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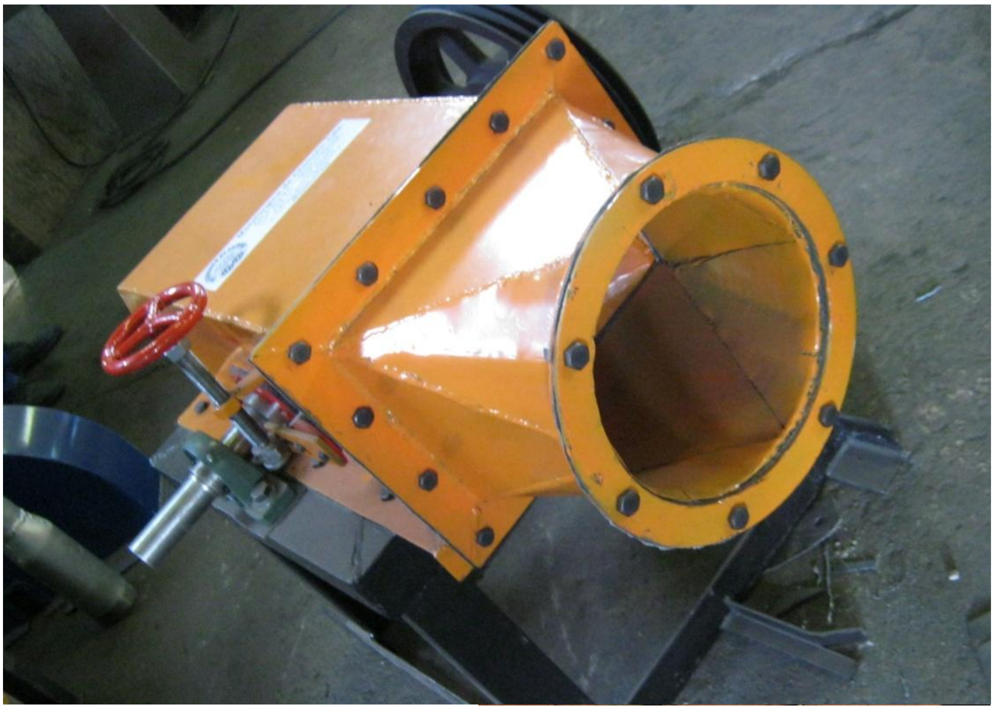

Pico and Micro Hydropower in Remote Areas of Mozambique

An Assessment of the Potential for Rural Electrification

Master of Science Thesis in the Master Degree Programmes:
Electric Power Engineering
Industrial Ecology – for a sustainable society

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Division of Environmental System Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2012
Report No. 2012:20
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Cover:
A micro hydro turbine manufactured in Chimoio, Manica province.

Göteborg, Sweden 2012

Abstract

Mozambique is a developing country situated on the south-eastern coast of Africa. The poverty level is high, although the last years have shown a high economic growth rate. The country has low population density with 60% of the population living in rural areas. Only 6.3% of the rural population have access to electricity, a service considered crucial for poverty reduction by the World Bank. Extending the national main grid is a time-consuming process, which suggests studies of off-grid electrification possibilities. The use of pico and micro hydropower for rural electrification in other countries has shown it is the off-grid alternative with the lowest cost, although the site specific design might pose a barrier. This report investigates the potential for pico and micro hydropower to be used for rural electrification in remote areas of Mozambique.

The potential of the technology is evaluated in two different aspects. A mapping of barriers to pico and micro hydro is done by conducting interviews with stakeholders in Mozambique. The interviews are semi-structured and designed to find the opinions on barriers and ways to overcome barriers. As a second aspect, the potential of available technology, estimated topography and water resources is evaluated for two turbines of different functionality and size in four Mozambican provinces, using a model with precipitation data and turbine ratings. The turbines are Pelton 50 kW and Crossflow 3 kW, both locally manufactured in Chimoio, Mozambique.

The interview results show that stakeholders in Mozambique find three barriers especially important. These are *Lack of access to finance*, *Lack of proper maintenance* and *Poor knowledge management*. Ways of overcoming these barriers are to increase the investors interest by enabling future connection to the main grid and by displaying and promoting functional cases, to increase local involvement and capacitate local companies, and to involve universities, improve documentation of projects and do study visits to functioning schemes. The model results show a high dependance of the water flow in the rivers, and a limited capacity to cover large loads throughout the year. The smaller Crossflow turbine, which in this case is also suitable for low heads, shows potential to be a good complement to the larger Pelton turbine.

Acknowledgments

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Also thanks to Jimmy Ehnberg who gave feed back and good ideas on the model and thanks to our examiner Sverker Molander.

Abbreviations and acronyms

AKSM Associaçao Kwaedza Simukai Manica

DPREME Provincial Directorates of Mineral and Energy Resources

EDENR Strategy for New and Renewable Energy Development (Mozambican strategy document)

EdM Electricidade de Moçambique (National electricity utility)

ELC Electric Load Controller

FAO Food and Agriculture Organization of the United Nations

FUNAE Fundo de Energia (National energy fund)

GIS Geographical Information System

GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit

HCB Hidroelectrica de Cahora Bassa (Cahora Bassa Hydroelectricity Plant)

INAM Instituto Nacional de Meteorologia

IRENA International Renewable Energy Agency

IRES Integrated Renewable Energy Systems

JFM January, February and March

kW kilowatt

LCREP Low Cost Rural Electrification Plan

MoE Ministry of Energy

MW megawatt

NGO Non Governmental Organization

OND October, November and December

SIDA Swedish International Development Cooperation Agency

UNDP United Nations Development Programme

WB World Bank

Contents

1 Introduction **1**
1.1 Aim . . . 2
1.1.1 Stakeholders' opinions . . . 2
1.1.2 Technological and resource potential . . . 2
1.1.3 Scope . . . 2

2 Background **4**
2.1 Benefits of rural electrification . . . 4
2.2 Pico and micro hydropower development in Asia and Africa . . . 4
2.3 Mozambique - History and power sector development . . . 5
2.3.1 History . . . 5
2.3.2 Power sector development . . . 6
2.3.3 Rural electrification in Mozambique . . . 6
2.3.4 Pico and micro hydropower in Mozambique . . . 6

3 Theory **8**
3.1 Pico and micro hydropower . . . 8
3.1.1 Hydropower equipment . . . 9
3.2 Electro-mechanical equipment . . . 9
3.2.1 Turbines . . . 9
3.2.2 Generators . . . 12
3.3 Barriers to pico and micro hydropower from literature . . . 12
3.4 Ownership models . . . 14
3.5 Payment models . . . 14
3.6 Demography . . . 15

4 Method **17**
4.1 Method for analysis of stakeholders' opinions . . . 17
4.1.1 Selection of interview topics . . . 17
4.1.2 Selection of respondents . . . 18
4.1.3 Conducting the interviews . . . 18
4.1.4 Data condensation and analysis . . . 19
4.2 Method for analysis of technological and resource potential . . . 22
4.2.1 Data used in model . . . 22
4.2.2 Selection of designs . . . 23
4.2.3 Field surveys . . . 23
4.2.4 Modeling . . . 25
4.2.5 Load profiles . . . 27
4.2.6 Cost estimation . . . 28
4.2.7 Extrapolation of data . . . 30
4.2.8 Assumptions and limitations . . . 30
4.2.9 Analysis . . . 31

5 Results **32**
5.1 Barriers to pico and micro hydropower from interviews 32
5.1.1 Availability of equipment 32
5.1.2 Community relations 33
5.1.3 Data and measurements 34
5.1.4 Demand 35
5.1.5 Design 36
5.1.6 Finance 38
5.1.7 Knowledge and education 39
5.1.8 Legislation 41
5.1.9 Payment 42
5.1.10 Project administration 43
5.1.11 Resources 44
5.1.12 Main challenges 45
5.2 Technological and resource potential model 46
5.2.1 Province characteristics 46
5.2.2 Reliability of water resources 47
5.2.3 Installation cost 49
5.2.4 Validation of system power output 52
5.2.5 Sensitivity analysis 52

6 Analysis **54**
6.1 Barriers to pico and micro hydropower 54
6.1.1 Main barriers and most mentioned barriers 54
6.1.2 Less mentioned barriers 58
6.2 Technological and resource potential model 59
6.2.1 Pelton turbine 59
6.2.2 Crossflow turbine 59
6.2.3 Comparison of the two turbines 59
6.2.4 Installation cost 59

7 Discussion **61**

8 Conclusion **63**

A Interview guide - FUNAE B **68**

B Interview coding **72**

C Applications for all load profiles **73**

D Site characteristics and flow variation curves **74**

E Barriers - all respondents **76**

Chapter 1

Introduction

A life without access to electricity is the reality of more than 1.5 billion people in the world (WB, 2008). Access to modern energy is crucial for economic development and world poverty reduction (WB, 2009). Among the countries with the most alarming rates of rural electrification is Mozambique, situated in Southeast Africa (Gaul et al., 2010).

To improve access to electricity in a country like Mozambique is far from easy. The country is vast with a low population density where a large share of the population resides in isolated communities far from the national electricity network. This makes it costly to extend the national grid, the main approach to increase access to electricity today (SIDA, 2011). Recently, the Mozambican government has become aware of the importance of introducing off-grid electrification as a complement to extension of the national grid (MoE, 2011).

Off-grid electrification is defined as electricity generated in separate systems for each household or in a power station connected to a local stand-alone grid, isolated from the national grid (Kaundinya et al., 2009). Most common technology options available for off-grid electrification are diesel generator schemes, solar photo-voltaic systems (solar PVs) and pico and micro hydropower stations (WB, 2008). Previous Mozambican rural electrification programmes have included installation of solar PVs and diesel generator schemes for off-grid use. Even though pico and micro hydropower has been used historically in the country, both to run grinding mills and to support tea plantation areas in Zambézia province (Chambal, 2010), today it remains a relatively untapped resource. Reports state that Mozambique has significant hydro resources both for large scale on-grid application and small scale off-grid application (IRENA, 2012a; Gaul et al., 2010; Chambal, 2010; MoE, 2011) and new governmental strategies for renewable energy are set up to support use of pico and micro hydro (MoE, 2011).

Pico and micro hydropower technologies have different ranges of power output. The definition of the limits vary in literature, but the most common definition is that power stations with power outputs between 10 - 100 kW are called micro hydro (WB, 2008) and power outputs below 10 kW are called pico hydro (Maher et al, 2003). In this study these definitions will be used.

There are many advantages with pico and micro hydropower. Out of the possible alternatives for off grid electrification, the World Bank Energy Unit states that pico hydropower technology is likely to have the lowest cost (WB, 2008). The environmental impact is low, especially in the schemes where there is no dam. The high capacity of pico and micro hydropower, in comparison with the capacity of solar power systems, is an advantage since it facilitates productive use[1]. For electrification of rural areas to result in productive use, it is a great advantage that the power has no fuel costs. In comparison, diesel generator schemes, with high cost of fuel, often run for only short times during the evenings which limits the potential of the electricity to contribute to productive use (Williams, 2009).

Apart from barriers for rural electrification in general, like the lack of access to spare parts, pico and micro hydropower have distinctive barriers to face. The technology is very site specific. The water flow and fall, the topography and soil around the scheme, and other altering parameters affect the design (Penche 1998/2004). This is less so for pico turbines, which are often made in standard sizes (Williams, 2007). The use of an electricity grid often requires community cooperation, which is not the case with for instance keeping solar panels on each house since there is no need for a grid at all. Nevertheless, there are other drawbacks with solar home systems. In Kenya, expensive solar panel systems have led consumers to buy non matching components piece by piece, which reduces the quality and capacity of

[1] The concept productive use is described as the application of electricity to create goods and services directly or indirectly for the production of income or value, for example milling, water pumping or cotton production (EdM, 2007).

systems (Williams, 2009).

The urgent need of electricity in larger parts of Mozambique, in combination with problems with currently used power systems, encourage studies of alternative solutions like pico and micro hydropower. The need for community cooperation and site specific design may turn out to be crucial disadvantages for the technology. But the apparent availability of hydro resources indicates a high potential, as well as the low cost, the simplicity of the system, the absence of fuel cost, the high capacity and the low environmental impact. Understanding the potential for pico and micro hydropower in Mozambique would be of great importance for rural electrification, and by extension also for the economic development of the country.

1.1 Aim

The aim of the study presented in this report is to investigate the potential for utilizing pico and micro hydropower to boost electrification in remote areas in Mozambique.

The potential will be investigated in terms of stakeholders' opinions on the barriers to, and possible solutions for pico and micro hydropower development, and also the potential for different provinces, based on geographical, technological and demographical factors. The site specific design of hydropower requires mapping of potential sites and yearly measurements of river flow to conclude exact numbers of total available capacity. Since very little data exists, the potential will be investigated through a model based on available data and estimations. The three research questions presented below, will be answered in order to reach the aim.

1.1.1 Stakeholders' opinions

Stakeholders' perception of a technology and its barriers is a good measurement of the potential of the technology (Mikkelsen, 2005). Stakeholders are the actors expected to implement, promote and invest in the technology and to show what barriers they recognize and which of them they consider crucial can be of good help to understand future development of the technology. A comparison of barriers can be made with earlier hydropower projects as well as with barriers for other technologies. Mapping of barriers and the possibilities to overcome them can give an indication on what the future possibilities are for the technology. Based on this the first two research questions are defined as:

- What are the stakeholders' opinions on existing barriers for utilizing pico and micro hydropower in rural Mozambique?
- What are the stakeholders' opinions on the possibility to overcome these barriers?

1.1.2 Technological and resource potential

A third research question was defined to evaluate the potential of pico and micro hydropower from a resource perspective. The design of a hydropower scheme is influenced by several factors. There needs to be a river with enough capacity to support the demand. There needs to be technology suitable to generate electricity as efficiently as possible. And the electrified community needs to be structured in a way that makes electricity distribution feasible. The third research question is defined as:

- What is the potential of pico and micro hydropower in Mozambique, based on geographical, technological and demographical factors?

Here, "geographical factors" are defined as hydrological and topographical characteristics of Mozambique (meaning head and flow of different sites within the country). In focus for investigating the technological factors is choice of turbine, which influences constraints for capacity, cost and head/flow. Demographical factors are estimations of different village sizes and load curves, which influences constraints for capacity and cost. What relevance the answers to the questions above hold in a long term perspective will be discussed.

1.1.3 Scope

This subsection presents the decided delimitations for this report. Concerning the research questions related to the stakeholders' opinions, the spatial delimitations are set to Mozambique. The respondents are asked to answer only for opinions regarding pico and micro hydro in Mozambique. For the third question the report is spatially limited to provinces regarded by the respondents as likely to have a high potential for pico and micro hydro. These are Niassa, Zambézia, Tete and Manica provinces. Spatial delimitations are also set to areas with no plans of getting connected to the main grid within at least 5 years.

Two different capacity ranges are defined, one to answer the research questions related to stakeholders' opinions and one for evaluation of system design factors. Due to varying level of knowledge of pico and micro hydro the interviews cover opinions of systems up to 1 MW. It should be kept in mind that systems with a capacity this high differs significantly from pico systems, but since many respondents do not have personal knowledge of smaller systems, their opinions on larger sizes are still considered relevant. The second range is defined as 3 kW/50 kW based on the capacity of turbines currently manufactured in Mozambique.

The environmental aspects will not be in focus in this report. No conclusions will be based on environmental issues related to pico and micro hydro, since they are considered small (Penche, 1998/2004). Entities considered to be stakeholders are FUNAE, EdM, Ministry of Energy, donors, NGOs, private sector actors and consumers of electricity.

The report is divided into eight chapters. The *background* chapter gives an overview of known benefits of rural electrification from a hydro energy perspective. It presents examples of how pico and micro hydropower have been used as a means for rural electrification in other developing countries. Given this the power sector of Mozambique is described. The *Theory* chapter gives a thorough description on the pico and micro hydropower technology. It also gives a summary and definition of themes of barriers to development of pico and micro hydro.

The *method* chapter of this report is explained in Chapter 4. The method used to answer the first two research questions is a qualitative analysis based on semi-structured open ended interviews with stakeholders in the pico and micro hydro sector and visits to hydropower stations in Manica province, Mozambique.

The third research question is answered by designing a mathematical model based on input data collected during the literature analysis and the field trip. The topographical and hydrological data consists of 17 sites in Manica province, with measurements of head and flow, and precipitation curves from the meteorological institute of Mozambique. The modeling of the technological and resource potential focuses on turbine designs. Additional electromechanical equipment and civil works are not in focus in this report. The technological data are collected from a turbine manufacturer in Manica province, and from literature examples of head ranges and efficiency curves for the turbine designs. The two turbine alternatives in the model differ in both size and function. The demographical data is modeled using examples from literature.

The interview analysis has provided an understanding of what type of data can be expected to find, and what estimations normally have to be made, concerning for example hydrology data. One of the field surveys has set an example of a hydropowered community, to compare with findings from the simulations.

The *results* section presents the results of the method, followed by an *analysis*. Then follows a *discussion* part. Finally, *conclusions* are made in Chapter 8.

Chapter 2

Background

This section gives an overview of known benefits of rural electrification from a hydro energy perspective. It presents examples of how pico and micro hydropower have been used as a means for rural electrification in other developing countries and what experience can be gained from these examples. Given this, the power sector of Mozambique is described; how the history of Mozambique has influenced the power sector, the development of today's power sector and the micro hydropower scene in Mozambique.

2.1 Benefits of rural electrification

Access to modern energy is considered crucial for economic development and world poverty reduction (WB, 2009) and in 2011, approximately 1.4 billion people lack access to electricity, mainly in rural areas in the least developed countries (WB, 2008). In Sub-Saharan Africa the situation is critical with less than 10 % of the rural population having access to electricity. It has been proved that social benefits are generated by access to electricity (Gustavsson 2007; WB 2008) even though access in itself is not necessarily said to generate economic growth and social development. More likely it is an important step stone to improve social services such as health care and education by improving opportunities for lighting, water treatment, storage, refrigeration and communication (UNDP, 2011). For rural electrification to generate economic growth it has been argued that productive use of electricity and complementary rural development investments are necessary (Barnes and Floor 1996; Holland et al. 2001). All this indicates the need for a certain level of development in an area for rural electrification to lead to development benefits. If other demands like access to fresh water, infrastructure and sanitation are more urgent electrification is likely to get down prioritized.

