like this year in our budget analysis, I think also conducted by WESTNET shows that you know, what has gone to domestic water supply, sanitation and hygiene is about 0.08% of the national budget, quite meagre…that’s one of the key challenges…on paper this sector is prioritised, but it is not evidenced by the financing…over the past years the range has been around 2% [of the national budget]. District Officers get as low as MWK150 000 to K200, 000 [US$288 to US$384] at most per month for them to provide all the support they need in the development of water, sanitation and hygiene and that is very low” (Int8, WASH NGO)

As is discussed in the next sections lack of funding causes lack of monitoring which in turn causes substandard installations. The interviewees urged the government to provide adequate funding though on its part the government has no money. For instance, responding to a question in parliament, the minister responsible said money was not allocated to drill boreholes in the 2015/16 budget (Likomwa, 2016). Apparently, ways of generating income have to be sought for the households such as irrigated agriculture.

### 6.3.2.4 Corruption

The interviewees reported corruption as one of the major deterrents to carrying out effective water projects in the country. In a study for Ethiopia Calow et al. (2012) cites that internationally, the water sector is viewed as ‘high-risk’ for corruption because of the financial flows involved, weak government oversight, and significant public-private interactions. According to Calow et al. (2012), corruption includes: not building to specification, concealing substandard work or materials, failure to complete works, underpayment of workers, and fraudulent invoicing among others. In Malawi corruption is rampant at all levels and efforts to combat corruption and promote transparency have been carried out such as the President
speaking against corruption and erection of billboards such as the one in Figure 6.4 to remind the citizens to stop corruption. One of the biggest corruption cases and mismanagement of funds was uncovered in 2013 and was popularly referred to as “cashgate” (Majanga, 2015). In October 2013 international donor organisations froze direct budgetary support in response to this high level corruption scandal citing a lack of trust in the government’s financial management system and civil service (Central Intelligence Agency, 2017). The US Department of State (2011) substantiates that official corruption is one of the serious problems that Malawi faces.

![Figure 6.4: A billboard reminding Malawians to stop corruption](image)

Source: (African Democratic Institute, no date)

An interviewee pointed out that some contractors carry out substandard work in Malawi.

“If drilling contractors are not monitored, they many a time drill a shallower borehole than required and report that they have drilled the required depth. Problems would show up when the borehole which was thought to be deep gives low yield or dries out altogether” (Int17, Donor)

Common corruption issues in water projects as reported in the Malawi media include: misappropriation of funds and using inferior workmanship and/or material (Nyasa Times, 2012; Mtika, 2016). Other corruption incidences in the Malawi water sector are reported by Anscombe (2011) and include request for “favours” from contractors by some government staff, bribery during the tendering and award processes, and use of sub-standard materials.

One way of combating corruption is by close supervision and monitoring, which is lacking in the country. Anscombe (2011) reports that government supervisors were sometimes absent citing reasons of lack of finances for transport and accommodation. This finding suggests
there is need for Malawi government to tighten fiscal policy in order to gain the confidence of donors who contribute a larger proportion of the country’s budget.

6.3.3 Technical issues

Sub-themes in this group include lack of skilled human resources and entrepreneurs, lack of monitoring, failed management model, limited infrastructure and environmental degradation as shown in Figure 6.5.

![Diagram: Subthemes under technical issues]

6.3.3.1 Lack of skilled human resources

The interviewees reported that there was shortage of human resources both in the water and energy sectors. For example, the water ministry was reported to have 35 to 40% vacancies at both ministry and district level and a high staff turnover rate. In the energy sector, it was reported that there is lack of qualified experts at higher levels and technicians at lower levels. Without qualified experts in the country, the development of technologies is slowed down; hence, this calls for the need to train more experts both in the water and energy sectors. Chipofya (2012) noted that it derailed the development and management of water resources in Malawi. According to Zalengera et al. (2014), lack of human resources in the energy sector in Malawi is one of the main causes of non-functionality of systems and also high financial expenditure because for some energy projects human resources have to be imported or sometimes components have to be sent outside the country for maintenance.
In terms of entrepreneurship, a variety of issues that range from lack of capacity in manufacturing, distributing, installing and maintaining RETs were raised. Firstly, there are few distributing, installing and maintaining entrepreneurs. Even for the few that exist, their competence and skills are limited. In addition, they are based in the major cities of Blantyre and Lilongwe, which makes the systems more expensive because of the added travel costs as pointed out by one of the interviewees:

“We travel from here [Southern Region] to the North to install or maintain some water pumping systems because there are no other entrepreneurs in the North or Centre to match our capability and quality standards. More time is spent travelling and the distance adds to the cost of the system” (Int21, Entrepreneur).

Other interviewees thought the entrepreneurs lacked skills to develop business plans that would enable them to operate an RET business. Scott et al. (2016) notes that the level of local skills in Malawi is low and companies have to train their own staff. This demonstrates the need for training institutions in RETs. The interviewees recommended establishment of vocational schools specifically for solar products and others the establishment of renewable energy service centres. These would help locals sustain their use of RETs installed in the rural areas, which would be closer to where the services are provided. Other interviewees were of the view that the government should provide business training specifically for RETs companies.

6.3.3.2 Lack of monitoring

The interviewees reported that lack of monitoring caused the existence of substandard products. Though the Malawi Energy Regulatory Authority and Malawi Bureau of Standards have both issued standards to be followed for acceptable solar products and installations, some counterfeit products still find their way in the country. For instance, counterfeit RET products on the market were reported to damage consumer confidence and puts sustainable market development at risk, as one interviewee reported:

“There is lack of proper monitoring… you find that the products that are found on the market are not durable, that they don’t meet the standards” Int15, Microfinance NGO.

According to a report by Scott et al. (2016), Sunnymoney, a distributor estimated that 25% of products that are not sold through their channels are of low-quality and/or counterfeit products. Business Innovation Facility (2014a) carried out research in Malawi on pico-solar products and found that the quality of products appeared poor with a high proportion of customers returning or being dissatisfied with products. As reported by the interviewees, some
companies resort to buying counterfeit products, which are usually of low quality and short-lived to avoid high costs. The low-quality products easily fail and do not meet customers’ expectations, which results in mistrust about RETs amongst the users. Interviewees recommended that the responsible organisations, namely, the Malawi Energy Regulatory Authority, Malawi Bureau of Standards and Malawi Revenue Authority had to be more vigilant in enforcing regulations and standards on RETs. In a press statement Community Energy Malawi (Mbizi and Bayani, 2016), also voice out and note the unsatisfactory enforcement of standards by these organisations.

In terms of water (Anscombe, 2011) mentions that some contractors use substandard materials which cause non-functionality of boreholes in Malawi. There is no enforcement of standards (Gutierrez, 2007; Chipofya, Kainja and Botha, 2012; Chowns, 2014). Chowns (2014) found that installation quality was a major influence on functionality of a borehole and she argues that quality of boreholes was compromised because there was no monitoring. This was exacerbated by the absence of penalties for substandard installations. For lack of monitoring, drillers and contractors installed in areas that were more accessible or where ground water was accessible instead of installing where they had been requested. Most times verification is not made on whether the borehole has been drilled or not and this causes lack of equity (Gutierrez, 2007) which was discussed in section 4.4.3

6.3.3.3 Failed community management model

It was reported that management and sustainability of water points was a challenge, which should be taken into consideration when designing SWPSs. After commissioning the borehole, it is handed over to the community after which the NGO or implementing partner leaves the community:

“Because we are an NGO we do not stay in the community forever” Int9, WASH NGO.

However, most of the times things do not go smoothly as planned. At one of the projects that was visited, Tikwere Primary School (Int13, Headmaster), it was reported that solar modules were stolen, and the school and community were unable to replace them. The implementing NGO could also not assist them because that project was concluded. Fortunately, for them because of the floods that happened in the area, a different NGO had an opportunity to come into the community for disaster emergency assistance. They replaced the solar modules but were unable to replace tanks, which were damaged during the period when there was no water. If it were not for the floods, the system would still be non-functional. To prevent a repeat of theft, some security was factored in by placing the solar modules close to a teacher’s house.
A high number of boreholes are not functioning at any time and interviewees estimated them to be in the range of 25% to 45%. Gravity fed systems also experience non-functionality issues such as broken taps and pipes and interviewees reported that the more the number of taps served by gravity fed system, the more the need for having a managed technical services team. Non-functionality may be caused by normal wear and tear; or because of theft and vandalism and may remain non-functional because the communities are unable to pay for the O&M costs. In the Algerian Sahara Regions SPWS uptake was reported to be low because of fear of being robbed (Bouzidi, 2011). Pedaflo solar pumps first installed in the country in 1998 were discontinued also because of theft and vandalism (Int2, Government). Theft and vandalism was also discussed in section 4.4.6.

The NGOS reported that it is ensured that spare parts shop and pump mechanics are within the vicinity so that they are able to maintain the boreholes with less downtime. In her study for Malawi Chowns (2014), found that access to spares was not a problem, rather it was the finances required to buy the spares that was lacking. In addition, area mechanics were reported to be available but insufficient. Chowns further discusses that contributed money is kept in the house and when time comes to use the money, it is found that the money has been used and is not available. For SSA (Harvey, 2007), reports about lack of transparency and accountability relating to the finances by WPC members as a reason of people not willing to contribute towards O & M. There is no consensus to what extent communities are expected to repair the boreholes, such that when a borehole breaks it is not known exactly whose responsibility it is. Sometimes the WPC members move away with no proper handover as reported by an interviewee:

“The other challenge is on sustainability because when we have trained the water point committee and they are not ready to train other people and when they leave there is a gap and when the pump breaks there is nobody to take it up so that’s the challenge, that means you have to go again to train” Int9, WASH NGO.

The problem of departure of WPC members was also cited by (Harvey, 2007). Some interviewees noted that the current model of rural water management had some flaws and there should be a better ownership model whilst others thought there should be special funds to aid O&M as the comments below illustrate:

“For me the major challenge is over real ownership and responsibility which is connected with ownership for the upkeep of infrastructure or operation and maintenance side… this is a huge challenge in Malawi and I think one of the biggest issues is that the current kind of model for rural communities is community owned so it means in some level there is a disconnect between the government
or even the districts in terms of their responsibility …to me the lesser challenge is putting in the infrastructure, and the bigger challenge is managing it” (Int18, Donor)

“There should be a fund at the District right from the beginning and it should be used for O&M…” (Int17, Donor)

Chisenga (2014) also concurs and recommends that the NGOs should set aside some money for O&M even at the expense of constructing fewer boreholes. She argues that it is better to have fewer boreholes that will work for a long time than have more boreholes that will end up failing. Failure of the community based management systems has been documented in (Foster, 2013; Moriarty, Smits and Butterworth, 2013; Chowns, 2014). These authors recommended change of the system in such areas as alternative service delivery models, professionalization of community management, change in policy, regulation, and adoption of life cycle costing, among other recommendations. Another alternative would be to link the community with a micro-finance organisation to assist the community in managing the collected contributions.

6.3.3.4 Limited Infrastructure

Interviewees felt the country has limited infrastructure such as roads, power supply, water supply and telecommunications services, which hinders potential investors to come to Malawi and therefore constrains development. Similar challenges were also cited by (GSMA & TNM (2012) who indicated that electricity and transport infrastructure are the biggest challenges to the economic development of Malawi. In the urban areas where services are available, they are characterised by low quality and intermittency. Entrepreneurs find it unprofitable to invest in the country and particularly in the rural areas as some interviewees observed:

“As a sector I would say the number one challenge is limited infrastructure. By this I mean issues of connectivity-network, power outages, poor roads, lack of essential services in the rural areas …” (Int16, Microfinance NGO).