2.2 Pico and micro hydropower development in Asia and Africa

Pico and micro hydropower have been used as a means to electrify remote areas in different parts of the world. Today, the largest market for pico hydropower systems is found in Vietnam and China (Meier and Fischer, 2011) where the most common designs are low-head pico hydropower systems in the range 100-1000 Watts. They are typically family owned providing domestic lighting and battery charging (Paish and Green, 2001). The market is characterized by use of low quality equipment manufactured in China with low up-front cost making it easier for private owners to afford, but reducing the life time of the system (Meier and Fischer, 2011). Other countries manufacturing and having installed low head pico hydropower systems are Nepal, Bolivia, Colombia, Peru, India, Sri Lanka, Laos and Indonesia.

In Nepal, the market has grown in the past few years. Case studies in Nepal and Kenya have identified pico hydropower as having good potential because of its relatively low capital cost and flexible power production (Williams et al. 2009). Today, the usage in both countries has expanded to include commercial projects. The studies have shown that pico hydro is usually the lowest cost option for off-grid rural electrification though the site specific design remains a major drawback (Williams et al., 2009). In Tanzania, mini and small hydropower stations were developed to supply power to missionaries' centers during the pre-independence era (Mtalo, 2005).

A working paper from the agency IRENA (IRENA, 2012b) presents a cost analysis for hydropower. The cost range for small hydropower projects is stated as 1 300 - 8 000 USD/kW, with no clear definition of small hydropower, since this differs between countries. Examples from South Africa, Rwanda and

Ethiopia of hydropower smaller than 1 MW cost between 3 400 and 4 500 USD/kW, with one deviating value of 7 500 USD/kW. The World Bank Energy Unit states that pico hydropower is likely to be the lowest cost alternative out of the possible alternatives for off-grid electrification (WB, 2008). A collection of data on investment cost for 80 village electrification schemes in Indonesia shows a 5 kW system would be expected to cost around US$ 10,000 per kW, whereas a 25 kW system would be budgeted at US$ 4,000 per kW (Meier and Fischer, 2011).

Most pico and micro hydro projects implemented in developing countries are financed by foreign aid or by donor funds. A Rwandan case study has investigated private sector participation in micro hydro development and concluded that there exist more cost-effective and sustainable ways to implement micro hydropower projects than only using public funds (Pigaht and Plas, 2009). The case study in Kenya stated further capacity building as one of the prerequisites to ensure that the knowledge of micro hydropower becomes more widespread (Maher, 2003).

2.3 Mozambique - History and power sector development

Mozambique is situated on the south-eastern coast of Africa, sharing borders with South Africa and Swaziland in the south, Zimbabwe and Zambia in the west, Malawi and Tanzania in the north and the Indian Ocean to the east, see Figure 2.1 (Commonwealth of Nations, 2011) . The total land area of the

Figure 2.1: Map of Mozambique (Commonwealth of Nations, 2011).

country is 799,380 km^2 and it is divided into eleven provinces; Maputo, Maputo City, Gaza, Inhambane, Manica, Sofala, Zambézia, Tete, Nampula, Niassa and Cabo Delgado. The provinces are divided into 129 districts which are further divided into "Postos Administrativos" (Administrative Posts). The population of Mozambique is 23.9 millions with a population growth of 2% (WB, 2012).

2.3.1 History

Mozambique was colonized by Portugal in the sixteenth century. In 1975 the liberation movement succeeded and it gained its independence after a decade of fighting for independence. Connected to this, 90 % of the Portuguese left the country leaving gaps in skills and a decreased number of people with higher education (Commonwealth Yearbook, 2012). The following years the country was ruled with strong socialist ideals and soon after civil war broke out, ending in 1992. During the civil war much of the social and economic infrastructure built up during the pre-independency era was destroyed and more than 1 million people were killed.

Since the end of the civil war Mozambique has experienced a more stable political situation with democratic elections, and infrastructure has slowly been re-built (Gaul et al., 2010; EdM, 2007). Despite a high economic growth rate in the past years, the poverty level in Mozambique is high. With 54.7% of the population living below the poverty line (World Bank, 2008) and the country being ranked as 184 out of 187 on the Human Development Index (UNDP, 2011a) it is indicated that the vast majority of the Mozambicans remains poor. The economy of Mozambique is mainly dependent on agriculture. Traditional exports include aluminum, prawns and other marine products, tobacco and cotton. Electricity from the Cahora Bassa hydropower station is also exported. Recently found large reserves of natural gas and coal, have driven a strong economic growth (Commonwealth of Nations, 2011).

2.3.2 Power sector development

Today, most of the electricity generated in Mozambique comes from the privately owned hydropower station Cahora Bassa situated in Tete province in the north-west. The power station is owned by Hidroelectrica de Cahora Bassa, HCB. Electricidade de Moçambique , EdM, is the national utility responsible for transmission, distribution and supply of electricity. Since EdM has low installed power generation capacity of its own it buys most of the electricity from HCB. EdM has developed an electrification master plan focusing on extending the national grid with a goal of national access to electricity of 20% by 2020 (EdM, 2007). Extensive work has been done to connect all district capitals in the country, a goal which is soon reached (EdM, 2010). The growth rate in electricity demand is estimated to 7% and in 2012 national access to electricity was 16 % of the total population (EdM, 2010). However, despite the progress in extending the national grid, the large rural areas of the country remain out of reach for national grid extension for many years to come.

2.3.3 Rural electrification in Mozambique

The low access to electricity is partly due to the geography of Mozambique making it troublesome to reach remote areas. Many periurban and rural areas lie out of reach of the national grid (MoE, 2011) and the rural electrification rate is as low as 6.3 % (Gaul et al., 2010). Even though the national grid will be extended over time, large parts of the country will stay unconnected in a foreseeable future. Considering the fact that the population density is low and more than 60 % of the population live in rural areas (WB, 2012) transmission and distribution of electricity are major challenges for the country.

To address the challenge of giving access to electricity to rural areas FUNAE, Fundo National de Energia, was established in 1997. FUNAE is an energy fund whose objective is to promote, fund and implement low-cost energy supply to poorer rural areas and to promote renewable energy technologies and sustainable management of energy resources (FUNAE, 2012c).

The governmental institutions agree that a combination of national grid extension and off-grid electrification is necessary to increase the access to electricity in remote areas. In 2011, the Ministry of Energy developed a Strategy for new and renewable energy development (EDENR) stating that "Supplying power through isolated systems will continue to be of great socioeconomic and political importance in Mozambique, particularly in the country's periurban and vast rural areas." (MoE, 2011,6). In earlier off-grid rural electrification programmes launched by FUNAE focus have mainly been on solar PVs and diesel generator sets. Only recently has micro hydropower been included as a means for off-grid electrification. The new strategy emphasizes the use of renewable energy sources and states as one of the assumption valid for the period of which the strategy has been defined: "Supplying power through isolated systems combines renewable and nonrenewable energy technologies, including traditional biomass-based energy systems and high-quality renewable energy systems. Whenever possible, these systems give preference to renewable over nonrenewable sources." (MoE, 2011,6). The electricity tariffs for FUNAE's off-grid systems in rural communities are set at the same level as tariffs on the main grid, thereby providing a social service (IRENA, 2012a).

2.3.4 Pico and micro hydropower in Mozambique

Mozambique is said to have significant hydro resources both for large scale on-grid application and small scale off-grid application (IRENA, 2012a; Gaul et al., 2010; Chambal, 2010; MoE, 2011). The country has a long tradition of using hydropower, with the Cahora Bassa station being built in the 1970s, though the focus has been mainly on large scale stations (FUNAE, 2012a).

Concerning off-grid use of hydropower, remainders of water mills can be found in the central parts of the country telling about historical use of water power mainly to run grinding mills. Water mills are also said to have played a part in providing power to tea plantations in Gurué district in Zambézia province before the civil war (Chambal, 2010). Still, comparing these activities to those of other Sub-Saharan countries like Rwanda and Kenya, the knowledge and experience of pico and micro hydro in Mozambique has been built up during a shorter period of time. Rwandan development is also at an early stage but the level of experience has increased during the past years (Meier and Fischer, 2011) and commercial projects already exist in Kenya (Williams, 2009).

Today, there are four main actors on the pico and micro hydro scene in Mozambique. These are FUNAE, a local NGO, AKSM (Associaçao Kwaedza Simukai Manica), an international NGO, Practical Action, and a private actor, GIZ. FUNAE recently shifted some of their focus for rural electrification from solar PVs towards hydropower. So far, FUNAE does not have any hydropower stations running. They have projects initiated and the upcoming plan is to establish 11 hydropower stations in the range 20 kW-200 kW mainly in Niassa province until 2015 (FUNAE, 2012b). The guidelines of FUNAE's Renewable Energy Program for Rural Development advises a maximum investment cost of 10 € per installed watt (FUNAE, 2012b). The aim of the Government of Mozambique is to double their capacity of small hydro (stations with a capacity up to 10 MW) to 125 MW by 2025 (FUNAE, 2012a). One of the first pico and micro hydro projects in Mozambique was launched by the Manica provincial government and funded by GIZ, in 2006. The 80 kW station was unsuccessful due to insufficient feasibility studies and mismanagement and was rebuilt in 2011.

Practical Action started a five year micro hydro program in 2008 including 15 sites in Mozambique, Malawi and Zimbabwe, where eight of the stations are found in Mozambique. GIZ started a longer project in the Manica province the same year. Both entities launch systems in cooperation with AKSM and are financed by foreign aid and donor money.

There is no reliable data on flow measurements and no database of potential sites for micro and pico hydro, in Mozambique (Gaul et al., 2010). To change this, and to facilitate the development of hydropower, a FUNAE project has been launched on extensive data collection to assess the hydroelectric potential and create a hydro atlas for pico, micro and mini scale finishing in 2014. Meanwhile, potential sites are identified by all involved actors separately through data collection and yearly flow measurements (Gaul et al., 2010). Old water mills point out sites with potential, sites which were used as a starting point for both GIZ and Practical Action.

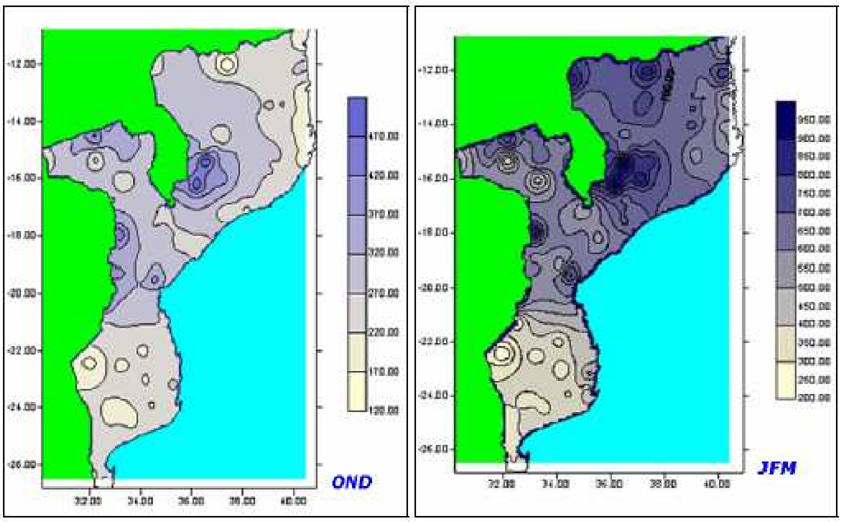

Figure 2.2: Typical precipitation during dry season (October to December) and rainy season (January to March) in mm (INAM, 2012).

Most of the existing pico and micro hydro stations in Mozambique are situated in Manica province on the mountainous western border to Zimbabwe. This is due to the favorable topographical conditions. Mountainous terrain and perennial rivers are found in central and northern provinces Manica, Tete and Niassa and to some extent in Zambézia province (Chambal, 2010). The annual average precipitation varies from over 1000 mm in Northern Mozambique to about 500 mm in the Southern parts, see Figure 2.2 (INAM, 2012). There are also variations in rainfall level within the year with 60-80 % of the total annual precipitation in the period December to March (WB, 2007).

Chapter 3

Theory

The theoretical chapter deals firstly with a brief technical overview of pico and micro hydropower, from the river to the power lines. The electromechanical equipment is introduced and the two different modeled turbines are described. Second, barriers to pico and micro hydropower found in literature are presented. Country specific factors which affect the magnitude of certain barriers are described for the Mozambican case. These are ownership models in use, existing payment systems and demography. The ownership models in use in Mozambique are described. Following this is an explanation of how demography plays a role in selecting sites and its influence on investment costs, followed by a section on existing payment systems.

3.1 Pico and micro hydropower

The basic principle of pico and micro hydropower is utilizing the power of falling water. When water is transported from one point to another, the kinetic energy is lost against rocks and vegetation or through turbulence. In a hydropower system the water is directed into a canal, tunnel or pipe with low friction, designed to induce low level of turbulence. With as little loss in energy as possible, the water is led into the power station and into the turbine, which converts the kinetic energy into rotational energy. The water is thereafter returned to the river or used for additional uses e.g. irrigation (Penche, 1998/2004).

The power converted between the two points A and B, in Figure 3.1 (British Hydro, 2004) is expressed by Equation 3.1 (Penche 1998/2004; Williamsson, 2012).

$$P = p \cdot Q \cdot g \cdot H_g \tag{3.1}$$

$P - Power\, capacity\, [kW]$

$p - Specific\, density\, of\, water\, [1000\, kg/m^3]$

$Q - Flow\, [m^3/s]$

$g - Gravity\, constant\, [9.82\, m/s^2]$

$H_g - Gross\, head\, [m]$

The gross head is simply the difference in height between the two points. For more precise calculations when more is known about the way the water is led from the river, all energy losses from friction in curves, joints or valves in pipes, or unevenness in canals, are subtracted to express the useful "net head". Designing the system so that the net head is as high as possible is of high importance for the capacity of the power station.

While the head level is constant, the water flow can vary substantially over the year. The choice of turbine has to be considered carefully using a flow duration curve. Such a curve is produced from measurements taken throughout at least a year and describes the percentage of time where the flow exceeds certain values. Since the turbines are designed for a specific range of flows it is very useful to know if there will be periods where the flow is too low to produce electricity with the selected turbine. A too high level of flow may indicate a risk of flooding.

If there are periods when the flow is too low, this can be helped by adding a dam to preserve the excess water during high flow periods. For larger hydropower stations the outlet of this dam is regulated

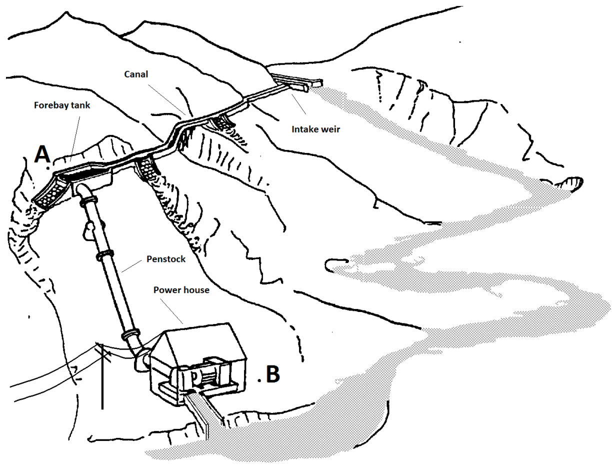

Figure 3.1: A run-of-the-river pico hydropower station (British Hydro, 2004).

for best performance. In smaller systems the design is often of a "run of the river" type which means that there is no regulation of the outlet, if there is a dam at all. (Penche, 1998/2004)

3.1.1 Hydropower equipment

The equipment needed in a pico or micro hydropower station of a run-of-river type, is illustrated in Figure 3.1. The intake weir is where the water is directed into the canal. Depending on where the intake weir is situated in relation to the rest of the system, the water could be led horizontally in a canal to the forebay tank. In the forebay tank, the water is slowed down. This allows particles in the water to settle out, not to damage the turbine. There can be a short storage of water in the forebay tank, to regulate the flow. There is also usually a rack which protects the turbine from stones, seeds and larger objects (a trash rack). The water transports the water from the forebay tank to the power house, in a pressure pipe called penstock (British Hydro, 2004). The penstock must have valves to regulate the flow, and to shut the water off if needed (Penche, 1998/2004). The number of joints in the penstock decreases the net head and lowers the possible output capacity of the system.

The turbine is located in the power house, together with the generator and possible gears and load controller. After passing through the turbine, the water is discharged and led back into the river or to some other application, like irrigation. (British Hydro, 2004)

3.2 Electro-mechanical equipment

Different types of turbines, generators and control equipment that are used in pico and micro hydropower schemes are presented in this section.

3.2.1 Turbines

A water turbine is a device that converts the kinetic energy of falling water into mechanical energy, more specifically rotation of a turbine shaft. The rotational energy can be used for mechanical purposes, like milling or grinding, or be connected to a electric power generator. Turbines can be classified by their head range, as low head, medium head or high head turbines. They are also defined by their way of operating, then as impulse turbines or reaction turbines.

The impulse turbines are driven by one or several jets of water, impacting on the turbine blades. The reaction turbines are immersed in water, utilizing the pressure difference to create a lifting force on the runner blades, causing them to rotate.

Two impulse turbine designs will be presented here. These are "Pelton" and "Crossflow" turbines. One of the advantages of impulse turbines compared to other types, is for example the simplicity of the design, which makes it easier to manufacture and maintain and gives better access to spare parts. The turbines are less sensitive to sand or seeds in the water and if the head is within the efficiency range, the flow can vary without loosing too much efficiency.