“Our problem is not that people are failing to pay back but for us to monitor the loans because of distance to the rural areas…it is our major stumbling block” (Int15, Microfinance NGO)

It is difficult to reach the rural areas and perform duties because of the long distance and bad roads or no roads at all. Besides, organisations such as banks would not set up offices in such areas because of irregular clientele. Also drillers are reported to drill in villages that are easily accessible to them (Gutierrez, 2007), hence villages with no road infrastructure may have less water points.
6.3.3.5 Environmental degradation

Environmental degradation was reported to be widespread and the mentioned causes are human activities such as planting along the rivers, deforestation caused by dependency on biomass for energy and construction, land clearing for agriculture, and use of artificial fertilisers which all cause damage to the water sources such as siltation and pollution. Increased turbidity was also experienced in gravity fed systems because of deforestation and encroachment in the water catchment areas. Whereas in the past the water needed little or no treatment, nowadays the water may need to be filtered and treated and move the intake positions to higher ground. One interviewee reported as follows:

“But also, environmental degradation...lots of tree cutting in water catchment areas that are contributing to the drying of rivers ... that contributes to the decline and pollution of water resources... We are witnessing a decline in terms of groundwater levels in that we have seen a number of shallow wells that are drying up” (Int8, WASH NGO).

‘Dry boreholes’ is one of the problems encountered at drilling stage, and was attributed to low water tables probably due to climate change impact among other reasons:

“There have been a lot of complaints that there are dry holes. It might be that our water tables are lowering...” (Int17, Donor).

In some instances, boreholes dried up in the dry season:

“We dig the wells in the rainy season, but come the dry season they dry up...” (Int9, WASH NGO).

MacDonald and Calow (2009) stated that wells and boreholes are less likely to be seasonally dry if they are carefully located in good aquifers with enough porosity and permeability for storage and movement of groundwater. They further recommend that the design and siting of water points be informed by an understanding of hydrogeological conditions and user demand in order to increase the resilience of rural communities to climate variability. Studies by Bonsor et al. (2010) indicate that improved rural water sources that access groundwater over 20 m below ground surface are likely to be more sustainable in the face of climate change. Among other things interviewees felt that afforestation should be encouraged and some of them were working on environmental protection sensitisation issues including afforestation.
6.4 Drinking water case study: Water Mission

Two drinking water projects were visited namely, Tikwere Primary school and an NGO called Water Mission. Water Mission will be the focus of discussion in this case study. The interaction with this stakeholder included an in-depth interview and a field visit to one of their projects.

6.4.1 Introduction to Water Mission

According to the Malawi country director, Water Mission (formerly called Water Missions International) was founded in South Carolina, USA and has offices in ten countries but reaches out to more than 50 countries. In Malawi, they are based in the capital city, Lilongwe and they were registered in the year 2010 as an international organisation, with a goal to be the best in class Christian engineering ministry that transforms lives through sustainable safe water solutions. Though they identify as a Christian organisation the director said they do not discriminate any people that do not subscribe to their beliefs. Their core mission is safe water supply though they also work in promoting sanitation and hygienic practices. They respond to both emergencies and normal developmental contexts that need potable water solutions. Water Mission is one of the very few NGOs in the country who implement SWPS for the rural areas. They may use diesel generators in emergencies such as in disaster areas, depending on circumstances.

6.4.2 Why solar PV?

The organisation chose solar powered water pumping due to the advantages it has over handpumps, diesel and grid power. Firstly, solar pumping has higher flow and head capacity than handpumps. Secondly, the systems can serve more people per borehole than handpumps and can serve from multiple points, by so doing reducing long queuing times and distance to the water point. At Tikwere Primary School, one of the visited projects, a single borehole was providing drinking water to a school and distributed to three other standpoints at a 500-m radius which catered for five villages with an estimated population of 3,000 people. At the recommended number of 250 people per borehole, three thousand people would need 12 boreholes, which apparently could be more expensive.

Other NGOs are also planning for solar PV systems, as pointed out by one of the interviewees:

“There are some high yielding aquifers that we have discovered where we see the opportunity to use solar energy… instead of us drilling 5 wells which would cost 20 million Kwacha [USD9, 600] we find it would be cheaper to drill only one well” (Int11, WASH NGO).
According to the Director, the number of water-points from a single borehole depends on the size of the community. Currently their largest number of water points from a single borehole is 12 and their largest distribution system is up to 5-km radius. Thirdly, solar makes it possible for surface water to be treated, stored in a tank, distributed, and be used when needed.

Fourthly, solar can be used in remote areas where electrical grid power is not available and is able to provide excellent service which in terms of the water pumping application is at par or even much better than grid electricity. This is of great applicability for Malawi because most of the rural areas that lack potable water are not connected to the grid. Water Mission is therefore able to reach out to typical villages in the remotest parts of the country with safe drinking water. Lastly, solar systems (particularly the ones that do not include batteries, charge controllers, or inverters) have minimal operation and maintenance costs as compared to the grid, diesel generators or even handpumps. Furthermore, diesel generators would be unsustainable because the people in the rural areas would find it difficult to meet the diesel costs, whereas there are no fuel costs with solar PV. Lastly, unlike diesel generators, solar systems are sustainable, use renewable energy and are environmentally friendly.

On the disadvantages of solar PV, the director said high investment cost remains a major challenge and hence affordability by individuals on local basis is problematic. In their case, the cost is met by their donors and well-wishers. The other challenge is limited power generation, in that it can only be generated during the day and it is sensitive to dust, shading, and clouds, which can significantly reduce the generation. Such problems have been addressed with proper design, cleaning the modules and storage of water in tanks. High vulnerability to theft and vandalism is another challenging issue faced by solar water projects, particularly in developing countries (Espericueta, Pronaf and Juárez, 2004; Meah, Ula and Barrett, 2008; Bouzidi, 2011; Cloutier and Rowley, 2011). As a security measure, Water Mission constructs the system close to dwellings and welds the bolts of the modules to the structures, which have been successful on their projects.

### 6.4.3 Stakeholder roles and responsibilities

The organisation works hand in hand with the government, which is their main stakeholder. Firstly, the government provides the policy framework to guide water provision in the country. At lower levels, the organisation works in the capacity of the District Councils whose role is to advise where there is need for water. The District Councils also assist in mobilising the communities, monitoring of the impact and functionality of projects and offer technical support. Water Mission have interacted with the government in the water sector at various levels but there has been no interaction with Government in the energy sector.
The second stakeholders are the communities themselves, which comprise of the Traditional Authorities, group village headmen, village headmen, village development committee, WPC, and the beneficiaries (users). Since it is a church based organisation, they also interact with the various churches in the area. Donors are the other stakeholder and are backbone of their activities since they provide finances. These consist of Rotary International, Trusts, churches, and individuals who assist them through their headquarters in the United States of America. In Malawi, they have a Partnership and Cooperation Agreement with UNICEF in which they are supplying safe water to schools and communities and have affected over 150,000 people. In addition to funding provision, some of the donors participate in the implementation of the projects during the whole process and may be involved in providing proposal guidelines, verifying sites, training, and monitoring. Finally, Water Mission as an NGO also interacts with other NGOs whether at international level, national level and local levels.

In terms of supply of equipment, Water Mission has a partnership with ‘Solar World’ and ‘Grundfos’, who are international companies who supply them with solar modules and pumps respectively, at a subsidised cost and provide an extensive support agreement. Other materials such as tanks, steel structures and cables are sourced locally though some may be imported.

6.4.4 Water Mission’s project life cycle of drinking water system

The water system has five stages as illustrated in Figure 6.6 and as explained in the following sections.

6.4.4.1 Initiation Stage

Water Mission liaises with District Councils in order to identify areas that have water needs or sometimes uses information from country reports. In other cases, some NGOs, communities, politicians or individuals approach them, but such requests still have to be vetted by the District Councils. The community makes a formal application and Water Mission then conducts an assessment to verify the need. After a community is selected, Water Mission through its mobilisation team engages with the community regarding participation, engagement and ownership and explains the values of the investment. They then sign a memorandum of understanding (MOU) in which the community agrees to own and sustain the system through regular monetary contribution and are required to put in place a committee to manage the water and to open a bank account. The arrangement is such that the villagers contribute sand, quarry stone and unskilled labour during construction.
According to Water mission, the first obstacle encountered is the conception that water is supposed to be free (see section 6.3.1.3). Hence, in initial engagements with the community, one of the first issues to address is that the community will own the system and make a commitment to sustain the system by continued maintenance using the community-based management model. Giving them ownership encourages the community to take care of the system. On the contrary, other authors and interviewees reported that the model has some flaws as discussed in section 2.5.6 and 6.3.3.3, respectively.

The second obstacle is the speed at which the communities make and act upon decisions. Most were found to be generally slow, which resulted in delaying the project. Gutierrez (2007) notes that communities with educated members are quick to understand issues and therefore can easily access resources. This issue is linked to awareness in section 6.3.1.3 and low education status of the households as discussed in section 4.2.3. The third challenge is that the community populations grow rapidly, and they quickly outgrow the capacity of the system, which was partly solved by good design. In section 4.4.3, growing population was one of the reasons given for insufficiency of water.

6.4.4.2 Design stage

Water Mission have their in-house engineers, technicians and artisans who carry out all the design and construction activities. An MOU is made between Water Mission and the
community after which Water Mission identifies a source of water, which can be surface water or underground water. If water is not available, they move to another community. They have found that most parts in Malawi have relatively adequate solar irradiation as also discussed in Chapter 5.2.4. For their current boreholes, they have managed to strike water at depths of 20 to 60 m. They also have labs where they can carry out microbiological tests and for extra investigations; they are supplemented by the government’s central laboratory. Drilling is the only job they have to contract-out to other organisations. The design is prepared according to the yield of the borehole, and the water needs of the community, which depends on the size of the community and how they are dispersed. Water Mission designs the system with a target to provide at least 15 litres of water per person per day for domestic use and they assume water for other purposes such as washing can be obtained from alternative sources such as shallow wells or rivers (WHO, 2011). When the design is completed Water Mission draws up a budget after which they produce a project concept. The concept can also be used to appeal for funding from donors in cases where they do not have their own funds readily available.

6.4.4.3 Construction stage

The community is asked to provide unskilled labour and local material such as bricks, sand, and quarry (gravel). A complete basic water pumping system with one stand post and which comprises of solar modules, tanks, solar motor-pump set and the ‘The Living Water Treatment System (LWTS)’ system (as discussed in Appendix 6.2) costs approximately US$25,000. A distributed system costs up to US$90,000. Water is pumped into storage tanks at an elevation of up to 6 metres; steel towers are preferred over concrete because they are more durable. The major drawback in construction is scarcity of some major materials on the market. For example, specified tanks and steel structures are subject to an ordering process from abroad which may take up to six months. The other challenge is lack of foreign exchange, which may not be readily available when components are needed (also discussed in section 6.3.2.1). The director recommended that the government should develop a policy advocating for SWPS but at the same time, work to attract investment such as the production and importation of solar products so they are readily available on the market, which is not the case at present. Furthermore, although there is tax exemption on solar modules it is not applicable to associated components such as water pumps, and cables. Therefore, they hope the government should consider tax exemption on such accessories.
6.4.4.4 Commissioning stage

The system is handed over to the community, and is managed by the community’s WPC. Water Mission continues to monitor the system for 12 months to identify the efficiency, impact and any existing gaps in the training, after which it is fully handed to the community.

6.4.5 Operation stage

As stipulated in the MOU, the community are to sustain the system by continued investment and contribution, towards O&M costs of the system. Water Mission has three payment models for the communities. In the first model, the households pay a fixed monthly contribution. The amount paid depends on the community population, the area and cost of system but typically varied from US$0.48 to US$0.78 per month. In the second model, households pay per litre, which is customised to a 20-litre bucket and cost, is on average around US$0.02 per bucket. The third model is the recent LIFELINK system where they pay per litre and instead of using cash to collect water; they use real-time Global System for Mobile Communications (GSM) monitoring system (see Appendix 6.2). In this system, it was found that men also collected water. Similarly in Ghana, men were reported to have begun to participate in the traditionally female role of collecting water because of improved water supplies (Blagbrough, 2001). On the contrary, in Mozambique water provision did not change the gender roles (Van-Houweling, 2016).