The torque generation mechanism for impulse turbines occurs when a water jet with a certain velocity exerts a force on the turbine blades or cups, producing a torque. The rotational speed of the turbine is given by the velocity of the incoming water. The law for conservation of energy gives that the velocity of the water jet can be expressed as $v = \sqrt{2 \cdot g \cdot H}$ where H is the gross head, not including energy losses in friction or turbulence. If the head is too low, this will slow the rotational speed which lowers the usability of the turbine (Williamsson et al, 2012).

The low speed of the turbine, due to insufficient head, can be helped with a gear box. The additional cost of the gear box has to be balanced with the cost for the system, and the efficiency of the gear box would have to be taken into account (Jonker Klunne, 2012a). A low speed generator is another solution to be used at low head sites (Williamsson et al, 2012).

Pelton turbine

Pelton turbines are usually selected for high head sites. For large scale systems the head should normally be above 150 m, but for pico and micro applications the head range can extend as low as 20 m. (Jonker Klunne, 2012b)

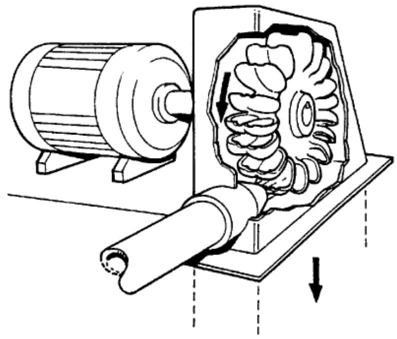

Figure 3.2: Pelton wheel (British hydro, 2004).

The cups of a Pelton turbine are situated at the periphery of a circular disc with the water jet striking them from one or several nozzles at 165 degrees, causing the disc to rotate. It can be fitted horizontally or vertically depending on the application. Figure 3.2 shows a Pelton turbine. The introduction of several jets to the Pelton design (multi-jet Pelton), in the case of a low head but high flow sites, increases the speed and also presents an advantage in the ability to use a reduced number of jets when the flow is lower (Jonker Klunne, 2012b).

Crossflow turbine

A Crossflow turbine is considered more suitable for low head sites than the Pelton, since it can be run at higher speeds with less flow. The minimum head required is as low as 3 m (Williamsson et al, 2012).

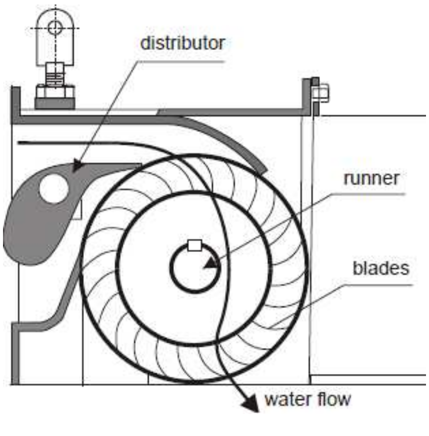

Figure 3.3: Crossflow – microhydropower.net

The blades of a Crossflow turbine are curved, connecting two circular discs to create a runner in a cylinder shape (Figure 3.3). The runner is always used horizontally with the water jet coming from a rectangular nozzle as wide as the runner itself. The water jet flows through the full length of the runner, striking the blades both as it enters and exits (Jonker Klunne, 2012b).

Part flow efficiency

A turbine is designed for a certain water flow. This is called the rated flow. Figure 3.4 shows typical efficiency curves at different part-flows for the Pelton and Crossflow turbine, among other designs. The efficiency is a function of the flow to rated flow ratio (British hydro, 2004).

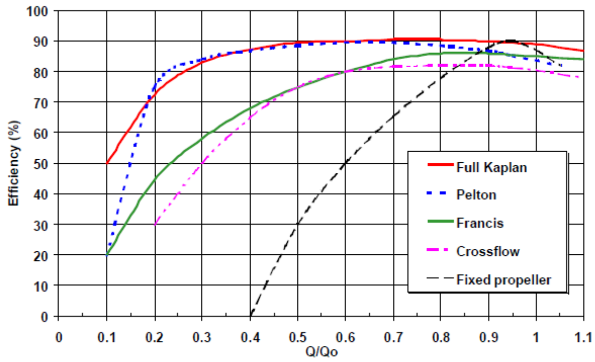

Figure 3.4: Efficiency at part flow, for various turbine designs.

When the rated flow of the turbine is not met, the efficiency of the turbine decreases. Both the Pelton and the Cross-flow can be designed to perform better when the flow is below the rated flow. For Pelton, the design is called "multi-jet" and is based on adding nozzles to the turbine. When the nozzles cannot be supported with rated flow, the turbine can be run on a reduced number of jets. This means that the nozzles still in use still could produce jets at rated flow.

For the Crossflow, adjusting the water jet through the turbine by separating the nozzle in divisions, increases the efficiency at lower flows. By only using a part of the runner, as shown in Figure 3.5, the water jet can be maintained at rated flow, instead of loosing rotational speed in the runner.

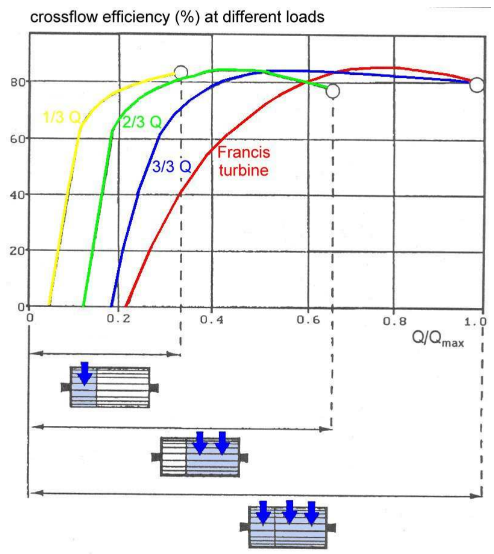

Figure 3.5: Cross flow efficiency – microhydropower.net

3.2.2 Generators

Generators transform the rotational energy from the turbines, to electrical energy, using electromagnetic circuits. The required magnetization is provided differently, depending on the type of generator. Synchronous generators use a magnetizing current provided by an excitation system, while induction generators are designed to obtain this current from the grid they are connected to, by using reactive power from other power sources in the grid. If there are no other power sources, or if the capacity of the induction machine is large compared to other power sources, the magnetization will not work (Penche, 1998/2004). In a guidebook from the European Small Hydropower Association, the author recommends to use induction generators for main grid connected schemes below 1 MW, due to the relatively low price. However, for off grid applications synchronous generators are preferable since they produce their own reactive power for excitation (Penche, 1998/2004).

There have been projects with induction generators in isolated grids, where excitation capacitors magnetize the circuit. In those cases, careful sizing of the capacitors is important (Ekanayake, 2002).

Frequency control

Electric applications are manufactured for a specific frequency. The generator produces this frequency if connected to a turbine rotating with the rated speed of the generator, or to gears if the rated speed of the turbine does not fit the generator (Penche, 1998/2004). For larger systems there is generally a hydraulic governor designed to regulate the flow into the turbine, and keep the speed of the turbine constant when the load varies (Ramakumar, 2001). However, the frequency can also be controlled by keeping a constant flow to the turbine and regulate the load of the generator, so that the turbine always experiences full load and the flow can be unaltered. Electronic Load Controllers (ELCs) use a dump load to regulate the load power. They have no moving parts and can therefore be a better alternative to hydraulic governors (Practical Action, 2002).

3.3 Barriers to pico and micro hydropower from literature

This section covers barriers to pico and micro hydropower present in scientific literature. The selection and grouping of presented barriers is based on a conducted literature review, and the authors' own comprehension of implementing technology, from master studies in electric power engineering and industrial ecology. The barriers are presented in categories into themes in the same way as they are grouped in the methodology section, where themes are in italics. The themes are *Investment cost*, *Consumer prices*, *Availability*, *Suitability*, *Education and knowledge*, *Administration*, *Legislation*, *Infrastructure*, *Demand* and *Quality*. Ahlborg (2012) has identified barriers to rural electrification in sub-Saharan Africa from literature. This work has been used as a starting point to find relevant scientific literature. Some barriers are general for all kinds of off-grid electrification and are included since the topics are expected to be covered during interviews.

Few studies exist on barriers to pico and micro hydropower development in Africa. The Food and Agriculture Organization of the United Nations, FAO, listed key barriers hindering the development of small hydropower in Africa, as background material to a ministerial conference on water for agriculture and energy in Africa (FAO, 2008). Similarly, barriers to the dissemination of micro hydropower, gathered from interviews and reports, are stated in a report by former GTZ (Gaul et al., 2010). Finally, barriers to small hydropower in southern Africa are identified by Jonker Klunne (2012).

Barriers associated with the *investment cost* of a hydropower station are divided in two. First, the inability to suggest a pico and micro hydropower project due to high investment costs. If other technical solutions are less expensive funders are more likely to exclude pico and micro hydro in their funding programs (WB, 2008; Jonker Klunne, 2012a). This complication is mentioned for other types of renewable energy systems for rural electrification as well, like solar home systems and wind power systems (Alzola, 2009). Secondly, lack of motivation among investors. Experience from solar PV pilot projects in Zambia tells of difficulties to provide credits through financial institutes in rural areas (Ellegård et al., 2004). Banks are perceived as uninterested and lack local presence. Earlier studies have showed that the availability of financing can be low even though there are investors, due to lack of information and motivation among investors (Meier and Fischer, 2011). One of the main barriers to small hydropower according to FAO (2008) is the lack of incentives and motivation. It also states lack of private sector participation as a main barrier. Hankins (2008) states the introduction of feed-in tariffs[1] as a stimulus

[1] Feed-in tariffs regulate the minimum price at which a private operator can sell electricity to the national electricity

for investors to start off-grid micro-hydro projects in Kenya. Similar legislation changes has been made in Rwanda only this year (RURA, 2012).

Categorized as *consumer prices* barriers are barriers related to problems with paying for electricity, low ability and willingness to pay and problems with tariffs set too low to meet operational costs. Rural areas generally suffer from a higher poverty level than urban areas, where rural affordability for electricity will be limited to replacing amounts currently spent on other sources of energy like kerosene and batteries (EdM, 2007). The risk that the running cost exceeds the consumer's ability to pay can thus pose a barrier. As a way to make more people afford electricity, prices can be subsidized. When not done carefully, unreasonably low tariff levels that does not reflects the true cost of the service can lead to poor maintenance of the power station (Kirubi et al., 2009; Meier and Fischer, 2011). Furthermore, it is discussed that people living below a certain poverty level often have more urgent needs and thus lack willingness to get access to electricity and to pay for it. The willingness to pay for electricity competes with the willingness to pay for household needs like school fees, protein-rich food and fertilizers to improve farms (Murphy, 2001).

There are several aspects of *availability* as a barrier to technology development: Lack of available equipment, including both lack of local and international suppliers, and lack of available spare parts needed for maintenance. Maher (2003) sees improved availability of components as an important factor to create a demand for pico hydropower. Before the Ministerial Conference on Water for Agriculture and Energy in Africa held in Sirte (FAO, 2008, 10), "Lack of infrastructure in the design and manufacture of turbines, installation and operation" was stated as one of the main barriers to the development of pico and micro hydro. A barrier specifically associated with available suppliers can be high import duties hindering development by raising investment costs and introducing a difficulty to access equipment (Gaul et al., 2010).

Pico and micro hydropower are limited by site specific design requirements and seasonality in resources. The technology requires sites to have sufficient head and flow rates to be considered *suitable* and lack of year-round water supply can be a major barrier for the development of the technology (WB, 2008). The World Bank (2007) discusses the fact that most rivers origin inland in other countries. The water supply depends on activities up streams out of Mozambican country boundaries which increases the vulnerability. Another barrier concerning the suitability of pico and micro hydropower for a site, is that the technology requires building a local grid. Low population density means adding a high cost component for the grid per household, in the form of investment cost. Also, rivers situated far away from the community state a barrier as it requires longer transmission and maybe stepping up of the voltage. The distance to clients is also crucial to provide maintenance and arrange payments. This can be a problem specifically when the operator is a centrally situated company or governmental entity (Ellegård, 2004).

One barrier concerning *education and knowledge* dealt with in literature is the lack of local capacity to operate and maintain the hydropower stations (Gaul et al., 2010; FAO, 2008; Jonker Klunne, 2012a). Another barrier is the lack of technical expertise in the design process. Experience from Rwanda tells of poor plant designs done by informal techniques and improper calculations (Meier and Fischer, 2011). This leads to inefficient power stations. Lack of technical expertise also hinders during the data collection phase and finding suitable sites. The data collection itself and availability of a data base of hydrological data is crucial. Lack of a proper data base or lack of a strategy to create one are considered barriers by both FAO (2008), Jonker Klunne (2012) and a recent report by former GIZ (Gaul et al., 2010).

If knowledge of a technology exists in a country, information dissemination is important for people to share this knowledge. There needs to be education, university programs and possibilities to network. Experience from Rwanda and Kenya point out the importance of awareness campaigns (Meier and Fischer, 2011; Maher, 2003). FAO (2008, 10) states both "Lack of awareness" and "Lack of access to appropriate technologies pico, micro, mini and small hydropower. Networking, sharing of best practices and information dissemination through forums and conferences." as barriers.

Administration barriers comprise of time consuming administration, poor operation management and lack of cooperation between actors. Lack of joint venture, public and private sector partnership are presented as main barriers by FAO (2008). The choice of owner and operator of a power station is important for the sustainability of an electrification project in remote areas. Especially local involvement in the management of the power system is proposed as a critical issue (Alzola, 2009; Maher, 2003; Pigaht, 2009; Williams et al., 2009).

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grid.

Concerning *legislation*, laws supporting other technologies or lack of legislative frameworks can be barriers since project administration can get more time consuming and even hinder a project start. When regulation of pico and micro hydropower is only part of a broader regulatory framework for rural electrification in general, important aspects like access to water and water infrastructure are often not included (Jonker Klunne, 2012a). Furthermore, policies need to be up to date and there needs to be awareness of the legislative framework (Pigaht and Plas, 2009; Gaul et al., 2010).

Since pico and micro hydropower sites can be situated in remote areas the *infrastructure* and conditions of the roads are of great importance. If it is impossible to reach remote sites the site potential becomes unimportant. Reaching such locations can be extremely difficult for project staff and suppliers (WB, 2008). Accessing sites pose a barrier for several kinds of rural electrification (Kirubi et al., 2009).

A potential barrier is the risk of oversizing or undersizing the hydro station in relation to the *demand* and the capacity of the river. The system needs to be designed to meet the demand at the lowest resource availability from seasonal and daily resource variations which adds an extra cost to the project. This would mean excess power is generated during the other months for no use if no complementary load is found (WB, 2008). Pico and micro hydro are considered by the World Bank as good energy alternatives to supply productive use of electricity, but this requires activities of productive use in areas suitable for hydropower (WB, 2008). Over optimistic evaluations of the potential of local productive activities can lead to unsuccessful projects. The cost of a micro hydro system can, according to the World Bank, be justified if productive loads are large enough and can complement community electricity needs (WB, 2008).

Low *quality* of equipment is considered a barrier since low quality equipment is more likely to break down and have a shorter life time. Import of equipment is not always a guarantee to high quality (Ellegård et al., 2004). Low quality of equipment can make lack of infrastructure a more severe barrier since low quality equipment demands more frequent maintenance. Barriers connected to maintenance are also categorized as quality barriers in this report. Proper maintenance is important for sustainability of off-grid rural electrification projects (Maher, 2003). Case studies on renewable energy systems in Kenya have shown that training of local technicians is an important component (Alzola, 2009). Murphy (2001) states the need for technical skills and experience to maintain as a constraint for grid expansion as well as for solar home systems and bio gas systems for rural electrification.

This section has described barriers to pico and micro hydropower development. Some of the barriers depend highly on country specific factors like what ownership models are traditionally used in community projects, existing payment systems and the population density of a country. Different ownership models, payment models and the demography of Mozambique are described in the following sections to give better understanding of the specific conditions for Mozambique.

3.4 Ownership models

The barriers to pico and micro hydropower found during interviews show that the choice of ownership is important (Section 5.1.2). Three different ownership models exist for pico and micro hydropower projects; private shareholder model, institutional owner model and private owner model. In the shareholder model the power station is community owned through a committee. The more labor provided to the project by each community individual, the more shares in the power station is gained, and the profit is shared accordingly. What signifies the institutional owner model is that a school or a hospital includes the power station in their responsibilities. A private owner model is where there is an entrepreneur personally responsible for the power station, including the canal and the electromechanical equipment. In some cases the grid is donated to the community and not owned by the entrepreneur. In the private owner model the owner is responsible for maintenance, operation and collecting revenue from users. The private owner model is the most commonly used ownership used model in Mozambique for pico and micro hydropower projects.

3.5 Payment models

This section explains different ways of collecting revenue from customers using electricity. There are today three different payment systems available for a hydropower station in Mozambique: Flat rate system , monthly payment system and pre-payment system. In a flat rate system, the customer pays a fixed amount at the end of the month regardless of the amount of electricity used. The tariff is differentiated with social tariffs, household tariffs, farming tariffs and general tariffs. The flat rate system is the common system for off-grid pico and micro hydropower systems where the rate for domestic use is normally set to 200 MTS per month (approx. 7 USD). Some areas use monthly payment systems where electricity is paid for at the end of the month according to electricity usage. The prepaid system in Mozambique is called CREDELEC and was introduced in 1995 (EdM, 2012). The principle is to pay for electricity before using it by buying credits, similar to buying credits to a cellphone. It is today used for grid-connected customers in many parts of Mozambique though it is not implemented in any off-grid rural pico or micro hydropower projects.

3.6 Demography

The investment cost for electrification of a community depends partly on the remoteness of the community, the density of the households and the spatial pattern of the settlement design. Remoteness, in the sense of having few roads and towns in the vicinity, increases the cost for transportation of equipment. In areas where the population density is low, that often means long distances between households, which results in an increased cost for distribution cables. Figure 3.6 (MoE, 2009) shows how the population density differs geographically in Mozambique.

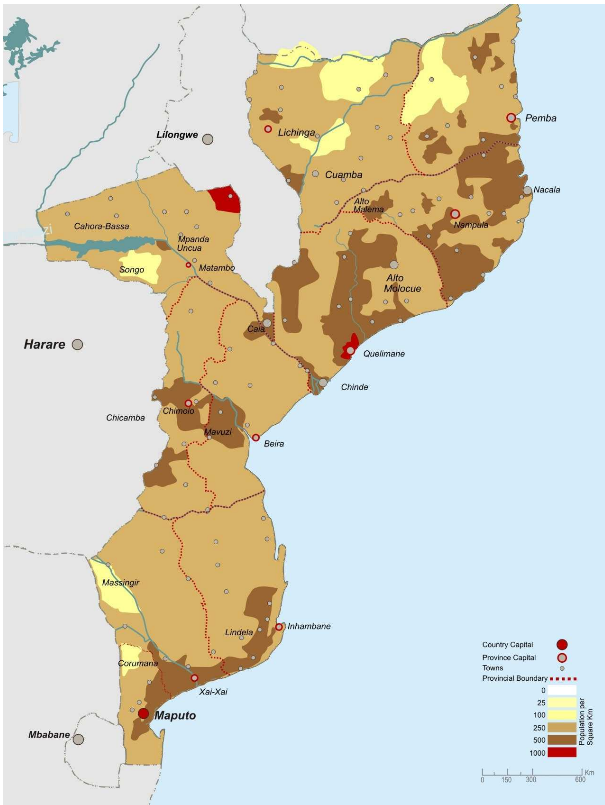


Figure 3.6: Population density (MoE, 2009).

The numbers presented in this figure are based on rural as well as urban areas in Mozambique, therefore it shows a comparison of different provinces and does not represent figures for rural population density (EdM, 2007).

The spatial pattern of the settlement design can cause increased cable length due to difficulties in the structure of the grid. An urban structure is preferred since cables can be used more efficiently. Figure 3.7 (EdM, 2007) shows four typical rural settlement patterns in Mozambique.

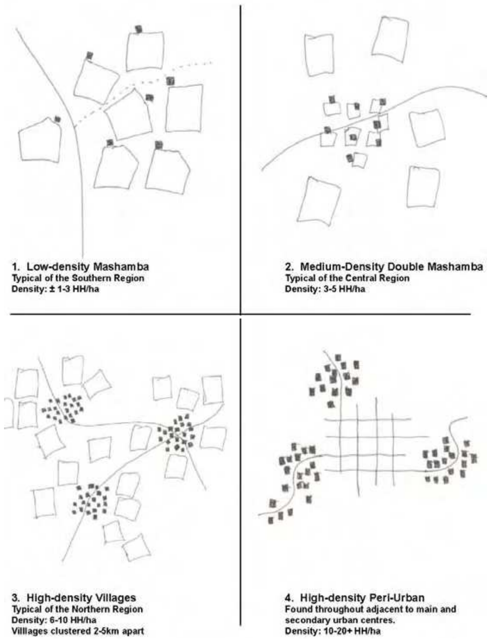


Figure 3.7: Typical rural settlement patterns (EdM, 2007).

Results in this report shows that low density structures in communities is one of the barriers to electrification. A higher density pattern is favourable according to interviews about off-grid electrification, and it is also what main grid extension projects favour, according to EdM (EdM, 2007). If the pattern is similar to the lower density examples the layout is considered inefficient for electrification or may require involuntary resettlement and loss of mashambas (personal farming land) (MoE, 2009).

Chapter 4

Method

This section describes the methods used for the study. It is divided into two parts; Method for analysis of stakeholders' opinions (Section 4.1) and method for analysis of technological and resource potential (Section 4.2). This is done in order to cover several aspects of the potential of pico and micro hydropower. In the following Results chapter the first part maps what barriers to pico and micro hydropower development stakeholders see based on conducted interviews. These results are then used to define how the evaluation of the potential based on geographical, technical and demographical factors is done. Important constraints brought up during the interviews have been selected and modeled to investigate how they influence the technological and resource potential in different areas of Mozambique.

4.1 Method for analysis of stakeholders' opinions

In development studies, interviews and documents are key sources (Mikkelsen, 1995/2005). The source of information for the research questions regarding stakeholders' opinions in this report is in the form of qualitative interviews. Semi-structured interviews with open ended questions were conducted to answer the question on what are the stakeholders' opinions on existing barriers to utilizing pico and micro hydropower in rural Mozambique and how to overcome them.

A qualitative semi-structured interview with open ended questions means a set of questions is predetermined, but is used as a flexible checklist and the respondent is allowed to talk around these questions. New questions can emerge during the interview. Also, the predetermined questions are adapted to the respondent's professional experience and his or her role. Strengths with this method are the possibility to keep the interview fairly conversational and that apparent gaps in the interview guide can be filled in during the interviews. However, it is important to remember that it may lead to topics not being covered by some respondents, reducing the comparability of the interviews (Mikkelsen, 2005).

4.1.1 Selection of interview topics

The selection of interview topics was based on the barriers found in current literature on pico and micro hydro. The topics were categorized into themes according to barrier themes found in literature; *Investment cost*, *Consumer prices*, *Availability*, *Suitability*, *Education and knowledge*, *Administration*, *Legislation*, *Infrastructure*, *Demand* and *Quality*. *Safety* was added as a theme even though no barriers found in literature were connected to the topic. If a technology is considered complicated or associated with *safety* risks, it could be less likely to be developed. A perception of the technology as high risk technology can be considered as a barrier. Another barrier concerning safety which was considered is the risk of flooding in areas suitable for pico and micro hydro. A small hydropower station is more sensitive to flooding and can more easily be flushed away.

Interview guide

An interview guide was created before the field trip based on the ten themes to facilitate conducting the interviews. Each theme was associated with five to ten questions to ensure the topics were covered. These questions were somewhat revised during the process. An example of a theme and its questions can be seen in Table 4.1.

Theme	Question
Education and knowledge	How widespread throughout the country is knowledge of small scale hydropower? (FUNAE, investors, contractors, consumers, EdM)

Table 4.1: Example of theme and questions.

In total the interview guide comprised of about 50 questions. The interview guide used for respondent FUNAE B can be found in Appendix A.

4.1.2 Selection of respondents

The respondents were selected as to cover as many stakeholder groups as possible associated with pico and hydropower development. The exact selection of respondents was made in Mozambique. Professor Boaventura Chongo Cuamba at the Eduardo Mondlane University in Maputo assisted in getting in contact with people working with pico and micro hydropower. Each interviewed respondent was asked for examples of people with influence on the development of the technology in order to find new respondents. Stakeholders were identified as governmental policy makers, the national electricity utility, the national energy fund, foreign aid representatives, NGOs, private sector actors and consumers of electricity.[1]

The list of respondents is presented in Table 4.2, sorted according to the location of respondents' work/activity. The experience of pico and micro hydropower of the individual respondent is presented, since this varies. The respondents experience of different power ranges for hydropower is stated for better understanding the analysis.

All interviews but five were recorded, with the permission of the respondents, and held in a semi-structured fashion with a prepared interview guide. The interview with Gov. ent. employee A was not recorded, as requested by the respondent. The interviews with the committee member and the power system owner were not conducted based on the interview guide, and the interviews with Gov. ent. employee C, and the manufacturer were not recorded and not conducted based on the interview guide. This was due to the circumstances at which the interviews were held. Some of the interviews were held while walking to sites, some were time limited, and some were only held to collect data for the modeling and did not require questions to the extent of the interview guide.

4.1.3 Conducting the interviews

The interviews were conducted during ten weeks (March to May) in 2012, in Mozambique. They were carried out at the respondent's place of work, at a nearby cafe, or during field trips.

18 interviews were conducted in total, where 15 were full length interviews and three of the interviews were shorter. Eight interviews were conducted in Maputo, eight in Manica province, in the central western parts of Mozambique, and two in Zimbabwe. A nonprofessional interpreter was used at four occasions and all interviews but three were recorded and transcribed afterward. All interviews were carried out with both authors present, with one asking question and one taking notes. The tasks were alternated between the authors. A presentation of findings so far was held before leaving Mozambique. All respondents were invited and encouraged to give input and correct possible misunderstandings.

[1] It would have been preferable to interview micro finance institutes as well as posto administrativos, but these were excluded due to lack of time.

Table 4.2: List of respondents. Location is where the respondent is situated, Respondent explains the respondent's role. The respondents will be named by their Abbreviation. Experience covers the respondent's experience of hydropower and Power range the range the respondent is supposed to have experience from.

Location	Respondent	Abbreviation	Experience	Power range
Maputo	National Directorate of New and Renewable Energy	NDRE	Governmental strategy documents.	< 80 kW.
	FUNAE	FUNAE A	Pre feasibility studies, feasibility studies, contact with donors, consultants and contractors.	< 1 MW
	EdM	EdM A	Studies of hydro schemes, worked with maintenance. Planning to start a consulting hydro power company.	500 kW – 1 MW (lower for the consulting company)
	International funding agency A	Donor A	Very limited experience of pico and micro hydro. Supported main grid extension.	< 1 MW
	International funding agency B	Donor B	Has been in contact with actors that want to establish with pico and micro hydro.	< 1 MW
	International governmental enterprise, employee A	Gov. ent. employee A	Economist working with pico and micro hydro power systems.	< 100 kW
	International consultants A & B	Consultants A & B	No experience of hydro, but of rural electrification in general.	< 1 MW
	International consultant C	Consultant C	Technical assistant in a hydro project with FUNAE.	< 1 MW
Chimoio	FUNAE	FUNAE B	Pre feasibility studies, feasibility studies, contact with donors, consultants and contrators.	< 1 MW
	EdM	EdM B	Experience of dams for large scale on grid hydro stations.	> 300 kW
	International governmental enterprise, employee B	Gov. ent. employee B	Technical engineer working with design of pico and micro hydro.	< 100 kW
	International governmental enterprise, employee C	Gov. ent. employee C	Technical engineer working with design of pico and micro hydro.	< 100 kW
	Local turbine manufacturer	Manufacturer	Electrical engineer, turbine assemblage.	< 50 kW
Manica Province	NGO	NGO A	Pico and micro hydro projects running in Manica Province. Executive director and technician.	< 50 kW
	Community committee member, Ndirire	Committee member	Committee member in a community with a running micro hydro system.	< 50 kW
	Power system owner, Chimukono	Power system owner	Owner of an unfinished micro hydro system in a community.	< 50 kW
Zimbabwe	NGO	NGO B	Pico and micro hydro systems running in both Manica Province and other countries. One technical engineer, one with social focus.	< 100 kW
	Rural District Council Office	RDCO	Engineer. Supporting communities with education and finance.	< 100 kW

4.1.4 Data condensation and analysis

The collected material was coded to facilitate analysis and interpretation of the data collected during interviews. The raw data was categorized into conceptual categories by coding it. Basically, a code is one or a few words that captures the content of a longer sentence or paragraph. A code should capture the meaning of what is said or the topic that is discussed. The codes were based on the predefined themes but extended by new codes when new topics came up during the interviews (Mikkelsen, 2005). First, the data was coded with a broader aim of providing an overview of the respondents' general opinions on pico and micro hydro. An example of a piece of data with its code can be found in Appendix B. Based on the coding a matrix was constructed with the respondents as the headings and codes as rows with what each respondent said as the input.

Second, all coded data was searched for data relating to barriers. Third, the codes were grouped into themes for better comprehension. These themes differed slightly from the initial themes used to create the interview guide since new topics had emerge during the interviews and some topics had shown to be out of importance. The change from interview themes to new code based themes and the associated barriers can be seen in Table 4.3, 4.4 and 4.5.

Table 4.3: Technical aspects. The transition from interview themes to code based themes and their associated barriers.

Technical aspects			
Interview theme	Barriers associated with interview theme	New theme based on codes	Barriers associated with new theme
Availability (suppliers, low power equipment)	Lack of access to spare parts High import duties	Availability of equipment	Low quality of local products High import duties Limited rural infrastructure Lack of access to spare parts
Quality (need for maintenance)	Lack of proper maintenance	Design	Poor design Lack of proper maintenance Scattered population in communities
Safety (electrocution, flooding, equipment protection)	-		
Suitability (topography and weather, village structure)	Lack of adequate data and measurements Lack of water resources Scattered population in communities Poor design Competing resource use	Data and measurements	Lack of adequate data and measurements
		Resources	Lack of water resources Competing resource use Long distance transmission

Table 4.4: Economic aspects. The transition from interview themes to code based themes and their associated barriers.

Economic aspects			
Interview theme	Barriers associated with interview theme	New theme based on codes	Barriers associated with new theme
Investments (investors' interest, district funds)	Lack of access to finance High investment cost Lack of investor interest	Finance	Lack of access to finance High investment cost Lack of investor interest
Consumer prices (willingness to pay, local financing)	Low willingness and ability to pay Lack of local contribution	Payment	Low willingness and ability to pay Poor payment management

Table 4.5: Social aspects. The transition from interview themes to code based themes and their associated barriers.

<table>
<tr><th colspan="4">Social aspects</th></tr>
<tr><th>Interview theme</th><th>Barriers associated with interview theme</th><th>New theme based on codes</th><th>Barriers associated with new theme</th></tr>
<tr><td>Education (technical schools, technical expertise, local capacity, information, motivation)</td><td>Poor knowledge management
Lack of technical expertise
Low quality of local products
Lack of local involvement
Lack of awareness of technology</td><td>Knowledge and education</td><td>Lack of awareness of technology
Lack of technical expertise
Poor knowledge management</td></tr>
<tr><td rowspan="2">Administration (project structure, operation management)</td><td rowspan="2">Poor project administration
Poor payment management
Time consuming processes
Community relations hinder power station management</td><td>Project administration</td><td>Poor project administration
Time consuming process</td></tr>
<tr><td>Community relations</td><td>Lack of local involvement
Community relations hinder power station management</td></tr>
<tr><td>Legislation (land permits, by-laws)</td><td>Too low electricity price

Lack of supporting legislation
Lack of grid code and feed-in tariffs</td><td>Legislation</td><td>Too low electricity price
Lack of supporting legislation
Lack of grid code and feed-in tariffs</td></tr>
<tr><td>Infrastructure (transport, distance operation)</td><td>Limited rural infrastructure
Long distance transmission</td><td colspan="2"></td></tr>
<tr><td>Demand (productive use)</td><td>Low demand and low level of productive use
Difficulties sizing systems</td><td>Demand</td><td>Low demand and low level of productive use
Difficulties sizing systems</td></tr>
</table>

A revised matrix was constructed with the final barriers as rows, grouped according to the new themes, and respondents as columns. The same procedure was repeated to construct a matrix to answer the research question: "What are the stakeholders' opinions on the possibility to overcome these barriers?" A matrix including both barriers and ways to overcome them can be found in Appendix E.

Further analysis was based on the matrices and the input data. When needed a review of raw data was made as to confirm a correct coding and to avoid information loss during the data condensation.

4.2 Method for analysis of technological and resource potential

A methodology which investigates how technological and resource potential varies with choice of system design and geographical conditions is necessary to answer research question three. As a first step, a literature study was performed to understand the basic functions of pico and micro hydropower systems. All parameters that could influence the suitability of a system design for a certain site were mapped and discussed. From literature and conducted interviews areas of importance for decision making where found to be: *reliability of water resources* to ensure continuous electricity supply throughout the year; the *introduction of a locally manufactured Crossflow turbine* to complement a Pelton turbine already being produced locally; the *installation cost* and the *sizing* of the hydropower system to meet the present and future demand. The third research question is answered based on how two factors, reliability of water resources and installation cost, influence the areas of importance, in four provinces in Mozambique. Figure 4.1 illustrates the choice of areas of importance and their origin in barrier themes.

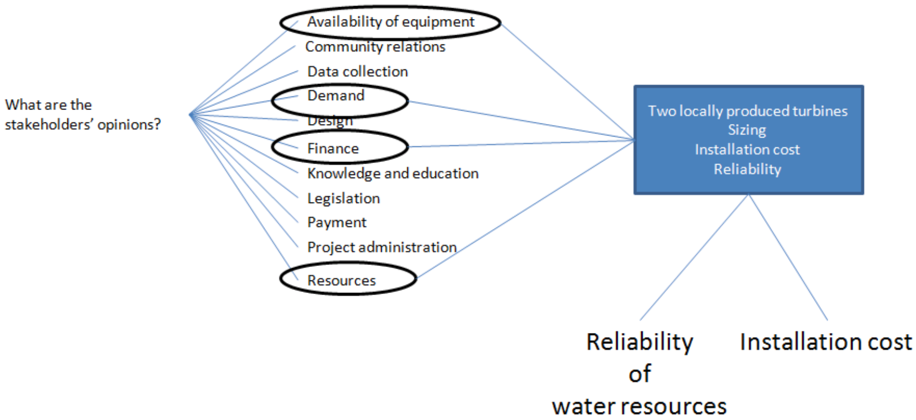


Figure 4.1: Areas of importance from barriers.

4.2.1 Data used in model

A selection of hydrological data, topographical data, precipitation data and other relevant data like equipment price information has been collected. The modeling of technological and resource potential is based on data from the NGO Associaçao Kwaedza Simukai Manica. Their database of possible sites in Manica in western Mozambique (AKSM, 2012), contains some measurements of head and average flow. For 17 of the sites there are measurements of both the head and average flow which can be found in Appendix D. These are used as examples for the model. Variations in flow are modeled using precipitation data in dekads[2] from meteorological measuring points in Manica, Niassa, Tete and Zambézia during the period 2007-2011 (INAM, 2012). The data used is the dekad average of the five year period. The load curves for different demand profiles are estimated from empirically collected data of power demand in rural communities in Tanzania (Blennow, 2004). Price of turbines used in cost calculations were retrieved from the local turbine manufacturer Metalúrgica in Manica, Manica province. Additional price information was collected during interviews and from pico and micro hydro projects carried out by Practical Action in Zimbabwe.