The WPC employs system operators who are trained to provide technical support such as cleaning the solar panels and mending of pipe and tap faults. Two tap operators are also employed to dispense water and collect money and are paid on commission basis. The collected money is kept at the bank and used for operation and maintenance of the system, however, Water Mission pointed out that the model is still under trial.

6.5 Water for irrigation case study: Tiyanjane Irrigation Scheme

Two irrigation projects were visited. The first one was commercial and the other one communal. Tiyanjane Irrigation Scheme will be discussed as a case study for insights into a communal irrigation project.

6.5.1 Background to Tiyanjane Irrigation Scheme

The Tiyanjane Irrigation Scheme is in the Southern Region of the country in Nsanje District, a few kilometres from Bangula Trading Centre. It is being funded by Grundfos, which is locally represented by BlueZone Ltd a company based in the Southern Region City of Blantyre. The funding is through DanChurch Aid (DCA) and implemented by a church-based organisation.
called Churches Action in Relief and Development (CARD), whose main office is also based in Blantyre but also with offices in Bangula. According to the Country Director for CARD, the organisation’s development activities aim at improving the food security and income levels for smallholder farmers in the rural areas. Nsanje is one of the districts prone to the effects of climate change and is characterised by annual floods and drought that result in hunger. Hence, CARD came in to assist towards the needs in line with the organisation’s goals. The overall objective of the project is to increase crop production and household income through diversified agriculture, access and linkages to markets and viable VSL groups. Solar PV was preferred to provide water because Nsanje was thought to be one of the districts with highest insolation and because solar PV technology was more mature in the country as compared to wind.

6.5.2 System description

Whilst the funders provided the technical expertise, solar modules, pumps, piping, and taps, the local community was responsible for the unskilled labour, bricks, sand and quarry. Spread on 7.8 hectares of land, the scheme is of the pressurised irrigation system type and is powered by two identical solar pumping systems, producing up to 250 m$^3$ of water per day. Each system has a 35-m deep, borehole, submersible pump, 50 solar modules and the controllers all housed in a small building as shown in Figure 6.7.

The scheme has two phases. The first one was built in 2012, consists of 20 solar modules, used for direct water pumping during the day. The second phase was added in 2014 after complaints that the water supply was not enough. It consists of 30 solar modules, which are used for storing the energy in batteries, used for pumping water during the night and watering of crops under non-rechargeable battery torch light. Watering is done at night because the watering stations are few and the farmers have to take turns watering their plots. The systems transmit water to 30 taps, which are spaced approximately 50 m by 50 m apart. Each tap is connected to a hosepipe, which is used for watering, and the hosepipe is shared amongst several individuals nearest to that tap. Figure 6.8 shows a woman using one of the hosepipes. The farmers grow crops such as onions, eggplants, cabbages, tomato, peppers, maize, and spinach.
6.5.3 Management of system

A 10-member committee consisting of five males and five females was trained to manage the activities of the project, which include security, finances and membership. At the time of the study, the scheme had 105 members (65 females and 40 males). Each member has a plot size of 20 by 35 metres. They are allocated a time slot to water their crops. An individual pays an initial membership fee of US$7.70 and thereafter US$1.90 per annum plus US$0.38 per
month. The money is used for paying security guards and for repairs. So far, the problems they have encountered are broken taps and leaking underground pipes. They also use the money for purchasing seedlings for sharing amongst the members. The members were taught how to clean the solar modules and from time to time, they carry out the cleaning. For the three years, the system has been in place they have not experienced any theft or vandalism, because they employed three guards for the night and the farmers take turns to keep the guards company.

Unlike the case with most other farmers in the country, fertiliser and pesticides are not a burden because they apply the “conservation agriculture approach” (Knowler and Bradshaw, 2007; Hobbs, Sayre and Gupta, 2008; Giller et al., 2009) and permaculture (Mollison et al., 1991). These methods advocate sustainable food growing methods in which plants are grouped in a mutually beneficial arrangement. For example, some are nitrogen fixing, some attract beneficial insects, and others repel harmful insects and hence benefit from or protect one another.

6.5.4 Benefits of system

The committee chairperson and vice chairperson who were interviewees mentioned several benefits of the project. Firstly, people are becoming interested in irrigation because watering of crops has become easier as compared to the traditional methods of using watering cans and treadle pumps both of which are labour intensive. Secondly, they can now have three to four harvests per year, which has led to food security and income-generation unlike depending on rain-fed agriculture. Their quality of life has improved because they now have steady incomes of an average of US$16 per day which is an increase from the previous income of US$1 per day. They have managed to build good houses roofed with iron sheets. In addition, they have bought livestock such as cattle, goats, and chickens and some other necessities such as bicycles, which they were not able to buy in the past. The income has also contributed to education improvement because the members are now able to pay school fees for their children.

These findings are similar to those reported by Burney and Naylor (2012) in which the farmers paid school fees or bought new pumps and livestock with the revenues from irrigated agriculture. In addition, the interviewees at Tiyanjane reported that marriages are now more stable because women no longer go out of the home to seek for money from other men. Availability of drinking water was also reported to affect family relationships. In Ethiopia, women were reported to having disputes with their husband because of water collection issues (Stevenson et al., 2012). In Mozambique, men were grateful for the water provision because women’s absence from the home often provoked accusations of infidelity and led to conflicts.
With water provision they needn’t worry that their wives would meet other men when they collected water at night (Van-Houweling, 2016).

Other benefits reported at Tiyanjane include protection to the environment because previously the community’s income generation activities included selling firewood, burning charcoal and mining quarry stones and some even resorted to theft, which they no longer do. Apparently providing the households with a sustainable method of generating an income may decrease the theft and vandalism of the borehole parts. Lastly, though the water was not meant for domestic use, it was reported by the chairperson that the people also use it for domestic purposes, it was thought to be safer than their previous sources from the river, and shallow wells, as cases of diarrhoea had reduced.

In Zimbabwe, a project evaluation by Oxfam for an irrigation scheme showed that household incomes increased by 286% for the very poor, 173% for the poor and 47% for the middle-income groups. Farmers no longer had to seek large-scale farm employment in exchange for food, but were now producing their own food and creating their own jobs (IRENA, 2016a). In Benin, solar water pumping for irrigation made a significant increase in food security in the villages and the communities had access to year-round food which improved their nutrition (previously children were reported to suffer from Kwashiorkor). The income of the women farmers also increased by an extra US$7.50 per week from the sale of extra produce which they used for helping to pay for school fees, medical treatment, and new small business development (SELF, 2015).

The Director of CARD concurs, and sees the Tiyanjane project to be a success because in the three years the project has been running their aims have been fulfilled, because there is food security and the households have an income. He further mentioned that there was a reduction in diarrhoeal cases in the area because the people were also using the water for drinking, though the water was not initially meant for drinking.

### 6.5.5 Challenges faced

One of the major issues for the development of a communal irrigation system was acquiring centralised land. Generally, each household owns their own piece(s) of land, which might have been handed to them by their ancestors according to the customary law of the country. According to the Director of CARD, accessing land was a lengthy process and took numerous discussions with the chiefs and communities to grant the land. Availability of land is mentioned as one of the barriers to the development of RETs (Mirza et al., 2009). However, land was not a challenge with the handpumps or drinking water SWPS by Water Mission, apparently because they do not take up large pieces of land.
The second challenge was changing the mind-set of the people, firstly regarding the change of income generating activities from the ones that they were used to and instilling into them that agriculture can be used for income generation as well as for food. Secondly, the households had been used to growing subsistence crops once a year and now the change to growing commercial crops was something new and challenging to them.

The other major problem, which has now been addressed, was that in the initial system, the quantity of water was not enough. To solve the problem; they extended the system to include a second set of modules, which charges solar batteries during the day and uses the stored energy to pump water at night. This shows that proper sizing and understanding of the water requirement is critical in the initiation stages of a project.

The fourth problem is unavailability of other ready markets to sell their produce. They currently sell as a group and have three institutions within the vicinity to which they supply their produce and the rest is supplied to the locals. However, they felt the markets were not sufficient and hoped they could find some more markets in the city of Blantyre, which is 60 km away. This problem can be solved by growing what is needed on the market and in quantities that are able to meet the demand; one of the interviewees recommended the following:

“… whatever is produced should be market driven and be tailored to respond to what the market needs… In the previous schemes members grew many crops in small quantities and therefore were not able to satisfy the market…” (Int6, Government Project).

He further advises that for the success of an income generating irrigation project, there is need for business plans, processing and value addition, and extension services to advise the farmers.

6.6 Chapter summary and discussion

This chapter has identified the current and potential stakeholders who can be involved in rural water provision using Solar PV. It provides an understanding of issues emerging from the water and energy sectors. The chapter analysed stakeholder roles, responsibilities, challenges and benefits. Findings of this chapter are summarised in Table 6.3. The findings show that the government is the major stakeholder responsible for providing guidance and monitoring through its policies, regulations, funding, and information. The interviewees recommended that the government needed to update its policies and enforce standards. The District Councils were thought to be the hub for coordination; they represent the government at the local level and are the interface between NGOs and the communities. Donors and NGOs provided the funding and technical expertise, among other things.
Several challenges were raised which were found to be interlinked and included, lack of coordination, financing, human resources, information and awareness, corruption, and political interference. These and others are summarised in Table 6.3. The current model of water management was found to be inadequate and linked with other challenges such as non-functionality of boreholes, lack of monitoring and substandard workmanship. The major challenge in the development of both drinking water and water for irrigation is the high capital cost. In the current models the capital cost is provided by the implementing partner as a donation and the households are supposed to pay for bricks, quarry, sand and unskilled labour and thereafter manage the system and carry out all the O&M costs.

From the case studies, the benefits of water provision using solar water pumping have been demonstrated. First, multiple water points from a single borehole reduces queuing and hence the time to collect water. Second the reduction of water-linked diseases. In terms of agriculture, the benefits that were indicated are income generation, food security, improved school attendance, (in terms of ability to pay school fees) and improved quality of life. The benefits are illustrated in Figure 6.9, which is an extension of Figure 2.4 and now includes the interventions required to meet the benefits.

Recommendations as summarised in Table 6.3 were put forward. Firstly, the government has to put in place enabling policies and ensure that enforcing the policies is done. In addition, there was need for availability of financing organisation to provide loans to communities, so they payback within a designated period. However, provision of water alone will not achieve the developmental goals. If the rural farmers are to go into commercial agriculture and be successful, they have to be trained, there has to be centralised land for communal systems, farm inputs and there have to be markets to sell their produce.