Data restrictions

The model structure was modified and adapted to the limited extent of data acquired. One method to analyze how variations of geographical conditions influence technological potential is to use a Geographical Information System, GIS. To do so, maps of essential data is crucial. If maps of population density, rivers, measurements of flow and head were available it would be possible to map and point out what areas are most suitable for different system designs. Measurements of yearly flow are required for at least

[2] A dekad is a ten-day period, where each calender month consists of three dekads. The first ten days constitutes the first dekad of the month. The second ten days of the month constitutes the second dekad, and the remaining days constitutes the third dekad.

a year as a part of each feasibility study for a possible site, and there is no general database to collect information of flows from, except the limited databases of NGOs and organizations, documenting their own measurements. In lack of detailed geographical data the geographical conditions would be modeled based on an extrapolation of site data from 17 sites in Manica province and no GIS has been used to process data.

4.2.2 Selection of designs

The two turbine designs compared in the model are selected because they are the only types that are manufactured locally in Manica province, Mozambique. One is the more common Pelton turbine, 50 kW, used in several schemes, and the other is the Crossflow turbine, 3 kW. The Crossflow has just recently been included in manufacturing. It is considered a complement to the Pelton due to its lower head range, suitable for terrains with limited head. The differences between the two designs are mainly the size, the price, the head range and the efficiency for different flows. It should be noted that Pelton turbines are manufactured in pico size as well. However, this design is not included in the study.

For larger hydropower systems, turbines are designed uniquely for each site. When implementing a pico or micro system, the cost of designing the turbine would be unreasonably high compared to the size of the system. Therefore, a lower efficiency must be tolerated. The turbine manufacturer in Chimoio has a limited amount of different turbine designs. To illustrate this the Pelton design and Crossflow design are estimated to have one single rated flow respectively, independent of site characteristics. The rated flow was calculated using Equation 3.1 with different levels of head, within the head interval of the 17 sites, to find a suitable value. The head level and corresponding rated flow resulting in high number of sites within head range of the turbines in combination with good system capacity were selected. The selected value for rated flow determines the lower boundary for the acceptable flow levels of the sites, since it affects the efficiency of the turbines. Turbines also have requirements on maximum and minimum head level to function. These intervals are selected based on specifications of a selection of available turbines (Chiaradia, 2008; Williamsson et al., 2012). Properties of the two turbines can be found in Table 4.6.

So far only synchronous generators are used in Mozambique. Since the generators are considered the same, the focus of this report is on the different turbines and therefore no generator properties are modeled.

Table 4.6: Turbine properties for the two turbine designs. Figures on price and capacity are taken from the local turbine manufacturer in Chimoio, Mozambique. Head range and rated flow figures are estimates based on literature and modeling.

	Crossflow	Pelton
Capacity $[kW]$	3	50
Maximum head$[m]$	40	80
Minimum head $[m]$	6	30
Rated flow $[l/s]$	30	200
Price$[USD]$	2000	4140

4.2.3 Field surveys

The field surveys comprised of visits to four hydropower schemes in Manica province in the western parts of Mozambique, bordering Zimbabwe. Experience and data collected during the visits have been used to justify estimates made in the model by setting examples of electricity use to base demand profiles on. The visits also helped in the selection of which turbines to model, and gave information on what safety equipment is used, what the difficulties can be, and how they are handled. Figure 4.2 shows pictures from the four visits.

The first visit made was to a potential site in Macate where measurement data of head and flow were collected. The community had a school, some smaller shops, but no healthcare center. Twelve houses were gathered around the school and the rest of the houses were very scattered.

The second site was situated in Chimukono, in Sussundenga district. The Chimukono site was nearly completed, where a 15 kW hydropower plant was planned. The construction was delayed because of financial problems and some design problems. The penstock was being relocated to assure the water could run through it properly. The intake was situated 700 m to 1 km from the powerhouse. The owner of the station explained the electricity would supply four shops, one school, a healthcare center, a restaurant and an administration office. It would also supply five street lights placed along the road.

(a) (b)

(c) (d)

Figure 4.2: Field surveys in Manica province. (a) Students doing measurements during the visit in Macate. (b) Power house and the first pole of the grid in Chimukono. (c) Hydropower scheme in Rotanda under construction. (d) The operator of the scheme in Ndirire.

The site in Rotanda, Sussundenga district, was a larger FUNAE owned hydropower station with a capacity of 630 kW. The community in connection to the site was today supplied with electricity imported from the Zimbabwean national grid, which meant a local grid already existed. However, an insecure financial and political situation in Zimbabwe had increased the need for local generation. This hydropower station was under construction. It was supposed to be completed at the time of visit, but was delayed by a conflict with the contractor. The current electricity demand was around 100 kW. The excess electricity supplied would be used by a local forestry company. In the same area a pico hydropower station was built to supply a shop and a restaurant. A water pump was used as a turbine which rendered significantly lower efficiency. To compensate this, higher flow is one solution, but the intake was placed downstream from the 630 kW site creating concerns that there was not enough water left.

The last visited site was the only one running, situated in Ndirire, Manica district. An old water wheel used to power a mill had been rehabilitated. The site now powered 80 households, two shops, and streetlights, with an output capacity of 27 kW. It had been running since 2010. The owner of the mill was also the owner of the electro-mechanical equipment, and the grid was owned by the community, organized by a committee. Parameters for the Ndirire power station are shown in Table 4.7 (Mutubuki-Makuyana, 2011). The number of households is based on the assumption that there are 8-10 people in every household.

Table 4.7: Parameters for hydropower station in Ndirire

Design capacity [kW]	Head [m]	Flow [l/s]	Investment cost [USD]	Beneficiaries [HH]
27	88	51	51 900	60-80

4.2.4 Modeling

The modeling is described from inputs to outputs, as straight forward as possible. Deeper explanations of some parts are described further on. The model was designed in MATLAB by MathWorks ™. The structure behind the model is presented in the flow chart in Figure 4.3.

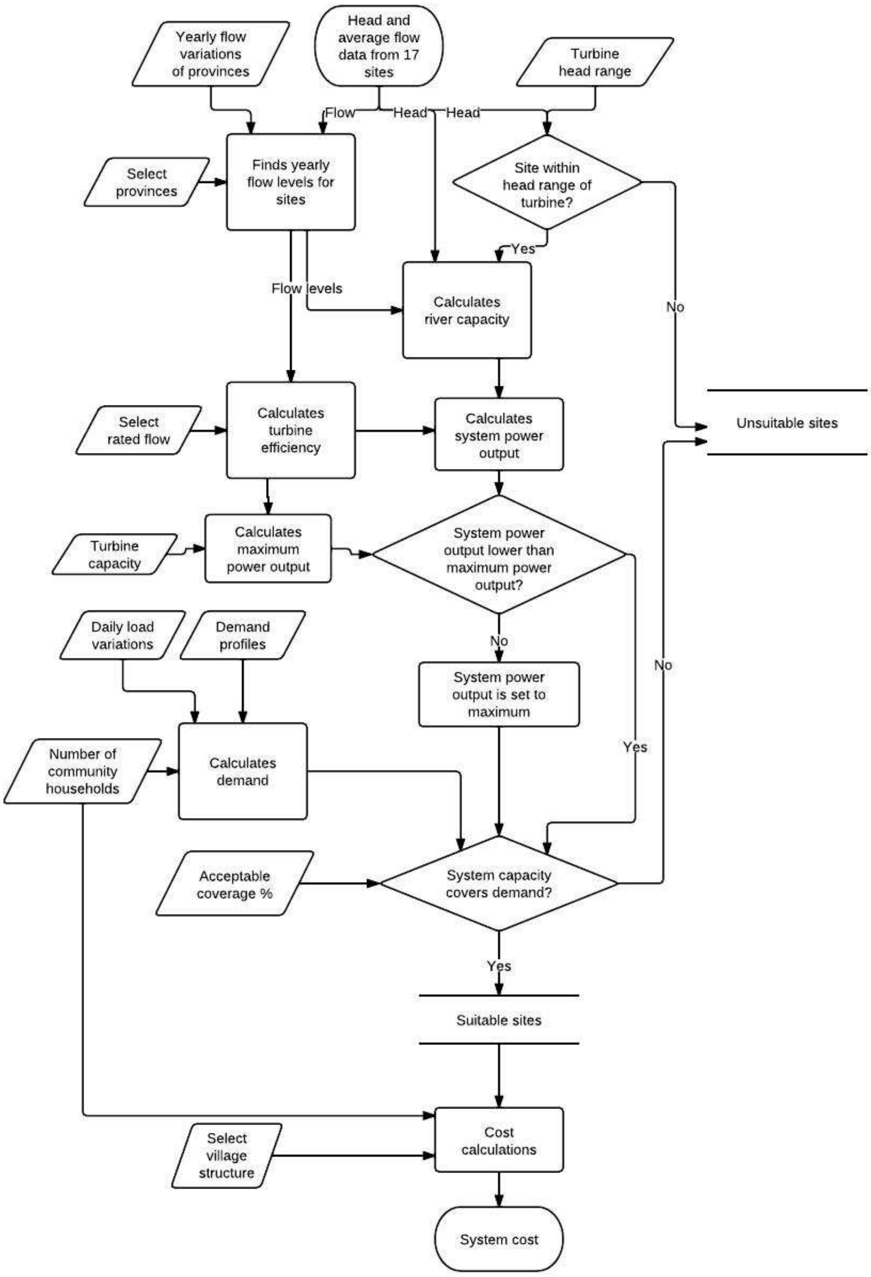


Figure 4.3: Flow chart of technological and resource potential model

The first inputs are head and average flow data from 17 sites in Manica province, yearly flow variations of Manica, Tete, Niassa and Zambézia province, and head range for the Pelton and the Crossflow turbine designs.

The head data of the 17 sites are checked against the stated head range from the turbine manufacturers. The sites where the head does not fall within the limits are defined as unsuitable during the rest of the simulation.

The yearly flow variations are based on precipitation data. Data from each province is normalized with the average precipitation to show only the variations in precipitation. When the precipitation is zero, this also sets the flow to zero, which does not well represent realistic situations in rivers. Therefore, all dekads with precipitation 0 mm were set to 1 mm. These variations are leveled with the average flow data from the 17 sites to form an estimated flow variation curve for each site. The flow variation curves for the 17 sites in Manica are presented in Appendix D.

The river capacity is calculated for the sites that are within the head range of at least one of the turbines. Inputs to this calculation are the head data from the 17 sites, defined as gross head, and the flow level for each dekad on the sites. The power capacity of the river is expressed by Equation 4.1 (Williamsson et al., 2011), an extended version of Equation 3.1.

$$P_{river} = p \cdot Q \cdot g \cdot L \cdot H_g \tag{4.1}$$

$$L = Net\,head\,factor\,[0.90]$$

A net head factor of 90 % was added to take into account the kinetic energy lost due to friction in the canal and penstock (Ajith Kumara et al., 2002, Renewables First, 2012).

The system power output is simply the river capacity , but where the turbine efficiency, η, has been considered, Equation 4.2.

$$P_{system} = \eta P_{river} \tag{4.2}$$

The turbine efficiency is a function of the ratio between flow and rated flow of the turbine (British hydro, 2004). Efficiency curves are shown in Figure 4.4 for the two turbine models used and for a Crossflow with divided nozzle. No studies have been carried out on the efficiency of the locally produced designs, so typical efficiency curves from literature are used. Taking into account complaints on the quality of the locally produced turbines it is likely that the real efficiency is lower than modeled.

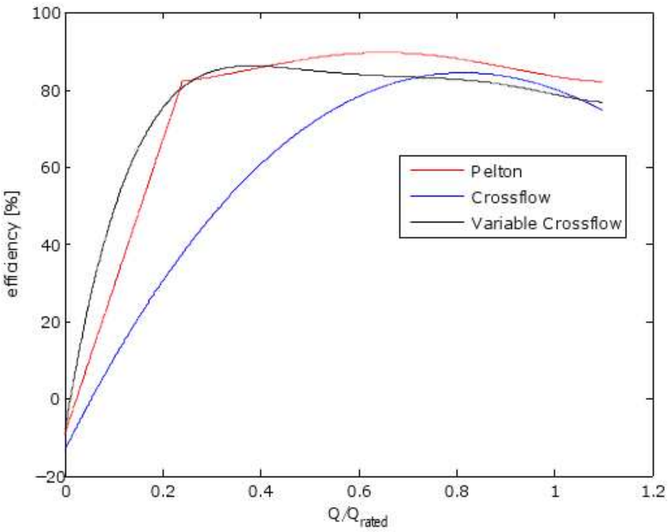


Figure 4.4: Turbine efficiency. The red curve shows the efficiency of a Pelton turbine, the blue curve shows the efficiency of a Crossflow turbine and the black curve shows the efficiency of a variable Crossflow.

In those cases where the calculated system power output exceeds the turbine capacity, the system power output is set to the maximum turbine output at the current efficiency level:

$$P_{system} = \eta P_{max,turbine} \tag{4.3}$$

Nine demand scenarios are compared against the calculated system power output to determine if the system power output is enough to suit a certain type of community. The nine demand scenarios are based on three load profiles with a selected number of households. Since the power demand in the load profiles describes the worst case demand at all times during the day, two variables control the acceptable demand coverage of the simulation. The first variable is *acceptable coverage level of demand*. It sets the percentage of maximum daily power demand covered to render an approved site. The maximum daily power demand is either during day or evening time depending on the number of households in the simulation. The second variable is *acceptable yearly coverage of demand.* It opens the possibility of accepting a site even though the demand is not completely covered during the dry season.

As a final step are installation costs calculated, after all sites have been evaluated as suitable or unsuitable to fit turbine designs and load profiles.

4.2.5 Load profiles

The load profiles created in the model are based on typical electrical applications, with corresponding power demand, that are used in communities in Tanzania. The applications are sorted as domestic use applications, such as light bulbs, radios and charging of cell phones; productive use applications as shops, grinding mills or welding devices; and public use applications, like schools, clinics, water pumps and street lights. Domestic use applications are aggregated into four levels of power demands: low, medium, middle and high (Blennow, 2004).

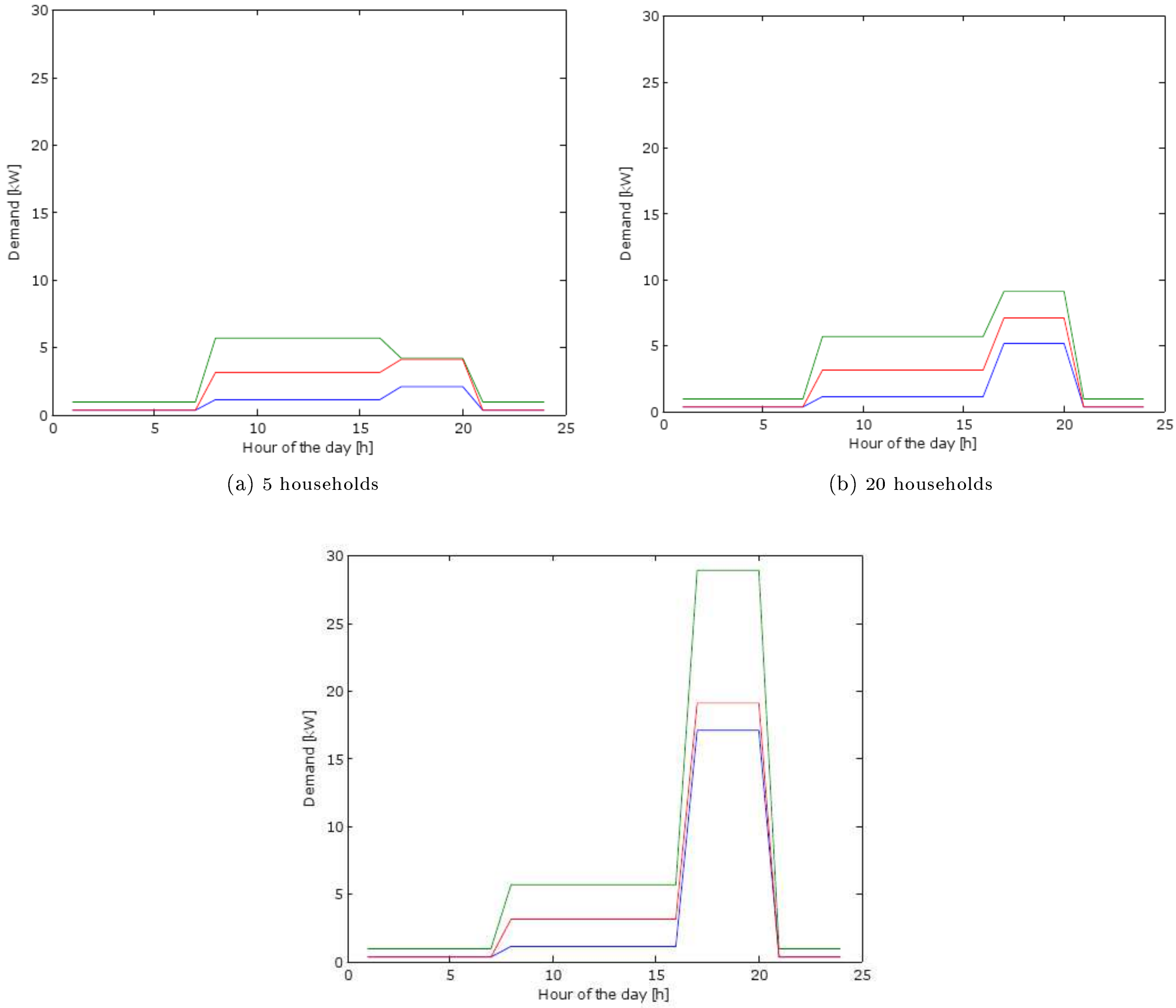
Three different community profiles are created, assumed as small, medium and large consumers of electricity. Applications from all usage groups are selected to the profiles. To facilitate analysis are nine demand scenarios created from the community profiles for 5, 20 and 80 households. The maximum demand level of the scenarios can be found in Table 4.8. A full presentation of the applications for all load profiles is in Appendix C.

Table 4.8: Maximum demand for a small, medium and large community profile for 5, 20 and 80 households.

No of households [HH]	Small [kW]	Medium [kW]	Large [kW]
5	2.1	4.1	5.7
20	5.1	7.1	9.1
80	17	19	29

The load demand is divided into day time, evening time and night time, to represent varying electricity use during the hours of the day. The electrical applications are sorted into these regions. Some applications, like households, are considered switched on during the evening, while most productive use was considered switched off.

The number of selected households does not influence the productive use or the public use applications, and therefore neither daytime or night time power demand. Figure 4.5 shows the three load profiles for a community of 5, 20 and 80 households.



(a) 5 households

(b) 20 households

(c) 80 households

Figure 4.5: Demand profiles for 5, 20 and 80 households. The blue, red and green curves represent small, medium and high demand profiles respectively.

4.2.6 Cost estimation

The installation cost of a hydropower station is estimated as a step in the evaluation of the technological and resource potential. The system includes civil works, penstock, electromechanical equipment, power grid and cost for household connections. Civil works comprises of building a canal, a power house and forebay tank. The calculations are based on two scenarios, one where the total cost for civil works is included and one where 50% of the cost is contributed by the community or the local operator. Local manpower is considered used in the community contribution case and does therefore not add a cost. Case studies in Zimbabwe show community contribution lowers costs of civil works with at least 25% (Mutubuki-Makuyana, 2011) and the operator of the Ndirire station had by himself built the canal and forebay tank, indicating this is a realistic assumption. Electromechanical equipment comprises the turbine, generator and controlling equipment. Gathered cost estimates are presented in Table 4.9. The figures are gathered from Mozambique as well as similar projects in Zimbabwe, Kenya, Nepal and Indonesia.

The cost for the power grid depends on the location of the river in relation to the community, and how scattered the people live. Mentioned in many interviews is the fact that people live very scattered. According to the local NGO a radius of 1 km from the power station is a normal limit for houses to be connected to the grid. The grid has been calculated in two ways.

A grid cost model, depending on number of households, is created with the purpose of giving a more likely scenario for the case of 1-10 connected households. It is not likely that the same amount of grid is

Table 4.9: Cost estimates. [1]Figures are from similar projects in Indonesia (Meier and Fischer, 2011). [2]Figures are from similar projects in Zimbabwe (Mutubuki-Makuyana, 2011) and Kenya (Maher, 2002). [3]Figures are from similar project in Nepal (Smith and Ranjitkar, 2000).[4]Electromechanical equipment comprises the turbine, generator and controlling equipment. All other figures are collected during the stay in Mozambique.

		Pelton [50 kW]		Crossflow [3 kW]	
		Price	Unit	Price	Unit
Civil works		94500[1]	USD	5670[1]	USD
Civil works	50% local contribution	47250[1]	USD	2840[1]	USD
Penstock	PVC	27[2]	USD/m	7[2]	USD/m
Electrical equipment[4]	Total cost	11070	USD	-	USD
Generator		-	USD	1134[1]	USD
ELC		-	USD	660[3]	USD
Turbine		-	USD	2000	USD
Power grid	Complete grid [4 km]	19680	USD	19680	USD
	Locally produced	4920	USD/km	4920	USD/km
Household connection	per household	228-320	USD/HH	228-320	USD/HH

used for 5 as for 80 households. Therefore, the grid length is modeled divided into three intervals, based on number of households. The distance from river to powerhouse is set to 1 km. The cost for 1 to 5 households is estimated as the cost of an initial cable length of 1 km and an additional 250 meters of grid per household. For 6 to 10 household, the initial length of grid is set to 1500 meters, adding 150 meters per household. Finally, for 11 to 100 households the total grid length, including river power house distance, is set to 4 km, corresponding to the standard cost of a grid stated by one of the respondents. At this point an increase of households is considered equivalent to an increase in house density and therefore no extra distribution cable is expected for each household.

Table 4.10 shows typical installation costs stated by a FUNAE employee, working closely with the international governmental entity GIZ. These costs are used as a comparison to the calculated installation cost. The cost of a FUNAE project is higher for a 50 kW system due to the obligation to tendering consultants and additional administrative costs.

Table 4.10: Data on investment costs from FUNAE employee.

	GIZ cost [USD]	FUNAE cost [USD]
Crossflow, 3 kW-system	8 800	-
Pelton, 50 kW-system	50 000	2 500 000

4.2.7 Extrapolation of data

Differences in precipitation in the provinces show Zambézia province have the highest amount of precipitation. Figure 4.6 shows precipitation normalized to the yearly variation in Manica province where Zambézia has a precipitation level above one, ten out of twelve months of the year. As an example Zambézia has a lowest monthly precipitation of 9 mm compared to Niassa where the lowest level is 3 mm.

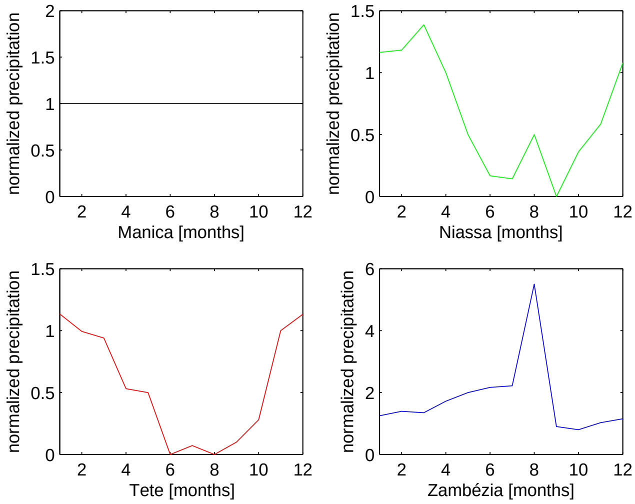


Figure 4.6: Yearly precipitation levels in Niassa, Tete and Zambézia provinces, normalized to the precipitation levels in Manica province.

Based on this, Tete and Niassa provinces are modeled with lower levels of flow, and Zambézia with higher levels, relative to the average flow in Manica province.

The head data for provinces other than Manica were estimated simply by adding a factor to the Manica head data, based on a topographical map. The estimation was also based on comments from respondents during the interviews, that Niassa and Zambézia have lower head levels than Manica. Chosen factors are presented in Table 4.11.

Table 4.11: Head factors used for extrapolation to Tete, Zambézia and Niassa provinces.

Province	Manica	Tete	Zambézia	Niassa
Head factor	1	1	0.7	0.5

4.2.8 Assumptions and limitations

The following is assumed in the modeling of the technical and resource potential of pico and micro hydropower in Mozambique:

- The 17 sites in Manica province can, in this thesis, represent the potential of Manica province.
- Head levels in Tete, Niassa and Zambézia provinces can be described by a factor of head levels in Manica province.
- Flow levels in Manica, Tete, Niassa and Zambézia provinces are directly linked to the levels of precipitation in the provinces.
- The turbines available are the Pelton turbine (50 kW) and the Crossflow turbine (3 kW).
- There is one single rated flow available for the Pelton turbine, and one for the Crossflow.
- All schemes at sites with head levels higher than the head range of a turbine, can be constructed to fit the rated head.

- All sites with head levels lower than the rated head for a turbine are considered unsuitable for schemes with that turbine.
- All schemes at sites with flow levels higher than the rated flow for a turbine, can be constructed to fit the rated flow.
- The electrical applications used in rural communities in Mozambique have a similar power demand as applications in rural communities in Tanzania.
- The installation costs of equipment from projects in countries other than Mozambique can represent Mozambican prices.
- Community labor can be voluntary or render shares in the schemes, therefore salaries are not included in the installation cost estimation.

4.2.9 Analysis

The results from the model calculations are shown in bar-diagrams to easily compare the power output from the different sites. The maximum power output guaranteed for 100%, 80% and 50% of the year is compared with the demand profiles to get an overview of the potential. This way of analyzing the results reflects the respondents interest in a continuous electricity supply.

The cost of the hydro schemes was evaluated as cost per household and cost per power output of the system in kW for sites with 5, 20 and 80 households. Since no estimate of the run time for electrical equipment was done, cost per kWh was excluded.

A sensitivity analysis was made to investigate how different input parameters influence the outcome from the model. The sensitivity analysis included analysis with a change of $\pm 10\%$ of head values, average flow values and spread of seasonal change in flow. The spread is altered by changing the flow data so that all data either approaches or recedes from the mean value, decreasing or increasing the spread.

Chapter 5

Results

All results from interviews and modeling are presented in this chapter. In the first section the identified barriers from interviews with stakeholders are presented in groups, together with the possible ways of overcoming barriers. This is followed by a presentation of the results from modeling the 17 sites in Manica.

5.1 Barriers to pico and micro hydropower from interviews

Barriers to pico and micro hydropower development have been mapped based on stakeholders' opinions. They are presented grouped in themes. A detailed description of the origin of the barriers in initial themes can be found in the methodology section. For each theme, the barriers are followed by possible ways to overcome them, suggested by stakeholders. The groups of barriers are illustrated with tables for each theme, where the respondents from Maputo are presented first from the left (1-8), and the respondents from outside of Maputo are presented to the right (9-13). Excluded from these tables are the respondents where the state of the interview was not semi-structured. A matrix showing all barriers and respondents is included in Appendix E.

5.1.1 Availability of equipment

Barriers connected to availability of equipment are divided into four areas. *Low quality of local products* concerns barriers originating in use of locally produced equipment while *High import duties* deals with those connected to importing equipment. *Limited rural infrastructure* concerns barriers caused by remoteness and poor road conditions and *Lack of access to spare parts* regards lack of lack of access to spare parts as a barrier. Table 5.1 shows which of the respondents that see different aspects of availability of equipment as a barrier to pico and micro hydropower development.

Table 5.1: Respondents addressing the matter of availability of equipment. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

<table>
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<tr><td>Low quality of local products</td><td></td><td></td><td></td><td></td><td></td><td>B</td><td></td><td>|</td><td>|</td><td></td><td>B</td><td>B</td><td>B</td></tr>
<tr><td>High import duties</td><td>B O</td><td></td><td>|</td><td>|</td><td></td><td>|</td><td>B</td><td></td><td></td><td>B</td><td>|</td><td></td><td></td></tr>
<tr><td>Limited rural infrastructure</td><td>|</td><td>B</td><td>B</td><td></td><td></td><td>O</td><td>B</td><td></td><td>|</td><td>|</td><td></td><td></td><td></td></tr>
<tr><td>Lack of access to spare parts</td><td></td><td>O</td><td>B</td><td>B O</td><td></td><td>B</td><td></td><td></td><td></td><td></td><td></td><td></td><td>O</td></tr>
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Low quality of local products

Most of the equipment used for pico and micro hydro projects not initialized by the government are locally produced (NGO A, FUNAE A and B). Gov. ent. employee A and B and both NGOs, all working closely with the present pico and hydro projects in Manica province, say the locally produced equipment in some cases have poor quality. The local respondents FUNAE B and EdM B have not mentioned this. They think it would be better to produce more locally because it is cheaper and creates work opportunities. Consultant C agrees that locally produced equipment has low quality. However, he does not point it out as a barrier, but argues that it is not always necessary to produce everything in Mozambique. Gov. ent. employee B says that a barrier to more locally produced equipment is lack of entrepreneurship among potential manufacturers. Few manufacturers have picked up the business after visiting workshops teaching local companies how to build turbines.

High import duties

Most equipment for larger hydropower stations is imported (Consultants A and B, Donor A, EdM A and B). The high import duty increases the cost of the equipment, which makes import disadvantageous (NDRE, EdM B). The quality of the imported equipment is questioned by Consultants A and B. Although they do not have experience of pico and micro hydro, they both agree that too much low quality equipment used in other on or off grid systems is imported from China and India. If the equipment is not locally produced, EdM A stresses the importance of training to ensure maintenance skills.

Some countries lower the import duties for renewable energy equipment. Gov. ent. employee B explains the difficulty of doing this, since it will also lower the income used for civil servants' salaries. NDRE considers local production a good alternative to overcome the economic barrier cause by the high price of imported equipment.

Limited rural infrastructure

Most stakeholders agree that the conditions of the roads are poor (FUNAE A and B, EdM A and B, NDRE, Gov. ent. employee A, Consultants A and B). FUNAE A and EdM A see the limited rural infrastructure as a barrier, and Consultant A and B see it as a main challenge to ensure sites are accessible. To get to a new site, a road must be built, so the consequence is an increased investment cost for the project (FUNAE A and B). EdM B finds there are problems, but there is always a way to solve them and Gov. ent. employee A claims it is a matter of planning construction during the dry period of the year. NDRE explains that accessing sites is not a problem since the government is interested in infrastructure projects.

Lack of access to spare parts

Both EdM A and Donor A say that the availability of spare parts can be a constraint. Gov. ent. employee A says that lack of spare parts is a financial risk for the operator since there is no revenue during stop.

Some respondents do not see lack of spare parts as a barrier to pico and micro hydro development. NGO B employees report that managing spare parts has worked well in their projects. Donor A, who sees it as a barrier, suggests a stack of spares should always be included in a project as a way to ensure availability of spares. FUNAE A agrees. NGO B employees' solution is to keep operators informed of where to find suppliers, and ensure there is a willingness to pay.

5.1.2 Community relations

Barriers associated with community relations are divided into three areas. *Lack of local involvement* covers problems where there is not enough involvement from the community. *Community relations hinder power station management* consists of barriers where ownership models and conflict management are central. *Lack of local contribution* deals with a lack of labor and material contributed by communities. Table 5.2 shows which of the respondents that see the different community relations areas as a barrier to pico and micro hydropower development.

Lack of local involvement

NGO B employees, Donor A and Gov. ent. employee B all see lack of local involvement as a barrier to pico and micro hydropower development. The NGO B employees learned that when a project failed it was often because they didn't include the operators in the construction process, and so there was no feeling of ownership. If the local leaders of the community have not been sufficiently involved, the NGO will not have good enough communication with the community to solve problems that might arise. Gov. ent. employee B feels that the local people should act as the promoters, to make the project sustainable.

The community interventions done so far by the governmental agency and NGO A and B has brought good examples, which marks them as a possible way of overcoming Lack of local involvement. Gov. ent.

Table 5.2: Respondents addressing the matter of community relations. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Lack of local involvement				B	B						B O	O	B O
Community relations hinder power station management								B		B	|		B O
Lack of local contribution											B	O	B

employee B and NGO A discuss how to work together with the operators, for example in the sense that the entrepreneurs, who build their own turbines out of old cog wheels, are to be treated with respect for what they have accomplished. To involve the operators, Gov. ent. employee B describes how the systems are changed from within, improving only the things the operators want improved and inspiring them with examples of better turbines in other communities. This is a better alternative to what is often the case, when the systems are changed or replaced entirely without the entrepreneurs' consent. NGO B does community gatherings to try to involve the local leaderships and the rural district council.

Community relations hinder power station management

Gov. ent. employee C and NGO B explain that the ownership model to use depends on how the community works socially. There are differences that need to be considered. A bad communication with the community can lead to difficulties in mobilizing the community. Community conflicts can get in the way and cause complications and delays (NGO B). EdM B thinks community based projects are more difficult to maintain due to community conflicts. The RDCO has experienced problems where people did not want to confront their neighbors, for example when some users breached their meters. Consultant C concludes that there are examples of community based projects that work, but that it often results in problems with payment, mismanagement of funds, people not having proper technical background, and that people trained by the project move away from the community. NGO B employees find the private owner model more sustainable when in use, but it is very difficult in the construction phase. With this model the owner is responsible for mobilizing labor from the community, which is complicated.

NGO B employees want to do projects to prove there are cases where independent power projects can be done by communities. "Communities can manage decentralized energy systems. They can do that!" they claim. To overcome the difficulties, the ownership model needs to be chosen by the community and clearly communicated. Gov. ent. employee B wants to promote the private owner model for Mozambique, along with almost all other respondents. For a system smaller than 100 kW Consultant C thinks there should be a private owner. Above that, they need to work with communities.

Lack of local contribution

In Mozambique, Gov. ent. employee B observes that voluntary work is slowly dying, which leads to difficulties for the operator to mobilize communities. He believes it is because donations from the western world has an incapacitating effect. NGO B employees find that people sometimes don't really anticipate how much work they have agreed on participating in. When they discover that they are less motivated.

Examples of ways to overcome barriers associated with community contribution, are for instance projects outside of Mozambique, where a shareholder model has been used. The RDCO describes how people living outside of the grid range, who would not benefit directly from the project, still came and did work to get shares in the station. NGO B employees tell of a project outside of Mozambique, where the project does not pay for community labor like carrying equipment, building structure and connections, and where material like pit sand and stones for the canals are provided as an investment from the community. They claim it had a good effect on the sustainability of the project.

5.1.3 Data and measurements

Data and measurements covers barriers associated with collecting and handling measurement data. Table 5.3 shows which of the respondents that see Lack of adequate data and measurements as a barrier for pico and micro hydro.

Table 5.3: Respondents addressing the matter of data collection. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Lack of adequate data and measurements		B O	B O				|	B O			B O		

Consultants A and B think the main data problem is accessing hydrological data. EdM A confirms this, saying that flow characterization of the rivers is something they lack. FUNAE uses precipitation data as a base for flow estimation, but FUNAE A feels that the precipitation data from the meteorological institute is not always accurate. Consultant C has experience of consultants who worked with listing potential sites, but lacked the competence of doing this properly. Consultant C also brings up the problem with inefficiency in government or company structures. The request for measurements have to go through the hierarchies, which can be very time consuming. Gov. ent. employee B's entity has collected data themselves during some time, but expresses the lack of continuously collected measurements.

Since FUNAE started using the program Google Earth as a tool in selecting sites for pico and micro hydro, there has been less time wasted on going to sites where there is clearly not any potential at all (Consultant A, B and C). EdM A thinks restoration of the old measurement stations from the pre-independency era would be helpful. FUNAE is already working on a hydro atlas for parts of Mozambique. FUNAE A thinks it could be possible to make an agreement with other organizations to work together with data collection. Gov. ent. employee B has ideas to use commercial companies or students to do measurements. This could be easily done since no engineering skills are required to do these simple tasks. The analysis of the measurement data could be done at a university with hydropower students.

5.1.4 Demand

Demand barriers are divided into two areas. *Low demand and low level of productive use* covers all opinions that the electricity today is not well used in the communities. *Difficulties sizing systems* contains barriers connected to difficulties in choosing the right size the of system. Table 5.4 shows which of the respondents that see the different demand areas as a barrier to pico and micro hydropower development.