It is evident from the findings of this chapter that water provision in the rural areas is a complex issue. With the challenges and opportunities that have been revealed in this chapter, some solution may be recommended to make water provision in the rural areas using solar PV a better option. Thus, the following chapter discusses and synthesises the findings from the three results chapters, Chapters 4, 5 and 6, and makes recommendations.
<table>
<thead>
<tr>
<th>No</th>
<th>Issues Arising</th>
<th>Effects</th>
<th>Recommendation by interviewees</th>
</tr>
</thead>
</table>
| 1  | Lack of policies or old policies           | • Lack of/slow uptake of technologies  
• Poor resource management  
• Absence of punitive measures                                                                 | • Develop/revise appropriate policies                                                                 |
| 2  | Limited research and development           | • Derailed development  
• Slow technology uptake                                                                                                                | • Support R&D for the academia and researchers  
• Design appropriate water abstraction technologies  
• Research on technologies applicable to Malawi                                                                                           |
| 3  | Lack of information and awareness          | • No database on resources availability  
• Lack of equity  
• Planning & budgeting challenges  
• Dependency on rain-fed agriculture  
• Enhances ‘aid culture’  
• Citizens unable to exercise their rights                                                                                               | • Develop information management systems for both the energy and water sectors (in real-time/GIS)  
• Share available information with stakeholders  
• Carry out awareness and sensitization through appropriate media  
• Consultation and engagement with communities on benefits of water and RETs and how to translate them into income |
| 4  | Lack of coordination                       | • Non-functionality  
• Environmental issues  
• Lack of equity  
• Planning and budget challenges  
• Evaluation constraints                                                                                                                  | • Harmonise policies  
• Integrated planning  
• Involve private sector                                                                                                                   |
| 5  | Political interference                     | • Lack of equity  
• Enhances ‘aid culture’  
• Encourages lack of sustainability/ownership  
• Substandard installations (non-functionality)                                                                                             | • Enhance political accountability                                                                                                      |
| 6  | High capital cost, High inflation and interest rates | • Few entrepreneurs  
• Lack of access  
• Unaffordability  
• Risky environment for investors                                                                                                          | • Establish RETs manufacturing companies  
• Tax and VAT waiver on RETs and accessories  
• Explore funding mechanisms such as apex fund, revolving fund and microfinance organisations                                                                 |

Table 6.3: Summary of stakeholder findings
| 7 | Lack of Finances | • Lack of water access  
    • Lack of monitoring  
    • Unaffordability  
    • Non-functionality | • Government loans and subsidies  
    • Work with VSL groups  
    • Involve microfinance institutions  
    • Explore irrigation water to enhance income  
    • Generating activities and improve incomes.  
    • Introduce mechanisms such as soft loan policies or private enterprises |
| 8 | Corruption | • Derails development  
    • Substandard installations | • Close supervision and monitoring |
| 9 | Lack of Human Resources including entrepreneurs | • Lack of Monitoring  
    • Derails development  
    • High financial expenditure  
    • Non-functionality  
    • Substandard installation | • Vocational schools for technology training  
    • Business training for entrepreneurs and communities  
    • Renewable energy service centre |
| 10 | Lack of Monitoring | • Lack of equity  
    • Sub-standard installations(Non-functionality)  
    • Presence of counterfeit products  
    • Corruption | • Government to enforce regulations and standards  
    • Tighten fiscal policy |
| 11 | Community management model's unsatisfactory delivery | • Non-functionality  
    • Unable to manage and set aside funds for O&M | • Explore alternative ownership model  
    • Empower communities with income generating activities  
    • Life cycle costing  
    • Ensure maintenance system is in place |
| 12 | Limited Infrastructure | • Lack of equity  
    • Investors are reluctant to come in the country  
    • Lack of entrepreneurs in the rural areas | • Government to put structures in place |
| 13 | Environmental Degradation and climate change | • Pollution of water resources  
    • Decline of water table | • Awareness on environmental; management  
    • Encourage afforestation  
    • Proper design and siting of water points |
Figure 6.9: Role of water in development and required interventions
7 Summary and Discussion of Findings

7.1 Introduction

This chapter summarises and discusses the key findings of the research in relation to the objectives as stated in section 1.4.1, and the sustainable livelihoods framework (SLF) discussed in section 2.3. The chapter further makes policy recommendations.

The aim of the research was to develop a financing and a decision support model for planning and analysis of sustainable rural water provision using solar PV in SSA, with Malawi as a case study. The study was interdisciplinary and employed a mixed methods approach consisting of:

i. Review of relevant literature;
ii. Household surveys with 219 rural households that were selected from 30 villages of Chiradzulu District;
iii. Four focus group discussions with selected participants from the villages;
iv. Semi-structured interview with 27 village heads;
v. Semi-structured interviews with 23 expert representatives from the water and energy sectors; representing government, NGOs, entrepreneurs and microfinance organisations;
vi. Four field visits; and
vii. Techno-economic analysis.

Quantitative data were analysed using statistical analysis, whereas qualitative data were analysed using thematic analysis and stakeholder analysis. The techno-economic analysis employed a technical design and the life cycle cost analysis. The study findings are presented and discussed in Chapters 4, 5 and 6 and at the same time, the findings are placed in perspective with the work of previous researchers.

7.2 Summary of findings

7.2.1 Households needs analysis

The first objective was to evaluate the developmental concerns related to water and energy availability, use and quality in the context of socio-economic indicators, sustainable development, and human well-being. The results are presented in Chapter 2, which is the literature review chapter. The study identified water provision as the most significant need for
sub-Saharan Africa. The SLF guided this study and was advantageous because it is flexible in the type of its analysis tools, which can be chosen to best suit the needs and purposes of a particular research. In addition, it is interdisciplinary, which is the case with this research. Literature on water and energy showed that they both have potential to have a positive impact on health, education, food security, poverty alleviation and women empowerment as stated in the developmental goals.

The available literature about Malawi investigated water quality (Pritchard, Mkandawire and O’Neill, 2007, 2008; Taylor et al., 2012), groundwater availability (Chavula, 2012; Mapoma and Xie, 2014), water management (Taulo, Mkakosya and Kululanga, 2008), and the relationship of water to disease (Masangwi et al., 2009). There is limited discussion on water access and the role of stakeholders in water provision. The available studies showed that boreholes on shallow wells in the rural areas of Malawi produced contaminated water and dried up in the dry season. Literature for SSA (Harvey and Reed, 2006; Foster, 2013; Moriarty, Smits and Butterworth, 2013) and Malawi (Chowns, 2014) showed that the community-based model for water provision in the rural areas had failed in ensuring functionality of water points.

Motorised pumps, which require electricity or diesel generators for pumping water, could enhance water accessibility by ensuring deeper boreholes. Studies showed that wells of more than 20 m are less susceptible to drying up and less vulnerable to contamination (Bonsor, MacDonald and Calow, 2010; MacDonald et al., 2011). However, there is low access to electricity in the SSA region (IEA, 2014). Researchers have carried out techno-economic feasibility studies to compare solar PV, wind and diesel generators for water pumping by calculating the LCW (Cloutier and Rowley, 2011; Al-Smairan, 2012; Parajuli, Pokharel and Østergaard, 2014) or payback period for the systems (Espericueta, Pronaf and Juárez, 2004; Sahin and Rehman, 2012). The authors preferred solar PV, albeit with high capital costs. Diesel generators were not ideal because of high operation and maintenance costs, difficulties in accessing fuel and negative impacts to the environment. Since energy is to be used to provide water, the research explored the synergies between the two on their role in development. The literature on willingness to pay revealed the determinants of willingness to pay for water in rural areas of developing countries. Chapter 3 provides literature review on the mixed methodologies employed in this research.

Overall, the literature review identified the following gaps:

i. Previous literature in Malawi looked at water quality, sustainability and availability of groundwater but literature about water access is limited. In addition, literature on energy is at national level, with limited literature at district level.

ii. There is limited literature on willingness to pay for water for rural households in Malawi.
iii. Stakeholder analysis literature on water supply for Malawi is inadequate, although some related literature became available in the course of the research (Chisenga, 2014; Chowns, 2014; Scanlon et al., 2016).

iv. Though SWPS is globally mature, there were limited publications on techno-economic analysis of SWPS in the SSA region and particularly for Malawi conditions.

v. Previous global research looked at each of the above issues independently or combination of a few, but this thesis integrated these into one study in order to have holistic results regarding water provision using solar PV in the rural areas of Malawi.

7.2.2 Water and energy access

The findings from the households show that households had low incomes; only 25% had an income of more than US$1 per household per day. Their educational qualifications were also low with only less than a fifth of them with more than 10 years of school attendance. Illiterate communities are reported to be slow in uptake of new technologies (Tchale, 2009; Mohammed, Mustafa and Bashir, 2013).

The study found that water access for the households is inadequate in terms of quantity; the recommended number of households per borehole was exceeded. This is despite the fact that the percentage of households with access to improved drinking water sources for the study is higher than the national average. Also, as a country, Malawi is ahead of the sub-Saharan average of the MDGs target (WWAP, 2015; National Statistical Office and ICF, 2017). The inadequacy of water resulted in queuing, which was reported to cause quarrels. Quarrels when collecting water have been reported to cause psychological stress on women (Stevenson et al., 2012; Sommer et al., 2014). Just as the case in SSA (WHO & UNICEF, 2015), some women and girls spent more than 30 minutes collecting water. In contrast to other research the time to collect water for this research is long because of queuing and low yield rather than distance (Blagbrough, 2001). In this study, inadequate water access is apparently caused by high population, low yield (or boreholes drying up altogether), disparity, and non-functionality. Apart from normal wear and tear, non-functionality is caused by theft and vandalism. Most of the boreholes remain non-functional because of the inability of the communities to carry out repairs because of lack of finances. Contamination was reported to be a lesser challenge but was initially thought to be the main issue to be addressed because it is well documented for Malawi (Pritchard, Mkandawire and O’Neill, 2007, 2008; Taylor et al., 2012). However, contamination is not ruled out because nearly a fifth of households in the survey experienced an incidence of diarrhoea in the six months prior to the study, suggesting the possibility of water contamination. Furthermore, collecting water affected school
attendance in a fifth of the households who reported that children were either late or absent for school because of water collection.

The majority of the households were in an agricultural-related occupation, implying irrigation water is desirable for them. Several households were engaged in small businesses that also used water like beer brewing, vegetables, and selling food items. The households were willing to venture in other businesses, if electricity where to be available. For irrigation, findings show that the households used traditional watering methods such as watering cans with a few using treadle pumps; both which are physically exhausting.

The majority of households were willing to pay double of what they are currently paying for safe drinking water. Educational qualification is a significant factor for determining willingness to pay for drinking water which is consistent with other studies (Whittington et al., 1990; The World Bank, 1993; Ahmad et al., 2003). This implies that their low educational qualifications may have been the reason for low WTP amount for drinking water. Further, the study found income and gender of the head of household to be significant factors for willingness to pay for irrigation water; men were willing to pay more than women. In addition, the households were willing to pay more for irrigation water for which they are currently not paying anything than for drinking water for which they are currently paying a monthly contribution. This is a significant finding because apparently, the people realize the link between irrigation and income generation, which points out that payback for irrigation water may be feasible.

In terms of energy, the findings show that biomass (firewood, crop residues and charcoal) is the only source of cooking energy used in the study areas. Biomass is used unsustainably, and its availability is getting scarcer and scarcer. The main method of lighting is torches powered by dry cell batteries, and batteries were also used for powering up radios. The batteries had to be replaced frequently, consequently that is very expensive and unsustainable to households. There is no proper disposal method for the used batteries. As for mobile phone charging, the majority of the households took their phones elsewhere for charging in some cases at distances of up to 20 km. These findings concur with other studies that show that biomass is the primary source of cooking energy in Malawi and other developing countries (Adkins, Oppelstrup and Modi, 2012; National Statistical Office and ICF, 2017), and demonstrates that the situation for biomass use has not changed for Malawi. On the contrary, the use of dry cell batteries has superseded the use of paraffin and candles as the main energy sources for lighting. The majority (85%) of the households were not satisfied with their current sources of energy.

Overall, the household survey results imply that there is need to increase drinking water access with well-designed water sources. There is need for promotion of small-scale irrigation
by designing suitable irrigation systems such as ones in Kenya (Kunen et al., 2015) which can be customised for small individual subsistence farmers. The individual systems would be ideal taking into account the difficulty in finding centralised land for group schemes and that individual water systems are more preferred than group ones (Kamwamba-Mtethiwa, 2016). These results also highlighted the need for sustainable energy choices such as electricity access to replace energy sources for lighting, mobile charging and power for radios.

This study has carried out comprehensive water and energy needs analysis to produce a body of knowledge and further explored ways in which their synergies could be utilised. It is one of the few Malawian studies to carry out willingness to pay for water studies in the rural areas. These findings add to the body of knowledge and demonstrate that though Malawi has surpassed the MDGs water goal, the reality on the ground seems to differ. In addition, they add to the body of knowledge by documenting and establishing willingness to pay for drinking and irrigation water. Nevertheless, this research does not guarantee that the households would actually pay what they indicated. However, the results provide baseline information from which decision-makers and investors can engage with the communities.

7.2.3 Levelized cost of water

A SWPS was designed for a case study village to provide water for domestic use for almost 200 households and subsequently an economic analysis was performed. Findings of the study show that the modelled cost of the system is US$18, 600 and the LCW is US$0.34/m³, which is equivalent to US$1.08 per household per month. Costs for other researchers varied widely as illustrated in Table 5.5 of Chapter 5, and depended on the size of system or components that were included in the design. Results of the current study are in the middle of the range of these other studies as illustrated in Table 5.5. From the sensitivity analysis, the tariff (monthly contribution) followed by the capital cost were found to have the most impact on NPV and the LCW.

The findings show that the breakeven cost of water per household per month (US$1.08) is almost six times what the households are currently paying (US$0.19) and nearly three times what they are willing to pay (US$0.38). These results, together with the households’ incomes, show that the households cannot afford to pay for the capital cost or achieve breakeven within the system’s lifetime. Ways of meeting the capital costs suggested by the stakeholders included subsidies, loans, apex funding, and revolving fund through microfinance organisations. Other suggestions were tax and VAT waiver on RETs, which however would not considerably reduce the capital cost. Others suggested the establishment of RETs manufacturing companies and intensive research on low cost technologies for water abstraction.
Despite the high capital cost, the advantages of the solar PV system over the handpump are: A single SWPS (i) Would serve more people as compared to a handpump (ii) Would reduce the manual (pumping) labour for women (iii) Would have the potential to be drilled to greater depths than the handpumps. Deep boreholes have less susceptibility to drying up and contamination (Bonsor, MacDonald and Calow, 2010; MacDonald et al., 2011) (iv) Would make it possible to have multiple stand posts which could reduce queuing time hence time savings for women and at the same time lessen the stress caused by queuing.

7.2.4 Meeting the cost of water

The study developed a financing model that cross-subsidizes the cost of water with that of income from basic household energy services (charging rechargeable lanterns and mobile phones). At a cost of US$2,000, a charging kiosk was added to the designed SWPS and the new LCW became US$1.19 per household per month. If the households were to pay what they are currently contributing for water and energy services (charging rechargeable lanterns and mobile phone), the breakeven cost of water is reduced by over half, to US$0.49 per household per month. With little increase in the energy revenues, which is apparently achievable, the breakeven cost of water is reduced further to US$0.25 which is only US$0.06 more than what they are currently paying. There is a possibility of reducing this cost even further if the neighboring villages were to use the kiosk albeit at a small increase in capital cost.

The government is reported to lack finances; so, to meet capital cost, it can put in place policies to enable private sector and civil society to participate in water provision. These organisations may offer grants, loans with low interest, and other funds such as corporate social responsibility activities of which the communities can repay with flexible conditions. Such methods have been used in Bangladesh and Nepal (Bhattacharyya, 2013; Mainali et al., 2014) and may be adapted to the Malawian environment. However, it should be ensured that the processes are not politicised. To avoid mismanagement of money, as is usually the case in community management models and as reported by Chowns (2014); the research proposes that the system be partly commercialised. The commercial side can be run by people who are interested in running businesses from the village, though this arrangement would need further engagement and training for the communities. It is also recommended that the communities be linked with VSLs groups and micro-finance organisations to assist in the management of the funds including possibilities of reinvesting the money. Harvey (2007) recommends that the community can run a cooperative whereby the water funds are used to purchase livestock or to support a community farm. When funds are needed, the communal agricultural produce could be sold with an advantage of avoiding devaluation effects. Microfinance organisations
in Malawi have offered loans for other purposes to groups (Int14 and Int15, Microfinance). In the Northern Region of Malawi, VSLs groups were found to improve agricultural investments and income for small businesses.

Findings of this techno-economic analysis add to the body of knowledge by establishing the LCW in Malawi. It is one of the few studies to carry out and document a techno-economic analysis for a SWPS in Malawi. At the same time, it suggests opportunities for meeting basic energy services and generating income to payback for the system and for O&M costs.

7.2.5 Stakeholders analysis and challenges of rural water provision

The study identified stakeholders, their roles and challenges that they encounter. Firstly, the study recognised that the government is the policymaker and has to provide an enabling environment. This is in the way of formulating or revising harmonised policies that would enable uptake of SWPS for drinking and irrigation water, with little damage to the environment. At the same time, the government has to ensure that the policies, laws, standards and regulations are enforced by the already available regulatory bodies. The study further identified lack of coordination amongst stakeholders and amongst policies, which contributed to non-functionality, environmental degradation, lack of equity, planning and budget challenges and sector evaluation constraints.

Another finding is lack of information and awareness at several levels. Firstly, at national level the government lacked an easily accessible database on resources availability and distribution both for energy and water. In addition, stakeholders do not share the available information. This causes disparity in water access and planning and budgeting challenges. Communities lacked awareness and sensitization on the capabilities of SWPS. (Practical Action, 2016) recommends that decision-makers and financiers should be up-to-date with technological innovations in renewable energy and have clear guidance for energy planners about how to incorporate new technologies meaningfully. Such information should be passed on to the stakeholders including the communities, through appropriate media. However, it would need extensive consultation, engagement and training in order to change the communities’ mind-set.

In the current study, it was found that political interference is one of the major challenges in the water and energy sectors. For Malawi, other authors reported that it caused lack of equity (Gutierrez, 2007), it enhanced ‘aid culture’ which encouraged lack of sustainability and ownership and caused some of the substandard installations (Harvey, 2007; Baumann and Danert, 2008; Zalengera et al., 2014). Further, the research found that lack of monitoring caused lack of equity and non-functionality because of sub-standard installations and
presence of counterfeit products on the market. Apparently, lack of monitoring is caused by lack of finances and lack of human resources in the government departments. Similarly, in the private sector there are few entrepreneurs and lack of competition on the market. In Malawi because of lack of infrastructure, high inflation and interest rate, the cost of investment is high and risky hence the shying away of investors. Lack of finances is exacerbated since donors pulled out of the country because of corruption (Majanga, 2015; Central Intelligence Agency, 2017). On the other hand, corruption was also reported to affect the quality of installations, which derails development. Calow et al. (2012) cites that internationally, the water sector is viewed as ‘high-risk’ for corruption and could be lessened by close monitoring and supervision. However, monitoring was lacking in Malawi because of lack of finances and human resources as already mentioned.

The field visits demonstrated that using solar PV for drinking water could increase the number of water points from a single borehole as compared to a single handpump. A single SWPS was visited which served 3,000 people plus a school (from four standpoints) whereas the designed population per borehole is 300 people. A SWPS could therefore reduce queuing and the provision of taps can ease the physical burden of manually pumping water, and hence reduce the time spent collecting water. For irrigation water, it also reduces the drudgery of using watering cans or treadle pumps. Irrigation improved food security and income, which in turn had a positive effect on school enrolment and improved quality of life. At Tiyanjane, improved income enhanced environmental protection because the households were no longer involved in the previous income generating activities that were damaging to the environment. There was also reduction in theft and vandalism cases.

The research has added to the body of knowledge in that it has highlighted that provision for water in developing countries goes beyond the technical design, but there are social and managerial aspects that have to be considered as well. These findings imply that for enhanced uptake of SWPS, institutional, policy, financial and management frameworks have to be improved.

### 7.3 Applying the sustainable livelihoods framework

The SLF (DFID, 1999) was used to improve understanding of the livelihoods of the households. Hence, in this section the study findings are synthesised with the aid of the SLF, discussed in section 2.4 of this thesis. Appendix 7.1 shows the current study’s findings superimposed on the SLF chart and discussed in this section.
7.3.1 Vulnerability context

The vulnerability context includes shocks, trends and seasonality, which affect people’s livelihoods and assets and over which they have little control. For the households, climate change, which resulted in increasing the frequency of droughts and floods, affected food security (Coulibaly et al., 2015). Furthermore, low water tables resulted in drying up of boreholes indicating the need for deeper boreholes. There is rapid population growth which is one of the causes of inadequacy of water points and increased pressure on natural resources, for instance unsustainable cutting down of trees for firewood caused deforestation and siltation of water bodies. At national level, trends such as high inflation, interest, and lending rates, and currency devaluation, contributed to high capital costs and less buying power for the households. Lack of formal employment made their incomes unpredictable and left them more vulnerable. In addition, the households lacked influence to voice out their needs because they lack awareness and may not know what is available to them.

7.3.2 Livelihood assets

Livelihood assets are resources used to achieve livelihood strategies and the SLF recognises five such assets or capital, namely, human, natural, financial, physical and social. Household asset ownership widens livelihood options and decreases vulnerability and increases ability to withstand shocks. In terms of human capital, the households in this research had low education qualifications, and lacked awareness on the options available to them. This makes it difficult for the households to explore new livelihood strategies. At national level, there is also lack of awareness and information, lack of skilled human resources in the public and private institutions, and lack of training in RETs.

Positive natural assets include availability of groundwater and availability of adequate solar resources to enable livelihoods. However, on the negative side these resources are not fully exploited; for example, there are few SWPS to provide drinking and irrigation water. Households reported to having small land ownership and for communal schemes, it was difficult to obtain centralised land for group irrigation.

Financial capital for the households is inadequate because the households had low incomes and savings; they lacked employment and had low access to credit. Physical capital, as reported, was also lacking in that there are inadequate systems and infrastructure for water provision (drinking and irrigation), energy, health, schools and telecommunications. Roads were also reported and observed to be poor and the lack of roads hindered access to markets. The SWPS has potential to raise their financial capital by providing income generation activities.
There is positive social capital in the availability of VSL groups, WPCs, religious groups and possibilities of forming farmer’s schemes. Lack of security resulting in theft and vandalism is a major challenge for the households.

7.3.3 Structures and processes

Livelihoods are strongly influenced by external structures and processes, which determine assets and livelihood opportunities. Policies and institutions can increase or decrease individual vulnerability. Positive structures in the study included availability of government reporting structures at the national, district and up to community or village levels. In addition, there are donors and NGOs working at various levels and in different sectors. Micro-financing organisations are available but need to widen their services to include water provision services in the rural areas. Private sector participation is low and need to be improved. As for politicians, they have to exercise caution regarding their promises for free services. In terms of processes, there is lack of policies to address some of the issues that affect households for instance policy on solar water pumping and in cases where policies existed, there is lack of monitoring and enforcement. Furthermore, there is lack of coordination and harmonisation of policies; political interference and corruption (refer to section 6.3.2.4). The community water-management system was found to be failing to fulfil some of its duties. At village level, some social and cultural norms and customs affected livelihoods such as gender roles, which apparently are accepted as the norm.

7.3.4 Livelihood strategies

These are ways in which the households make a living and cope with shocks and vulnerabilities. The more livelihoods strategies that the households have, the more they can be secure against shocks and vulnerabilities. In the study area livelihoods strategies included subsistence agriculture, sale of agricultural products, food items and beer; casual labour, migration to the nearby city, remittances and donations from NGOs and religious organisations. At the household level, women had a larger share of the work burden. There is need to put in place structures and process that are able to enhance livelihood strategies, for instance, existence of policies to supply irrigation water using SWPS for agricultural activities.

7.3.5 Livelihood outcomes

Different livelihood strategies lead to different livelihood outcomes, which may be positive or negative. Livelihood outcomes influence the ability to preserve and accumulate household assets. Improved water provision has the potential to improve health, education, quality of life, income, food security, asset ownership, and improved environmental sustainability.
In conclusion, the SLF has assisted in identifying the factors that affect the households’ livelihoods and provided the influences and processes to help explore stakeholders involved in order to plan appropriate solutions around these existing circumstances.

7.4 Recommendations

Based on the research findings, the following are the proposed policy recommendations significant to the research:

i. Policymakers to enact policies that would allow for national standards on water abstraction using solar PV for both drinking and irrigation water, which will go hand in hand with standards for handpumps. Thereafter depending on the community, apply an appropriate SWPS. The policies have to be harmonised regarding planning, budgeting, and implementation by involving all the relevant ministries and stakeholders.

ii. Policymakers should monitor and enforce the policies and standards through the already existing regulatory bodies.

iii. Restructure the community-based management model to change from being voluntary to being semi-commercial by encompassing income-generating opportunities. The WPC would still be available on an advisory role. The households would be paying their current water contribution so as not to compromise their water access. The basic energy services for charging mobile phones and rechargeable lanterns or any other feasible energy service would provide the revenues for payback of the system and O&M costs.

iv. Policymakers should develop an information management system for both the water and energy sectors with information such as water and energy resource availability, and mapping of current water points and functioning status in real time and global positioning system. Such information could be useful for planning, research and development of technological solutions.

v. Policy makers should keep themselves up to date with technological innovations and such information has to be shared with all stakeholders including communities regarding costs and capabilities.