Table 5.4: Respondents addressing the matter of demand. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Low demand and low level of productive use		B	O		B	|	B	|				B O	B
Difficulties sizing systems			|				|	B			B	|	B

Low demand and low level of productive use

NGO A's impression is that the NGO partners in electrification projects evaluate the benefit for the community only by counting lights. "You have to look at power as part of community development, not only lights" he claims. Donor B and NGO B employees agree. There is a low demand in rural Mozambique. Sustainability is difficult with only household connections and to get more activities is a great challenge. FUNAE A is struggling to promote productive use. Consultant A and B believe industrializing agriculture could make electrification viable in general and not only considering hydropower. However, today agriculture is done by hand and at a small scale.

NGO A has many ideas of how communities could use electricity for productive purposes. He believes agro-processing is a good area to promote for economic growth, and that there should be a micro finance strategy to support businesses. Today crops are only available during their respective season, and then the market is flooded with them. If the fruit would be processed the prices could be higher and the income would be more stable. He also holds the opinion that EdM ought to promote electricity for cooking, although this is something not agreed on by the employees from NGO B. Their experience is that pico and micro hydropower cannot support the power for cooking, a very power consuming activity. Gov. ent. employee A has witnessed several examples where electricity access from hydro power systems has helped to create new business activities. “Many entrepreneurs will start developing or trying to upgrade their business undertakings as soon as they have access to electricity” he says. Consultant C does not believe electricity automatically means economic growth, but that there is a need for support to start productive activities. EdM A thinks the government should give fiscal benefits to make small industries move to off grid systems. Gov. ent. employee A and Consultant C point out hydropower as specifically suitable for productive use since it can use mechanical power and support high power loads.

Difficulties sizing systems

Consultants A and B say that people often consume less than expected from a baseline study. Gov. ent. employee A explains the problems that it might bring when the operator is financing the station. With a large station with few connected users the operator might not get enough revenue, and the loan cannot be paid back. The same problem is expressed by Gov. ent. employee B who would have liked to do some systems smaller. “We should have started with pico. Now everyone wants large stations even though pico would be enough. The systems we have now are working on 10-15%”. A certain over sizing is for future population growth. NGO A does not think it makes economic sense to build large systems for just a few people. Consultant C agrees. Sometimes the households can only afford one or two light bulbs. “You are just going to end up heating a lot of air with your stabilization system.” And if the system is too large there will be a lot of investment that cannot be used for anything else, he continues. The opportunity cost can be really high. The problem of under sizing the systems is also mentioned. EdM A stresses the need to plan for the future growth in the demand. “We have to think: If we introduce the egg today, how many chickens will we have in three years?” Still he is aware of the need for something to accommodate the gap between ability to pay and estimated installed capacity. Gov. ent. employee A says that productive use can be hard to predict, since companies might start unexpectedly. This increase in demand is difficult to take into account when sizing a system.

The method of starting with a small system and expanding it when needed, to overcome barriers originating from oversizing, is thought of differently. NGO B employees add that it increases the level of experience needed to operate and maintain the station. Consultant C has, along with respondents who do not consider difficulties sizing systems a barrier, not experienced any problems with upgrading systems so far, but he cautiously reminds that they are only in the beginning of pico and micro hydro development. Gov. ent. employee B is positive towards upgrading systems, but agrees that it is also a costly process. Also, the sizing of the systems is handled with a population growth in mind according to Gov. ent. employee B. They do not take any other growth factor into account since the present demand is only a fraction of the available capacity at the sites.

5.1.5 Design

Barriers associated with design issues are divided into three areas. *Poor design* describes general problems with designing pico and micro hydro. *Lack of proper maintenance* covers opinions where problems with maintenance are a barrier and *Scattered population in communities* describes the barrier of dispersed houses within villages. Figure 5.5 shows which of the respondents that see the different design areas as a barrier to pico and micro hydropower development.

Table 5.5: Respondents addressing the matter of design. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

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<tr><td>Poor design</td><td></td><td></td><td></td><td>B</td><td></td><td>B</td><td></td><td></td><td></td><td>B</td><td></td><td>|</td><td>B</td></tr>
<tr><td>Lack of proper maintenance</td><td>B</td><td>O</td><td>O</td><td>B O</td><td></td><td>B</td><td>B</td><td>B O</td><td>B O</td><td>B</td><td>B O</td><td>B O</td><td>O</td></tr>
<tr><td>Scattered population in communities</td><td>B</td><td></td><td>B O</td><td></td><td></td><td></td><td>B</td><td></td><td>O</td><td></td><td></td><td>B</td><td></td></tr>
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Poor design

Donor A and NGO B believes it is a barrier if systems are too complicated, since it will cause problems with maintenance and spare parts. The Power system owner has had problems with the system due to poor design that hindered water from flowing in the pipes. EdM B tells of a project where insufficient pre-studies led to bad design and failure in the system.

NGO B employees say that few bearings, and few gears and other mechanically advanced components in a design, is favorable to limit the need for maintenance. NGO A has been criticized for not designing the systems well enough. He agrees it would be better to make everything function perfectly, but the NGO has a limited budget and he thinks it is better to reach many beneficiaries.

Lack of proper maintenance

Lack of proper maintenance has been brought up as a barrier to pico and micro hydropower development by several stakeholders (NDRE, EdM B, Consultants A,B and C, Gov. ent. employee A and B, NGO A, FUNAE B). FUNAE B says it is important to have a functional system which delivers electricity continuously. If not, the customers get disappointed. NDRE and Consultant C have experience of damaged equipment and system breakdowns. Gov. ent. employee B says there is no culture of maintenance in Mozambique. In some local languages there is not a translation for the word. Consultants A and B have the same experience. NGO A explains how the problem sometimes is that there is no money to fix leakages or do reparations. FUNAE B adds that even if there is money, the administration can be lacking. In one project the money needed for maintenance was paid, but had disappeared too far up in the administrative hierarchy to be reached when needed.

NGO A thinks hydropower is technically reliable, as long as the maintenance is handled. Both Consultant C and FUNAE A think hydro is much easier to maintain than solar. NGO B employees and FUNAE B think the systems need to be designed as basic as possible. This will make the maintenance easier. The RDCO believes the hydropowered community in his district has been able to handle maintenance and other issues so well because of their feeling of ownership. NGO A and NGO B employees have made sure the operators know who to contact if there is a problem they can't handle. EdM A describes this as the way to overcome the lack of proper maintenance. "If you just train someone to do the maintenance, there will be no problem. If there is someone in the area who is trained, they can talk on the phone and get instructions." Consultant A and B stress the need to return to communities and follow up on the training. To include the operators and the rest of the community in the construction process will make them more confident and able to maintain and repair the system (Consultant A, B and C, EdM A and NGO B employees). Donor A believes it is important to have a maintenance policy from the beginning of a project. Gov. ent. employee B wants to capacitate a local turbine manufacturer so that they could be responsible for maintenance for the turbines they sell. "My dream is to have them on a motorbike. They would sell, deliver, install together with the Ministry of Energy, and then handle the maintenance." FUNAE A describes the plans to let local companies handle the maintenance and monitoring of their stations, to hold FUNAE's operational costs down. NGO A presents a solution to the lack of money for maintenance as to use money from revolving funds as a source for funds. This is soon to be put in use by the NGO. However it is criticized by Gov. ent. employee B, who has experience of projects dying because of this.

Scattered population in communities

EdM A describes what many agree is a barrier to rural electrification. "The problem is that in rural areas the network is so dispersed. To get a system for the people is quite difficult." NGO A explains that the budget allows for 1500 m length of line to cover for a scheme. And sometimes the houses are 200-300m apart. FUNAE B has a limit radius of 1000 m. Within that they are connected. Outside this it doesn't work due to the voltage drop. NDRE underlines this difficulty since the houses sometimes are even 1000 m apart. Consultant A and B believe there are very few places where there are as much as 500 people in the same village.

A solution to the problem of scattered houses is to offer people to move closer to the village center (FUNAE B). Young people will want to move. For those who don't want to, due to family or traditional reasons, there could be a battery charging station. EdM A and Gov. ent. employee B thinks there should be urban planning.

5.1.6 Finance

Financial barriers are divided into three areas. Barriers regarding the lack of financial resources in some way are coded as *Lack of access to finance*. When the problem seems to be that the technology is expensive, the coding is *High investment cost*. *Lack of investor interest* expresses the lack of interest from possible investors. Table 5.6 shows which of the respondents that see the different financial areas as a barrier to pico and micro hydro.

Table 5.6: Respondents addressing the matter of finance. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

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<tr><td>Lack of access to finance</td><td>B</td><td>B</td><td>B O</td><td>B</td><td></td><td>B</td><td></td><td>B O</td><td></td><td>B</td><td></td><td>B</td><td></td></tr>
<tr><td>High investment cost</td><td>|</td><td>B</td><td>O</td><td></td><td></td><td></td><td>B</td><td>B O</td><td>|</td><td>O</td><td></td><td>O</td><td>O</td></tr>
<tr><td>Lack of investor interest</td><td>O</td><td>B O</td><td></td><td>|</td><td>|</td><td>O</td><td>B</td><td>|</td><td></td><td></td><td>B O</td><td>B O</td><td></td></tr>
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Lack of access to finance

The barrier of there being a deficit in financial resources is addressed by many respondents (NDRE, FUNAE A, EdM A and B, Donor A and B, Gov. ent. employee A, Consultant C, NGO A and the Committee member). NGO A has applied for funding to start projects in other provinces, but says that the Ministry of Energy has replied they don't have funds to give. FUNAE A informs of budget cuts, from the Ministry of Energy, which have hindered projects from being realized. NDRE finds it is a challenge to get investments, and the Committee member states that the community station needs more finance to improve the leaking canal.

When it comes to ideas of who should do the financing, EdM A suggests there could be a grant available directly through the banks, or that FUNAE could work as a bank to provide means for other players to build and manage. Consultant C is not sure FUNAE should give loans at all. They are considered a give-away-organization, and the loans will not be paid back. He also claims that FUNAE's capacity to ensure that people pay back is insufficient. A bank or local administrative unit could work as an intermediate point to increase the capacity. To just give money away in projects is not always the best to do, claims EdM A. "The best is to combine grant and loans to make people responsible". The idea of private investors for smaller schemes is mentioned by Consultant C.

High investment cost

The perception that pico and micro hydro is an expensive technology from an investment perspective is shared by FUNAE A, Consultants A, B and C and the Committee member. Consultant C has heard people say FUNAE's systems are too expensive. If they would do cheaper systems they could do more.

All three consultants agree that some costs are easily overlooked, like the administration costs and the development costs. Consultants A and B describe how the systems can get more expensive than it seems if there for example turns out to be a need of a dam. The grid and meters are other examples of equipment that increases the investment cost. FUNAE B says it is the civil work that is most costly in the construction, and Consultant C describes how the distance to the river adds a huge component to the price. The committee member would like to line the canal of the community system with concrete, but that is much too expensive (the canal is 5-6 km long). FUNAE A's opinion is in line with the others. To decrease the investment costs is one of their focus issues.

A way of lowering the investment cost is if community members can be motivated to contribute in the construction and provide material for the scheme. EdM A, Consultant C, EdM B, NGO B employees and RDCO believe there is capacity and willingness in the communities to do construction work. In a project in RDCO's district, 20% of the investment cost comes from communities in the shape of labor and locally available materials.

Consultant C stresses the opinion that hydropower is not the best choice for every site. A solution can be to simply choose some other source of power, if hydro is not suitable. "If you choose hydro for some of these places where it doesn't make economic sense, it will be just to prove that you can do hydro." He says the accusation of FUNAE doing expensive systems is true, but that the problem is complex.

FUNAE is a government organization; they need to do systems that have a certain quality. NGO A, who has the opposite experience of being criticized because the costs are held down too much, thinks for their own conditions that it is better to do more systems even though they are not perfect.

Lack of investor interest

To give loans to private operators of hydro stations, banks request guarantees with a 100% cash deposit. This is a matter discussed by Gov. ent. employee B and NGO A. Gov. ent. employee B thinks the banks are blocking the process. He has started discussions with FUNAE, who could give loans for community projects. Recently, Gov. ent. employee B claims, FUNAE has started to ask for guarantees as well. "We assumed the financing institutes would take the electromechanical equipment as guarantee, but they don't. They would only put 10 or 25 percent of the investment into the equipment, it's nothing!" NGO A explains that the banks are unwilling to act at a community level and Gov. ent. employee B speculates on why. "The organizations come to the banks and give them guarantees, so they have all the projects they want. The mentality is spoiled; they are not looking for clients. They don't need your money." Consultants A and B do not believe international donor agencies will fund pico or micro hydro projects, because of administration barriers. Donor A and B agrees that there is low interest in funding at the moment. FUNAE A's opinion is that the government needs to give more space to private investors, which contradicts Consultant C who has a feeling FUNAE is a bit reluctant in promoting private sector participation.

To gain the investors' interest, the feed-in tariffs are considered an important step, in NDRE's and FUNAE A's opinion. Gov. ent. employee B agrees that selling electricity to EdM is the easiest business for the operator, and is determined to keep close contact with EdM. The new plans of the organization, is that their small sites must fit within the regulation of grid connection. Gov. ent. employee A is sure the that interest of financial institutions in financing pico or micro hydro power systems will increase if it can be demonstrated that private operator models work out and loans are paid back. NGO A plans to do some lobbying so that they can be heard at decision level and promote pico and micro hydropower.

5.1.7 Knowledge and education

Knowledge and capacity building issues are divided into three areas. *Lack of awareness of technology* concerns insufficient common knowledge of pico and micro hydropower in Mozambique. *Lack of technical expertise* regards barriers connected to lack of technical expertise in the country. *Poor knowledge management* deals with barriers connected to the present education system, spread of existing knowledge and difficulties regarding training people to operate power stations. Table 5.7 shows which of the respondents that see the different knowledge and education areas as a barrier to pico and micro hydropower development.

Table 5.7: Respondents addressing the matter of knowledge. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8 - Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Lack of awareness of technology	B O	B		B			B					B	
Lack of technical expertise		O	B				B	B				B	
Poor knowledge management	B	B O	B O			O	B O	B	O	O	B O	B O	O

Lack of awareness of technology

Many stakeholders agree that there is very little common knowledge of pico and micro hydropower in Mozambique (NDRE, Donor A, FUNAE A, Consultant A and B, NGO A) and that capacity building is needed. According to FUNAE A and the Power system owner, lack of awareness leads to lower involvement on several sector levels. FUNAE A claims that many companies are not yet involved due to a lack of awareness. The power system owner says users are less motivated when they don't trust an unknown technology.

To increase the awareness, NDRE will do a road show, spreading the awareness of pico and micro hydropower. Gov. ent. employee C describes how much the awareness has grown just over the past years. “Before, people only knew about electricity from the main grid”, he says. “Now, even though we don’t advertise our systems, people hear of them because they know someone in another village who has one.” Several respondents mention capacity building. RDCO believes study visits have played a large role in convincing communities to try hydropower. And once they have seen it work, almost everybody wants training. This perception is shared by FUNAE A who thinks this might even present a problem. “Everybody wants to run the power plant, but there has to be someone qualified doing that” he says.

Lack of technical expertise

EdM A mentions lack of skill to do maintenance, and the Committee member mentions lack of technical expertise locally as a barrier. Consultant A and B find that the lack of practical experience among engineers is a potential barrier and Consultant C speaks of lack of competence among engineers when it comes to data collection and site analysis. He finds that more people need to be educated on the design part of the process. NGO A describes a lack of technical expertise within the organization, but they are being capacitated.

FUNAE A claims people will have the capacity to run small systems. People to do simple civil works like digging canals already exist on a local level, according to EdM A.

Poor knowledge management

NGO A says “the most critical and weak part of everything we are doing is documentation” which makes it difficult to share information and knowledge within the hydro sector. EdM A points out that there is a lack of a body to discuss and share experiences today. Gov. ent. employee B says more focus needs to be put on universities to make sure earlier experiences can be shared continuously. NDRE says there is only one university teaching the technology today. A problem brought up by Consultants A, B and C is that the few educated engineers who graduate move to other countries to get higher salaries. Consultant A and B explain the issue of knowledge valued as power leading to unwillingness to spread knowledge among people. They also mention that the mentality of not questioning the education system results in poor learning. FUNAE A tells of older stations not working due to poor training of the operators. And Consultants A and B find there is a lack of continuation in training. There needs to be follow-ups on the training after a station is finished.

Sharing knowledge with operators and training them has, according to many respondents, worked well (Gov. ent. employee B, AKSM, EdM A, RDCO, FUNAE B, NGO B employees). Involved actors have training models including training in maintenance, leadership and economics. EdM A claims that good training is manageable, although quite difficult. EdM B finds that people in general accept and understand the instructions given. In those cases they do not, the problems are solved together with the community.

A common way to spread knowledge among communities, brought up during the interviews, is visits to other power station projects to see positive examples of stations that function well (Gov. ent. employee B, NGO B employees). Some of the respondents have themselves visited projects in adjacent countries to learn more (Gov. ent. employee B, NGO A). FUNAE A explains the energy fund has strategies to strengthen the capacity within the organization, confirmed by EdM B, and some stakeholders say there is communication and cooperation among them (Consultant C, Gov. ent. employee A, NGO A) leading to continuous capacity building.

Consultant C thinks it might work to start a specialization course or a master’s degree on hydropower. Consultant A and B think the mentality problem they mentioned will disappear with a few generations, making education easier. Gov. ent. employee B explains the plans of a “Centre of excellence”, a joint project between NGOs, companies and five universities, which is planned in Chimoio.

NGO B employees want to capacitate other organizations in how to do community interventions. The World Bank has requested increased cooperation between FUNAE and EdM. Gov. ent. employee A finds it a good development that several entities share an office building in Chimoio. EdM A, who expresses a lack of a body for meetings, noticed that the National Directorate for New and Renewable Energy were at the IRENA conference last year, and hopes the directorate became aware of this and acts on it. Gov. ent. employee B tells of an operator who built his own hydropower station and now works with the Ministry of Energy, lecturing about hydropower for rural communities.