7.5 Chapter summary

The study findings show that water access in the study area is inadequate and that sustainable energy access including for basic energy services is lacking. The interviewees were willing to
pay US$0.38 per household per month, which was not established whether they would actually pay. The designed cost of water was US$0.34/m³, which translates to US$1.08 per household per month. The findings of this study demonstrate that solar PV for drinking water can increase the quantity and quality of water as compared to a handpump, reduce queuing and ease the physical burden of manually pumping for water, at the same time reducing the time spent collecting water. For irrigation water, it can also reduce the drudgery of watering using traditional methods and improve food security and income, which in turn influences school enrolment and improved quality of life. For the realisation of the systems, there has to be enabling policies, financing mechanisms, and an improved community management model and enforcement of product and installation standards.
8 Conclusions and Future Research

8.1 Introduction

This chapter presents the conclusions of the research and the research novelty by highlighting contributions to knowledge. It further provides research limitations, recommendations for future research and ends with some concluding remarks. The research integrated needs analysis, stakeholder analysis and techno-economic analysis studies to develop a financing and decision support model for planning and analysis of sustainable rural water provision in the rural areas of Malawi. Studying this topic for SSA and Malawi in particular is significant because water provision has a positive impact on developmental issues such as health, education, women empowerment, poverty reduction and food security.

8.2 Summary of key findings

The findings of this research are summarised in section 7.2. The key findings of the research are now presented:

- The literature review identified the research gaps and shaped the objectives of the study. The findings showed that in Malawi there was lack of documented research on water and energy access at district level, WTP, stakeholder analysis and techno-economic analysis of SWPS.

- Despite the country having had achieved the MDGs drinking water target, the people living in Chiradzulu District, were found to be lacking adequate water access which was demonstrated by queuing and spending a long time collecting water.

- Inadequate access was apparently caused by disparity in the distribution of boreholes, high population growth, low yields and non-functionality. In addition to normal wear and tear, non-functionality was caused by theft and vandalism.

- Most of the boreholes remain non-functional because of lack of money to carry out repairs caused by failure of the community-based management system to save for O&M funds.

- In terms of agriculture, the majority of the households in Chiradzulu depended on rain-fed agriculture, which threatens food security in times of drought, and floods which are expected to continue because of climate change. A few households were involved in irrigated agriculture and used traditional watering methods, which are exhausting.

- Households were willing to pay more for irrigation water than for drinking water.
A deep solar PV water pumping system was designed for Potani village to provide approximately 200 households with drinking water. Deep boreholes of more than 20 m are said to be more reliable and have lower vulnerability to contamination and to drying up.

The households were currently paying US$0.19 per household per month and willing to pay a median of US$0.38, compared with a calculated cost of water of US$1.08 per household per month. These findings show that with their WTP amount, the households are not able to payback for the system in its lifetime. Thus, means by which water provision could be cross-subsidised were explored.

It was found that by using the solar PV water system to provide parallel energy services, such as rechargeable lanterns and mobile phone charging services, the cost of water could potentially be reduced from US$1.19 to US$0.49 per household per month. Further innovations were found to reduce the breakeven cost of water to USS0.25 which is only US$0.06 more than what they are currently paying. However, it should be noted that proceeding with this aspect would require further research in terms of verifying WTP data and the possible cross-subsidising innovations.

The study recognised the government as the main stakeholder and policymaker in terms of water provision in the rural areas of Malawi. It has the responsibility to provide an enabling environment to allow the other stakeholders to be able to invest in water provision projects. This was in ways such as formulating and revising policies, enforcing laws and regulations and monitoring of products and installations.

Several other challenges were identified in the energy and water sectors, which included high costs of RETs, lack of finances, lack of coordination between policies and between stakeholders, lack of human resources including entrepreneurs, political interference, failed community management model of water provision and lack of information and awareness.

Effects of these challenges were lack of water access, non-functionality, substandard installations or counterfeit RETs products on the market, ‘aid culture’, lack of sustainability of systems, slow technology uptake, planning and budgeting problems, and poor resource management.

From the field visits, the benefits of SWPS were access to adequate safe drinking water and a single SWPS can provide water to more people than a single handpump. Irrigation water reduced the drudgery of traditional watering methods, and improved food security, incomes, quality of life and education access.
The challenges and the effects are found to be interlinked and whilst they have been discussed in the context of water provision using solar PV, some of the challenges affect other sectors as well. Hence, may ably be addressed in other disciplines. The study recommends that the governments put in place enabling and harmonised policies that standardises SWPS for drinking water and irrigation water abstraction. The stakeholders have to be coordinated and the regulatory bodies should improve on monitoring the quality of products and installations. A SWPS for drinking water was designed and the research proposes a cross-subsidy model, which may be explored further to find appropriate financing models for Malawi that also considers the private sector. The rural community management model can be improved by including entrepreneurs to manage it. The country also needs to manage its fiscal policy, deal with corruption and manage the politicians. The policy-makers should be kept updated on new technologies and this information has to be shared with the other stakeholders including communities.

8.3 Research novelty

This research explored the potential contribution of renewable energy to evaluate the potential for sustainable rural water provision in SSA using integrated methods. The novelty of the research is that no work in Malawi or similar SSA contexts has developed such an all-inclusive integrated needs-driven approach, which helps identify solar PV powered water provision solutions. The research carried out the following (i) Assessed water and energy needs at household level (ii) Investigated willingness to pay (iii) Performed a techno-economic analysis and (iv) Carried out stakeholder analysis. The research also has used multiple methodologies, which assisted to give a rich and well-rounded understanding of the water sector dynamics and the potential of solar PV to provide water.

Particularly this research has made the following contributions to knowledge:

i. The study has used multiple methodologies to uncover existing practice in water provision in Malawi and the possibility of using solar PV to pump water. These results enrich the body of knowledge in both the water and energy sectors and provide baseline data for other researchers, policy makers, planners and other interested stakeholders.

ii. The study has added to knowledge on the water needs and challenges that are faced by households in the rural areas of Chiradzulu District, but can be replicated to other districts in Malawi and other countries in SSA. Particularly, the study has uncovered that though the country met the MDGs, water access is still inadequate.
iii. The study has established the extent to which rural households are willing to pay for water, and has set a reference point in that respect.

iv. The study has identified stakeholders, their roles and challenges that they face and the effects the challenges have on water provision in the rural areas.

v. The study has carried out a techno-economic analysis for a solar PV water pumping system for drinking water, and calculated the levelized cost of water.

vi. The study has developed a model to cross-subsidise water cost with basic household energy costs as one of the innovative ways to pay back for the SWPS.

vii. Many studies have investigated willingness to pay, techno-economic analysis and stakeholder analysis, separately or as a combination of a few. The current research is unique in that it has combined all of them into one study to uncover existing practice in water and energy provision in the rural areas of Malawi and at the same time seek synthesized solutions.

Research outputs during this PhD research are presented in Appendix 8.

8.4 Limitations

Methodological limitations for this research are discussed in section 3.6. An overall limitation is that this thesis is interdisciplinary and employed a mixed methods approach consisting of quantitative, qualitative, and techno-economic analyses. Accordingly, the researcher had to work across disciplines of Social Sciences and Engineering and Technology; and across the sectors of water and energy. For these reasons, the scope and depth of analysis and discussions might have been condensed. On the other hand, this integration was advantageous because it provided insights into the research aim that a single methodology or discipline could not have accomplished. For instance, some of the findings from the household surveys and the stakeholders’ interviews were used as inputs to the techno-economic analysis. It was also possible to compare the LCW to what the households are currently paying or willing to pay.

8.5 Recommendations for future research

This study recommends further research in the following areas:

i. Practical installation of the designed system is recommended and thereafter monitoring its technical and economic performance in the field, including testing of the cross-subsidy model.
ii. This research carried out a techno-economic analysis for drinking water; further research is recommended to carry out a similar analysis for irrigation water and other income generating activities mentioned by the households as aspired businesses.

iii. Replication of the study in other districts of the country is recommended in order to verify the current study findings and to capture the variability from district to district.

iv. An extension of this research is to establish the interconnection between energy and water in the Malawi context.

v. Further research is required to identify suitable financing mechanisms for water provision in the rural areas for the Malawian context.

8.6 Closing remarks

This interdisciplinary study used mixed methods approaches to evaluate the potential of solar PV to aid sustainable development in the rural areas of Malawi, and specifically evaluates the provision of water. The research found that water provision using solar PV in the rural areas of Malawi is a complex issue. It goes beyond the design and installation of a system but also encompasses some important social, economic, policy and management issues. Regardless of that, this research concludes that with proper planning, needs-based analysis, enabling policies for financing and managing the systems, enforcement of policies and standards, water provision using solar PV can help in providing water which has the potential to help meet developmental goals for Malawi and other countries in SSA. Further studies are proposed for the techno-economic analysis of irrigation water, which has the potential to improve food security and reduce poverty.
Appendices

Appendix 3.1: Household questionnaire

Modelling and Analysis of Renewable Energy for Sustainable Development in the Rural Communities of Malawi: A Focus on Water Provision

**HOUSEHOLDS QUESTIONNAIRE**

1. *Start with the Information Sheet and the Consent Form*
2. *Do not read out responses*

<table>
<thead>
<tr>
<th>Household ID:</th>
<th>Name of Enumerator:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of Village:</td>
<td>Date:</td>
</tr>
<tr>
<td>GVH:</td>
<td>Time started:</td>
</tr>
<tr>
<td>TA:</td>
<td>Time Finished</td>
</tr>
<tr>
<td>Consent Given</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NO</th>
<th>HOUSEHOLD DEMOGRAPHY</th>
<th>RESPONSE</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. DEMOGRAPHY AND SOCIO-ECONOMIC DATA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>What is the gender of the <strong>household head</strong>?</td>
<td>Male</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>2</td>
</tr>
<tr>
<td>2.</td>
<td>What is the age of the <strong>household head</strong>?</td>
<td>15 and below</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 to 21 years</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 to 59 years</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 and above</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Who assisted in answering the questions? <strong>Multiple Responses possible</strong></td>
<td>Head</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spouse</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Child</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>4</td>
</tr>
<tr>
<td>4.</td>
<td>What is the marital status of the <strong>household head</strong>?</td>
<td>Single</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Married</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Separated</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Divorced</td>
<td>4</td>
</tr>
<tr>
<td>5.</td>
<td>What is the highest educational level of the <strong>household head</strong>?</td>
<td>Illiterate</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can Read and Write</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PSLCE</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JC</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSCE</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tertiary</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unwilling to disclose</td>
<td>7</td>
</tr>
<tr>
<td>6.</td>
<td>What is the religion of the <strong>household head</strong>?</td>
<td>Christian</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Muslim</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traditional</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unwilling to Disclose</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Question</td>
<td>Options</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>How many people stay in your household?</td>
<td>Insert No of people</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>What is their age group? (Insert Number in each group)</td>
<td>0 to 5 years, 6 to 15 years, 16 to 21 years, 21 to 59 years, 60 and above</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>What do you do for your living (mention the main source of your income)</td>
<td>Subsistence farming, Commercial farming, Business, Employed, Casual Labour, Other</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>What is the average income for this household per month? Enumerator to calculate using Appendix</td>
<td>In MWK</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>On average how much is spent at this household (estimate per month)?</td>
<td>In MWK</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>In what activities are children (15 and under) involved at a household? Circle response(s) Multiple answer possible</td>
<td>Fetching firewood, Farming, Cooking/domestic chores, Fetching water, Selling goods at market, Other, N/A</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>What is the type of your house?</td>
<td>Mud walls with grass roof, Mud walls with iron roof, Brick walls with grass roof, Brick walls with iron roof, Other, N/A</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Does the household own any of the following assets in working condition? Yes=1; No=2</td>
<td>Radio, Mobile Phone, Treadle Pump, TV, Bicycle, Ox-Cart, Motor cycle, Motor vehicle, Land, Bank account, Solar Home System, Other</td>
<td></td>
</tr>
</tbody>
</table>

**B. WATER ACCESS**

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>What is your main source of drinking water?</td>
<td>Borehole, Open well, Protected well, Tap, River, Protected Spring, Unprotected Spring</td>
</tr>
<tr>
<td>Question</td>
<td>Response</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>16. Did you get any support in the construction of your water source?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>17. If Yes, mention the organization or individuals who assisted.</td>
<td>NGO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Government</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Village Mobilisation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Religious Organisation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>18. Do you experience any of the following problems with the current water source? On a scale of 1 to 5 how would you rate them? 1-strongly agree, 2-agree, 3-neutral, 4-disagree, 5 strongly disagree</td>
<td>Contaminated water</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sexual assaults/Rape</td>
<td>1</td>
</tr>
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<td></td>
<td>2</td>
<td></td>
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<td></td>
<td>3</td>
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<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Animals/insects</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
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<td></td>
<td>3</td>
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<td>4</td>
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<td></td>
<td>5</td>
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<tr>
<td></td>
<td>Distance</td>
<td>1</td>
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<td></td>
<td>2</td>
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<td>3</td>
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<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attack</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td></td>
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<td>4</td>
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<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low Yield</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Queuing /scrambling for water</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>19. Who usually goes to this source to fetch the water for your household?</td>
<td>Adult Female</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adult Male</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female Child (15 and under)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Male Child (15 and under)</td>
<td></td>
</tr>
<tr>
<td>20. How often does the member who usually collects water go to collect water?</td>
<td>Once a day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Twice a day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thrice a day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Four times and more a day</td>
<td></td>
</tr>
<tr>
<td>21. How long does it take to go there, get water and come back?</td>
<td>Water on Premises</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less than 30 mins</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 30 mins</td>
<td></td>
</tr>
<tr>
<td>22. How much water do you draw each day from the main source? (Estimate the quantity in litres)</td>
<td>…………………litres</td>
<td></td>
</tr>
<tr>
<td>23. How do you store your drinking water?</td>
<td>Covered clay pots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Covered buckets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jerry cans</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uncovered clay pots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uncovered buckets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>24. Is the water you draw from the water point sufficient to meet your household needs?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>25. If No, explain why?</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>26. Is there a water point committee (WPC) for your main source of drinking water?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>27. If yes mention the roles of this water point committee</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>28. State the things you want to see the WPC doing which they are failing to do or not doing satisfactorily.</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>29. Do you contribute money for maintenance of the water point (i.e. handpump spare parts and civil works)?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>30.</strong></td>
<td>If No, why not?</td>
<td></td>
</tr>
</tbody>
</table>
| **31.** | If Yes, how often do you make the contribution? | Monthly 1  
Quarterly 2  
When the water point is broken 3  
Other 4  
N/A 99 |
| **32.** | How much money per household do you contribute? | MWK………………… 99 |
| **33.** | Who is responsible for buying spare parts for the water point where you get water? | WPC 1  
The village head/ chief 2  
Other 3  
N/A 99 |
| **34.** | Who maintains the water points in this village? | Government officers 1  
Local artisans 2  
WPC members 3  
Other 4 |
| **35.** | Would you be willing to pay for drinking water pumped using communal solar PV for your use? (Enumerator to explain first) | Yes 1  
No 2 |
| **36.** | If yes, how much per month? | ……………………..MWK 99 |
| **37.** | How do you treat your drinking water? (Multiple responses possible) | No treatment 1  
Boiling 2  
Chlorination 3  
Filtration 4  
Sedimentation 5  
Solar disinfection 6  
Other 7  |
| **38.** | If No, why don’t you treat your drinking water? | Expensive 1  
We are used to the water 2  
Water is safe 3  
Do not know how to treat 4  
Others 5 |
| **39.** | Have any of the household members been sick from diarrhoea in the past six months? | Yes 1  
No 2 |
| **40.** | Have children in the household been late for school because of involvement in water collection | Yes 1  
No 2  
N/A 99 |
| **41.** | Have children in the household been absent from school because of involvement in water collection? | Yes 1  
No 2 |
| **42.** | Any suggestion or comment on water supply in your area that should be taken into consideration? |   |
| **43.** | Do you have sufficient water for your livestock and/or winter crops (dimba)? | Yes 1  
No 2 |
| **44.** | Would you be willing to pay for water for crops and livestock from a communal Solar PV source? | Yes 1  
No 2 |
| **45.** | How much would you be willing to pay for water for crops and livestock per month? | In MWK |

**ENERGY ACCESS AND USE**

218
<table>
<thead>
<tr>
<th>46.</th>
<th>Does the household use any of the following energy sources? Yes=1 No=2. For the energy used insert the cost per month if purchased and N/A if not purchased</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Source</td>
<td>Y/N</td>
</tr>
<tr>
<td>Grid Electricity</td>
<td></td>
</tr>
<tr>
<td>Paraffin</td>
<td></td>
</tr>
<tr>
<td>Candles</td>
<td></td>
</tr>
<tr>
<td>Dry cell batteries</td>
<td></td>
</tr>
<tr>
<td>Car batteries</td>
<td></td>
</tr>
<tr>
<td>LPG (Gas)</td>
<td></td>
</tr>
<tr>
<td>Solar Home System</td>
<td></td>
</tr>
<tr>
<td>Firewood</td>
<td></td>
</tr>
<tr>
<td>Animal dung</td>
<td></td>
</tr>
<tr>
<td>Crop residue</td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td></td>
</tr>
<tr>
<td>Charcoal</td>
<td></td>
</tr>
<tr>
<td>Solar Home System</td>
<td></td>
</tr>
<tr>
<td>Firewood</td>
<td></td>
</tr>
<tr>
<td>Animal dung</td>
<td></td>
</tr>
<tr>
<td>Crop residue</td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td></td>
</tr>
<tr>
<td>Charcoal</td>
<td></td>
</tr>
<tr>
<td>Straw/Grass</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>47.</th>
<th>What is the main source of energy for cooking?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood</td>
<td>1</td>
</tr>
<tr>
<td>Charcoal</td>
<td>2</td>
</tr>
<tr>
<td>Animal Waste</td>
<td>3</td>
</tr>
<tr>
<td>Crop Residue</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>48.</th>
<th>If purchased how much does it cost per month?</th>
</tr>
</thead>
<tbody>
<tr>
<td>--------------------------MWK</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>49.</th>
<th>If you use firewood what is your main source of firewood?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collected</td>
<td>1</td>
</tr>
<tr>
<td>Purchased</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>N/A</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>50.</th>
<th>If collected on average how many members collect firewood</th>
</tr>
</thead>
<tbody>
<tr>
<td>..................people</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>51.</th>
<th>If collected how long does it take for a round trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>..................Hrs</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>52.</th>
<th>How many times per week do members go to collect firewood?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once a week</td>
<td>1</td>
</tr>
<tr>
<td>Twice a week</td>
<td>2</td>
</tr>
<tr>
<td>Thrice a week</td>
<td>3</td>
</tr>
<tr>
<td>Four times and more a week</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>53.</th>
<th>Specify any problem faced with collection of firewood</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>54.</th>
<th>If firewood is purchased, how much does it cost per month?</th>
</tr>
</thead>
<tbody>
<tr>
<td>............MWK</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>55.</th>
<th>What is the main source of energy for lighting?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffin</td>
<td>1</td>
</tr>
<tr>
<td>Solar home system</td>
<td>2</td>
</tr>
<tr>
<td>Candles</td>
<td>3</td>
</tr>
<tr>
<td>Solar Torch</td>
<td>4</td>
</tr>
<tr>
<td>Batteries Torch</td>
<td>5</td>
</tr>
<tr>
<td>Straw/Grass</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>56.</th>
<th>How much do you pay for your lighting energy per month?</th>
</tr>
</thead>
<tbody>
<tr>
<td>..................MWK</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>57.</th>
<th>What source of energy do you use for charging your phone?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>1</td>
</tr>
<tr>
<td>Elsewhere for free</td>
<td>2</td>
</tr>
<tr>
<td>Elsewhere for pay</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Question</td>
</tr>
<tr>
<td>---</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>58.</td>
<td>If you charge elsewhere what is the distance to the charging place?</td>
</tr>
<tr>
<td>59.</td>
<td>How much do you pay on average per month if you have your phone charged elsewhere?</td>
</tr>
<tr>
<td>60.</td>
<td>Would you be willing to pay for charging your phone at a communal solar system close to your village?</td>
</tr>
<tr>
<td>61.</td>
<td>If yes, how much per month?</td>
</tr>
<tr>
<td>62.</td>
<td>How much do you pay for the batteries for your radio per month?</td>
</tr>
<tr>
<td>63.</td>
<td>What is the cost of other sources of energy not mentioned?</td>
</tr>
<tr>
<td>64.</td>
<td>Are you satisfied with your current energy sources?</td>
</tr>
<tr>
<td>65.</td>
<td>If No, What is the reason for your answer?</td>
</tr>
<tr>
<td>66.</td>
<td>If you were to have electricity, what are the businesses you would wish to have?</td>
</tr>
<tr>
<td>67.</td>
<td>Are you aware about the following major sources of renewable energy? Yes=1; No=2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>68.</td>
<td>Through which channel of communication did you get the information from? (Multiple responses possible)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>69.</td>
<td><strong>Comments, Observations, and Photographs</strong> (Photographs could be of water points, water storage, fireplaces, houses, lighting, village scenes, etc.)</td>
</tr>
</tbody>
</table>

*NB: Spaces were provided for answering the open-ended questions,*
Appendix to questionnaire
1. What crops did you grow, harvest and sell during the past 12 months?

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (acres)</th>
<th>Quantity (bags, carts)</th>
<th>Equivalent (Kg)</th>
<th>Quantity Sold (kg)</th>
<th>Amount(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 groundnuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 cassava</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 sweet potato</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 pigeon pea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 sorghum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 tobacco</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 coffee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enumerating to estimate monthly cost

2. What are the total number of livestock are currently owned, and how many were sold (and by-products) during the past 12 months?

<table>
<thead>
<tr>
<th>No. currently owned</th>
<th>No. Slaughtered for food</th>
<th>No. Sold</th>
<th>Total cost(K)</th>
<th>Monthly cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cattle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 goats</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 sheep</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 chicken</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ducks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 guinea fowls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 doves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 pigs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 rabbits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 turkeys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enumerating to estimate monthly cost
3. What are the other sources of income and economic activities of the household?

<table>
<thead>
<tr>
<th>No</th>
<th>Activity</th>
<th>Items (cash, maize, other-specified)</th>
<th>Cash Equivalent per month</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Property income</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Remittances (pension, allowances, organisational support, gifts, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Business/Home industry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Estimated Total Income per month

<table>
<thead>
<tr>
<th>No</th>
<th>Income</th>
<th>Cash equivalent per month</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Salaries/Wages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Crops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Livestock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3.2: Participant information sheet

Modelling and Analysis of Renewable Energy for Sustainable Development in the Rural Communities of Malawi: A Focus on Water Provision

Adult Participant Information Sheet

Main Investigator: Esther Phiri, E.phiri@lboro.ac.uk Contact number: +4401509 635325

Other Investigators:

Dr Paul Rowley; P.N.Rowley@lboro.ac.uk Contact number: 01509 635345

Dr Richard Blanchard; R.E.Blanchard@lboro.ac.uk Contact Number: 01509 221790

a: CREST, School of Electronic, Electrical and Systems Engineering, Loughborough University, Loughborough, LE11 3TU, Leicestershire, United Kingdom

What is the purpose of the study?
The purpose of this study is to evaluate the potential contribution of renewable energy to support sustainable development in Malawi. Particular emphasis will be on potable water provision in the rural areas using solar Photovoltaic. By the end of the study the investigators hope to develop a tool kit to aid decision-makers in providing potable water to the rural people of Malawi.

Who is doing this research and why?
This study is part of a Student research project supported by Loughborough University. The Commonwealth Scholarship Commission has sponsored me (Esther Phiri) to study Doctoral Studies in the UK. I am being supervised by Dr Paul Rowley and Dr Richard Blanchard of Loughborough University.

Are there any exclusion criteria?
Participants who suffer from physical, physiological or emotional conditions, which could be affected or aggravated by the study, will be excluded from the study.

What will I be asked to do?
You will be asked to complete a survey questionnaire.

Once I take part, can I change my mind?
Yes. After you have read this information sheet and asked any questions we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the sessions you wish to withdraw from the study please just contact the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing. Withdrawing from the study will not disadvantage you in any way.
However, once the thesis has been submitted (expected to be by 31 December 2016) it will not be possible to withdraw your individual data from the research.

**How long will it take?**

The time required to complete the questionnaire is approximately 30 to 45 minutes.

**What personal information will be required from me?**

**For households:**
Information required will be about members of your household: age, sex, highest educational qualification, occupation and income (economic status). The survey will also ask information on your water and energy use patterns.

**For other stakeholders:**
Information will be asked about your views on renewable energy technologies and its application to water pumping. Information will also be sought about your experiences with renewable energy.

**Will my taking part in this study be kept confidential?**

Yes. Only the main investigators will have access to the information that you have given us and all the study documents containing your information will be kept under key and lock. All your personal information will be kept confidential. The questionnaire will not bear your name and will be anonymised by using a study number instead of your name. Data will be put onto a computer but only the researcher will know the password to start the computer. None of the data on the computer will have your name on it. The information will be kept for a maximum of five years after which it will be deleted or destroyed.

**What are the benefits of my taking part in the study?**

There are no benefits for taking part in the study. However, the information collected could be able to influence government policies in the provision of water in the rural areas of Malawi.

**Are there any risks associated with taking part in this study?**

No. There are no known risks for taking part in this study.

**I have some more questions; who should I contact?**

You may contact any one of the investigators who are listed at the top of this information sheet.

**What will happen to the results of the study?**

This study is being undertaken as a PhD study at Loughborough University, UK. The results will be presented in a thesis. In addition, the results may be published in journal papers and presented at conferences. The Government of Malawi may also use the results to change policies for water provision in the rural areas of Malawi.

**What if I am not happy with how the research was conducted?**

If you are not happy with how the research was conducted, please contact: The Director General National Commission for Science and Technology, Lingadzi House, City Centre, Private Bag B303, Lilongwe 3, Malawi. Tel: 2651771 550.Fax: 2651772 431 Email: directorgeneral@ncst.mw Website: www.ncst.mw
Appendix 3.3: Informed consent form

Modelling and Analysis of Renewable Energy for Sustainable Development in the Rural Communities of Malawi: A Focus on Water Provision

INFORMED CONSENT FORM

(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee.

Yes ☐ No ☐

I have read and understood the information sheet and this consent form.

Yes ☐ No ☐

I have had an opportunity to ask questions about my participation.

Yes ☐ No ☐

I understand that I am under no obligation to take part in the study.

Yes ☐ No ☐

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

Yes ☐ No ☐

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

Yes ☐ No ☐

I agree to participate in this study.

Yes ☐ No ☐

Your name

__________________________________________________________

Organisation Name

__________________________________________________________

Your signature

__________________________________________________________

Signature of investigator

__________________________________________________________

Date

__________________________________________________________
Appendix 3.4: Stakeholder interview guide

Modelling and Analysis of Renewable Energy for Sustainable Development in the Rural Communities of Malawi: A Focus on Water Provision

Interview Guideline

Name of Organisation:

Name of Interviewee:

Position:

Phone:

Email:

Introduction

1. What are the core activities of your organisation?
2. What are the roles of your organisation?
3. In which parts of the country do you operate?
4. Regarding water provision projects in the rural areas: Who are the stakeholders involved and what are their roles?
5. What are the common challenges/obstacles experienced in water provision in the rural areas of Malawi?

Current Water Points

1. How do you select the areas in which to install the water points?
2. What are the current types of water points do you install?
3. What is the design population for each waterpoint? Is it achievable?
4. What is the depth of the water points?
5. What water treatment methods do you use for the water points?
6. What are the common challenges experienced with the water points and water provision to the rural areas of Malawi?
7. Do you have a say in the type of water points to be constructed?
8. Do you have a limit on how much the installed waterpoint should cost?

Financing and management

1. What is the cost of each type of the water points listed above?
2. Do the rural people contribute towards the cost of the waterpoint? How much
3. How are the water points managed?
4. Do the rural people contribute towards Management of the waterpoints? How much?
5. How do you ensure the sustainability of the water points?
6. In your opinion, would the rural people be willing to pay for water? Would they be able?
Solar Photovoltaic-(SPV) Powered Water Pumping Systems

1. What are the reasons for (not) practicing water pumping using SPV?
2. Do you have any plans to use SPV water pumping for water pumping in future?
3. If yes, what are your reasons for considering SPV powered systems?
4. Are there any toolkits/documentations/guidelines for guidance on using SPV powered water pumping systems in Malawi?
5. What are the challenges/obstacles and opportunities to rolling out of SPV Water pumping?
6. Do you have an objection if your implementing partners were to use solar photovoltaic for water pumping in the rural areas?

In conclusion,

1. What in your opinion are the most relevant actions that the Government of Malawi could undertake for the successful deployment of Water pumping (for drinking/irrigation/agriculture) using SPV in the country?
2. Please give your views on any issues that have not been raised in the questionnaire regarding SPV water pumping and water provision in general in the rural areas of Malawi.
Appendix 3.5: Loughborough University ethical approval

From: Jacqueline Green  
To: Esther Phiri  
Cc: Richard Blanchard; Paul Rowley  
Subject: HPSC R15-P075  
Date: 25 June 2015 09:12:11

Dear Esther,

Many thanks for your response to the Sub-Committee’s conditional approval. On behalf of the Sub-Committee, I can confirm that the conditions of approval for the study have now been met and that the study R15-P075 now has full ethical approval.

If in the future you wish to make any amendments to the study, you should contact me in the first instance.

Kind Regards,

Jackie

Jacqueline Green  
Secretary, Ethics Approvals (Human Participants) Sub-Committee  
Hazlerigg Building, Research Office  
Loughborough University  
01509 222423  
J.A.Green@lboro.ac.uk  
Website: http://www.lboro.ac.uk/committees/ethics-approvals-human-participants/
Appendix 3.6: Malawi's ethical approval

Ref No: NCST/RTT/2/6

24 July, 2015

University of Malawi-The Polytechnic
Private Bag 303
Chichiri
Blantyre 3

Dear Esther Phiri,

RESEARCH ETHICS APPROVAL OF PROTOCOL PROTOCOL NO. P.07/15/47
MODELLING AND ANALYSIS OF RENEWABLE ENERGY FOR SUSTAINABLE
DEVELOPMENT IN THE RURAL AREA OF MALAWI: A FOCUS ON WATER
PROVISION

Having satisfied all the ethical, scientific and regulatory requirements, procedures and guidelines
for the conduct of research in the social sciences sector in Malawi. I am pleased to inform you
that the above referred research study has officially been approved. You may now proceed with
its implementation. Should there be any amendments to the approved protocol in the course of
implementing it, you shall be required to seek approval of such amendments before
implementation of the same.

This approval is valid for one year from the date of issuance of this letter. If the study goes
beyond one year, an annual approval for continuation shall be required to be sought from the
National Committee on Research in the Social Sciences and Humanities in a format that is
available at the secretariat. Once the study is finished, you are required to furnish the Committee
and the Commission with a final report of the study.

Wishing you a successful implementation of your study.

Yours Sincerely

Martina Chimuzimu
NCRS Administrator and Research Officer
Health, Social Sciences and Humanities
For: CHAIRMAN OF NCRSH
Appendix 3.7: Chiradzulu District Council research approval

University of Malawi-The Polytechnic
Private Bag 303
Chichiri
Blantyre 3
Email: enhir@poly.ac.mw
Mobile: 0991 396811

27th July, 2016

The District Commissioner
Chiradzulu District Assembly
Private Bag 1
Chiradzulu

Dear Sir/Madam

SEEKING APPROVAL TO CARRY OUR RESEARCH IN CHIRADZULU DISTRICT:
Modelling and Analysis of Renewable Energy for Sustainable Development in the Rural Areas of Malawi: A Focus on Water Provision

I would like to seek approval to carry out research in Chiradzulu District on the above title. The research will involve interviewing households in the rural areas of Chiradzulu.

I am a member of staff at University of Malawi-The Polytechnic and currently a student at Loughborough University in the United Kingdom. I have obtained ethical approval from the National Commission for Science and Technology (NCST), Malawi and from Loughborough University Ethics, whose approval letters are attached.

Further to this I would like to request information about the Traditional Authorities and villages in Chiradzulu to enable me select the villages and households in which to hold the study. In addition I would also like to request general information about Chiradzulu District in particular on water use, energy use, education and health statistics.

Your assistance will be highly appreciated.

Yours sincerely,

Esther Thiri (Ms)
Appendix 4.1: List of surveyed villages

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Total                       | 71          | 30       | 15     | 46      | 36      | 21     | 219    |
Appendix 5.1: Pump selection curves

SQF 2.5-2

SQF 3A-10

source (Grundfos, no date)
Appendix 6.1: List of interviewees and codes

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6 Malawi Rural Electrification Program  
7 Alternative Energy Sources
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Appendix 6.2: Water Mission innovations

1. ‘The Living Water Treatment System (LWTS)

Water Mission have their own patented water treatment systems for filtration and chlorination though at the time they had nothing for treatment of arsenic, fluoride and salinity problems. If the source is a borehole, the water is usually not turbid and will need only to be chlorinated using their Potable Water Chlorinator. However, surface water can be turbid, and so has to be filtered and treated using their system called ‘The Living Water Treatment System (LWTS)’, which is shown in Figure 0.1. It can treat 38 litres of water per minute producing enough drinking water for 5,000 people per day. Such a system costs approximately US$8,000, has a lifetime of 20 years, and Water Mission engineers are working on the designs to reduce the cost.

2. Trade Water” Private Service Delivery Programme

A newer water provision system is the “Trade Water” private service delivery programme developed by Grundfos, a Danish international pump manufacturing company that is Water Mission’s partner. It uses a system called the “LIFELINK” which is an automated water distribution point that is integrated with a secure payment facility and real-time Global System for Mobile Communications (GSM) monitoring system. The LIFELINK unit is fitted to the basic tap stand. The first LIFELINK unit in the country cost US$13,000 but Grundfos is working towards reducing the price of the unit to US$3,000 USD in order to make this option more feasible. It is more appropriate where it is not possible to have a community-based management system and allows for accountability and transparency which are difficult to implement in the community systems. In the LIFELINK system, the volume of water distributed and the amount of money received can be tracked at the Water Mission office in real time. The users buy water keys similar to ATM cards which are loaded with credit transferred either via mobile money or directly from a credit key that is held by the water operator. To collect water, the user inserts the water key into the LIFELINK unit; a pre-set collection fee is deducted from the water key for each litre of water collected.

Another advantage is that it has a provision for charging mobile phones. One such system was visited, and the water kiosk is shown in Figure 0.2 and Figure 0.3 shows the kiosk operator adding credit to the water key. The system was found to dispel the gender norm that only women collect water as Figure 0.4 shows a man collecting water. In Ghana (Blagbrough, 2001) reports that men have begun to participate in the traditionally female role of collecting water because of improved water supplies.
Figure 0.1: The Living Water Treatment System (Watermission, no date)
Figure 0.2: A Water kiosk that uses the LIFELINK unit

Figure 0.3: A water kiosk operator demonstrates how to insert credit
Figure 0.4: Collecting Water from a LIFELINK Unit

(even men can now collect water!)
Appendix 7: Study results displayed on the SLF chart
Appendix 8: Publications & Presentations

Presented


Planned Journal Papers


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253


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