Gov. ent. employee B was glad to find that operators they trained have a high initiative. When something needs fixing, they don’t wait for the NGO to visit, but instead they present what they have done to solve the problems. One way to overcome the problem of educated people moving to other countries is to offer them higher salaries. Consultant C explains salaries at FUNAE are higher than other governmental departments, in order to keep the employees.

5.1.8 Legislation

Barriers associated with legislation are divided into three areas. *Too low electricity price* regards the pricing of electricity. *Lack of supporting legislation* expresses the lack of support from the government. *Lack of grid code and feed-in tariffs* considers feed-in tariffs and common standards. Table 5.8 shows which of the respondents that see the different legislation areas as a barrier to pico and micro hydropower development.

Table 5.8: Respondents addressing the matter of legislation. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8 - Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Too low electricity price							B	|				B	|
Lack of supporting legislation		B				|					B	B	
Lack of grid code and feed-in tariffs	B O	B	B		B	B	B	B	|				

Too low electricity price

Some communities find the tariffs too low in terms of what they must spend for keeping the system running (NGO A). Consultant A and B have experience from diesel generators where the electricity price was set too low even to buy the fuel, and so it couldn't keep running. Consultant C agrees the real costs of running a hydropower plant are much higher than 8-9 cents/kWh, the tariff used for EdM customers. In Mozambique off grid tariffs are generally set at the same level as those of EdM.

NGO B employees tell of a community in Zimbabwe where the electricity price is set by the community themselves. They pay 16 cents/kWh instead of the national price of 9 cents/kWh.

Lack of supporting legislation

NGO A does not feel enough government support. "You do not see them pushing us or applauding us, and not financing either. What do we do when the international organizations leave?" One of the problems Gov. ent. employee B has met is that the ministries have different policies which do not meet when several are to be used simultaneously.

Many respondents find the legislation supportive of pico and micro hydropower, without more comments. Gov. ent. employee A cannot say the laws are supporting, but they are not hindering either. Gov. ent. employee B says the government is supporting, but that they do not yet have enough experience. And the problem is that there is not yet an awareness of what laws there are. Gov. ent. employee B is hopeful. "The director of NDRE is looking for projects that can demonstrate the application of the energy policy. That is like an open invitation to come and do wonders!" Concerning the problems with the different policies, Gov. ent. employee B has spent time together with representatives from the ministries and together with them developed a way of working through the policies.

Lack of grid code and feed-in tariffs

EdM A thinks the lack of a grid code is a problem. Consultant A and B say the cooperation between FUNAE and EdM has been poor, the standards of the equipment are not the same. FUNAE B claims that the FUNAE systems are constructed to be connected to the main grid, but Consultant C's view is that this is not done yet. Consultant A and B have seen problems with aging diesel systems, worn by tough weather conditions, that would be difficult to connect to the main grid without rehabilitation. They see a potential risk that similar complications can occur when connecting hydropower stations.

FUNAE A sees a commercial risk once EdM reaches the area of an off-grid system. EdM will have the cheapest prices and the off-grid system would probably have to shut down. The lack of feed-in tariffs that oblige EdM to buy electricity at a minimum price, is considered important by EdM A, NDRE, FUNAE

A, Gov. ent. employee A and Donor B. Consultant C says it is important not to build off-grid systems where it is not financially viable. “There is no use building a 250 kW plant in a place where the main grid is only three years away.” RDCO thinks it would be better for the community if they were not connected to the grid at all.

The NDRE is in a process with an American consultant company to develop feed-in tariffs for renewable energy in Mozambique, obliging EdM to purchase electricity from renewable energy sources, at a set price. EdM B does not see any problems with connecting off-grid systems.

5.1.9 Payment

Barriers associated with payment of electricity are divided into two areas. *Low willingness and ability to pay* regards insufficient willingness or ability to pay for electricity. *Poor payment management* include barriers caused by general difficulties with getting customers to pay for electricity. Table 5.9 shows which of the respondents that see the different payment areas as a barrier to pico and micro hydropower development.

Table 5.9: Respondents addressing the matter of payment. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8 - Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Low willingness and ability to pay		|	B	B	B			|	B			O	O
Poor payment management		|	B	|			B	B	B	|	O	B	B

Low willingness and ability to pay

Donor B expresses what many others discuss. “It is a big challenge for people in rural areas to pay for electricity. There is almost no willingness or ability to pay”. FUNAE B tells of an early project he visited and discovered was not very successful. “There were only a few lights visible. The customers didn’t pay, and then they were cut off”. FUNAE A describe the subsidized electricity prices and explains that there never is capacity to pay the whole price for electricity.

Others argue that the willingness to pay is there. Donor A says that those who have the ability are willing to pay for electricity since it raises their quality of life. Consultant C is fascinated by how much social impact electrification can have. “People wait to be electrified, they save money and then they buy a new house”. Gov. ent. employee C suggests this could be the result of a change in identity brought by electrification. NGO A and B are not worried about the willingness to pay. The NGOs do a baseline study and analyze how much people spend on energy. The committee does a selection to make sure only the ones that can afford to pay will be connected. “That way we are 90% sure the operators will have their revenues” (NGO A). NGO B explains how the willingness to pay changes as soon as people see the benefits of electricity.

Poor payment management

Consultants A and B explain what happens when there is someone in a community who cannot pay the electricity fee. For diesel systems this means the community has too little money to buy diesel. This results in shorter electricity hours for the community, which leads to discontent and more people refuse to pay. Consultant C stresses the need for a mechanism to generate funds for maintenance, but also states that there are often problems with payment and mismanagement of funds. According to Gov. ent. employee C and NGO B employees, these problems often emerge because people in small communities are relatives. Problematic situations can occur when there are people who don’t pay. Gov. ent. employee C also finds that large customers take advantage of their influence in the community and neglect payment. This can be compared with the statements from Donor A and EdM B that have experience of the main grid. There have been, or are still, problems with governmental organizations that get away with not paying for electricity.

FUNAE A has plans to let a private company collect monthly revenues. RDCO has good experience of how the community handled problems with payment. When there were people breaching meters, it was solved after they had a meeting.

Difficulties associated with the prepaid system are for example the extra investment cost they add to the project. NGO A explains how the system makes people use less electricity, which might result in too low income for the operator, who will not be able to pay back the loan for the system. This is also discussed by Gov. ent. employee C and can be compared with EdM B's report that the income of EdM was less when they introduced the prepaid system on the main grid. People will just spend what they need, no more. The RDCO has recently been involved in solving problems with people who breach their meters after being trained in maintaining them. Gov. ent. employee C considers the difficulty of finding spare parts for the meters when needed.

Although there are problems with the prepaid system, many prefer it to the postpaid system. If they could afford it both NGO A and B would like to use the prepaid system. NGO B employees do not like the postpaid system because there is not any switch off structure. EdM A has experienced problems with people stealing electricity when using the postpaid system. FUNAE A tells of people trying to pay with other means than cash, since it is difficult to have access to cash in the end of every month.

Both FUNAE B and NGO B employees agree that the flat rate system is very unsatisfying. "It doesn't make sense that everybody pays the same" say NGO B employees. Gov. ent. employee B want to improve the flat rate system by introducing user groups with different prices, so the payment is fair.

5.1.10 Project administration

Barriers associated with project administration are divided into two areas. *Poor project administration* contains barriers about how projects are managed from the organizations and companies side, separated from administration barriers on community level. *Time consuming processes* describes expressions on problems with long project processes. Table 5.10 shows which of the respondents that see the different project administration areas as a barrier to pico and micro hydropower development.

Table 5.10: Respondents addressing the matter of project administration. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8 - Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Poor project administration		B O		O	O		O	O	B		O		
Time consuming processes		B O		B			B	B		B	|		O

Poor project administration

One of the challenges the FUNAE hydro team deals with is to reduce the time and cost of the implementations (FUNAE A). FUNAE B, Gov. ent. employee C and Power system owner tell of projects that have stopped because of administrative problems.

Donors A and B are hesitant to whether more money is really the way of supporting FUNAE. Their impression is that FUNAE has a limited capacity to take on more projects. Donor B expresses the opinion that the activities FUNAE starts need to multiply without FUNAE having to control every detail. FUNAE A has an idea of making a call for proposals to the private sector. FUNAE could screen project proposals and give credits or grants. Consultant C thinks the pico and micro hydro sector needs to be more developed, so each entity could take on fewer roles in the processes and increase efficiency. He thinks FUNAE should focus on financing, and the GIZ on capacity building, to make local NGOs able to handle the projects on their own. When the private sector is more involved, FUNAE can take a step back, he says. Gov. ent. employee B describes the capacity building they do today. "We work together with people until they do it on their own. Soon they start taking own initiatives." Donor A and Consultants A and B mention the alternative to bundle projects together to minimize the administrative costs for each system. Or FUNAE could receive a sort of sector-budget support and select projects themselves.

Time consuming processes

Respondents agree that the time consumption can be an important barrier for hydropower (FUNAE A, Donor A, Consultants A, B and C, EdM B). From identification to implementation FUNAE A claims it is a four year process. Donor A and Consultant A and B describe the complicated process which they say usually takes six years, and Consultant C says it could take up to eight years if the initiator and proponent is also the financier. Donor A thinks there could be a slightly shorter process with smaller projects because there are fewer people involved, but when going through international financing agencies some administration rules must be followed, and it will still take a lot of time. Consultant A and B think that the technical training takes too long time, due to a bad learning mentality.

NGO B employees would like to share their experience with FUNAE, since they believe they could help to save time. FUNAE A wants to shorten the time consumption in the project process. Until now external consultants have done pre-feasibility studies, but if FUNAE does that themselves they could save time, not having to waste time on tendering consultants.

5.1.11 Resources

Barriers connected to resources are divided into three areas. *Lack of water resources* concerns lack of water supply needed for hydropower. *Competing resource use* regards barriers emerged from irrigation and other competing uses of water, and *Long distance transmission* concerns the cases where the geographical and hydrological conditions are met, but do not coincide with where there is demand. Table 5.11 shows which of the respondents that see resources as a barrier to pico and micro hydropower development.

Table 5.11: Respondents addressing the matter of resources. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply addressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8 - Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Lack of water resources				B O		B	B		B	|			B
Competing resource use									B				B
Long distance transmission		B					B	B					

Lack of water resources

Respondents have a unanimous awareness that the reliability of water resources varies within the country. EdM B, Gov. ent. employee A, Donor A and Consultants A and B all say that it is a challenge to have continuous water supply throughout the year in some areas of Mozambique. Consultants A and B don't believe there is enough rain to fill up the small rivers during the dry season, but they agree that the hilled parts in western Mozambique could be more reliable. However, during the interview with the committee member in the western region, he mentions the problem with poor electricity distribution when the water reaches a critical level in October. NGO B employees mention the problem of climate change. "You cannot predict the river flow in 10-20 years. It becomes really difficult."

Donor A thinks it could be reasonable to balance pico and micro hydropower with a diesel generator to ensure continuous electricity. It is not environmentally preferable, but economically.

Competing resource use

Use of water for other purposes than generating electricity can be a barrier for the development of pico and micro hydropower. NGO B employees explain that if a hydropower project is going to affect irrigation there is no point of doing it. FUNAE B describes examples where people lead away the water to use at the farms so there is no water left for the station.

Long distance transmission

Consultants A and B say it is an important challenge to find sites where the hydropower station can be located near enough to people. Consultant C agrees that if the distance is long it does not make sense to choose hydropower. FUNAE A mentions the political influence in selecting potential sites as a possible barrier.

Consultant C explains that when hydropower sites are located too far away it might be favorable to step back and use solar PVs instead. He describes the long distance between rivers and communities as specific for Mozambique. Since there is an annual flooding of the rivers, communities must always have a safety distance to the water.

5.1.12 Main challenges

All respondents have been asked the question of what they believe are the main challenges for pico and micro hydropower as a means of rural electrification in Mozambique. This is presented in Figure 5.12.

Table 5.12: Main challenges.

		NDRE	FUNAE A	EdM A	Donor A	Donor B	Gov. ent. employee A	Consultants A&B	FUNAE B	EdM B	NGO A	NGO B employee
Availability of equipment	Limited rural infrastructure							B				
	Lack of access to spare parts				B							
Community relations	Project - community relations				B	B						B
Design	Poor design				B		B			B		
	Lack of proper maintenance				B		B		B			
	Scattered population in communities							B				
Finance	Lack of access to finance	B		B			B			B		
	Lack of investor interest		B			B						
Legislation	Lack of supporting legislation		B								B	
	Lack of grid code and feed-in tariffs					B						
Payment	Poor payment management								B			
Resources	Lack of water resources								B			
	Long distance transmission							B				

NDRE chooses the financial barrier of lack of investments to implement the technology as a main challenge. FUNAE A feels the government needs to be committed and give more space to private investors to boost the field. He also thinks there is a need for more initiatives from entrepreneurs, from the private sector. FUNAE B states that the stations need to be close to perfect for the energy to be delivered continuously. The contract for tariffs needs to be good, as well as the system of flat rate fees, which is often unfair.

EdM A selects the investment issues as a main challenge as well, and specifies that the loans need to be "cheap". EdM B thinks the main challenge is lack of access to finance. He has also experience of failed projects, and mentions the importance of collecting detailed data during the feasibility studies. Donor A discusses four different areas where the main challenges are. The maintenance and general long perspective, having local people with you in the process, that spare parts are available and that the design is not too technically complicated. Donor B stresses the need for establishing hydropower as an activity people can engage in. Investors need to be connected to the demand side, which means that the challenge lies in seeing the economy in selling energy. This is linked to the current lack of feed-in tariffs.

Gov. ent. employee A sees the challenge of ensuring the quality of installation and maintenance as the most important, to have a continuous and stable supply of electricity. He also mentions the availability to credit facilities like banks as one of the main challenges. Gov. ent. employee B argues that the main challenge is having the projects in the hands of local people instead of using an outside drive. Today all the resources come from the top, he reasons. You rarely find someone who starts at the bottom, going up. Nobody takes people who want to promote the technology seriously. Another issue is the sustainability when project money runs out and NGOs or organizations leave.

NGO A feels that the main challenge is for the government to give more support and encouragement. NGO B employees stress the mobilizing of communities as most important. Consultants A and B describe the availability as an important problem for rural electrification in general, and the fact that people live so scattered today, and maybe far from the river. Consultant C was mistakenly never asked the question of main challenges so his opinion is not represented.

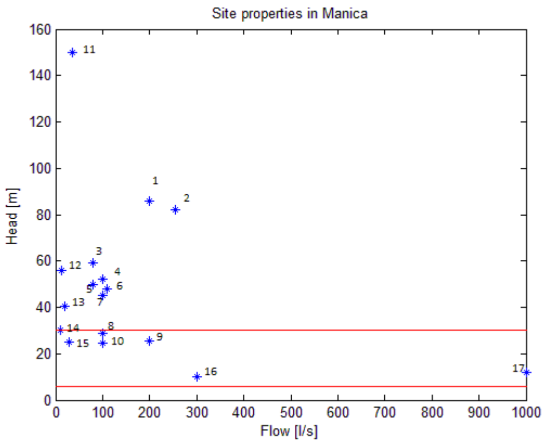
5.2 Technological and resource potential model

The modeling of the 17 sites in Manica province, with all other data provided, shows different aspects of the suitability for the two turbine designs. As earlier described, the data from the Manica model are extrapolated to estimate the characteristics of the provinces Niassa, Tete and Zambézia. The results of the modeling are presented here, to provide a combined description of how geographical, technological and demographical factors influence the potential of pico and micro hydro in the four provinces.

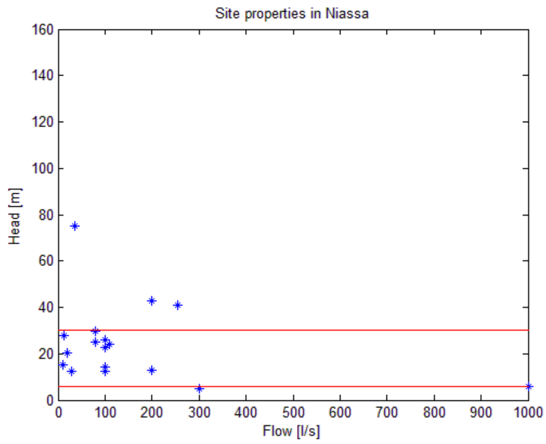
The province characteristics are described, as well as the result of the extrapolations of head range, followed by a presentation of the annual system power output. The costs per kilowatt and per household are presented for the sites where at least one of the turbines showed some potential. Finally, a sensitivity analysis is performed.

5.2.1 Province characteristics

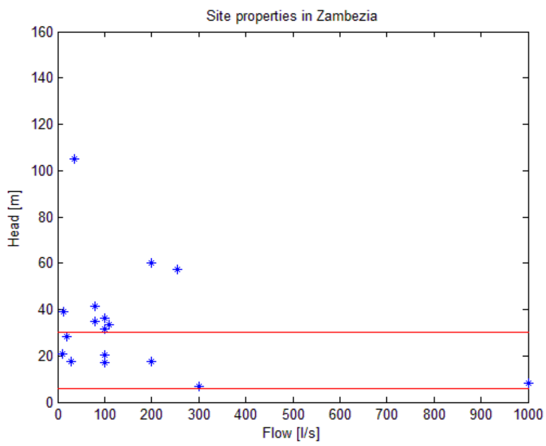
The base for the extrapolation of the data to the three provinces Tete, Niassa and Zambézia, is the 17 sites in Manica. The distribution of head and flow levels for the sites is presented in Figure 5.1 together with head ranges for both turbines. The province Tete is not presented, since the head levels are similar to those of Manica.



(a) Manica



(b) Niassa



(c) Zambézia

Figure 5.1: Distribution of sites. Red lines, lowest head for Crossflow/Pelton.

A comparison is made in Table 5.13 to show how the extrapolation affects what sites are considered suitable for the two turbines, according to head range.

Table 5.13: Number of sites with head within turbine head range.

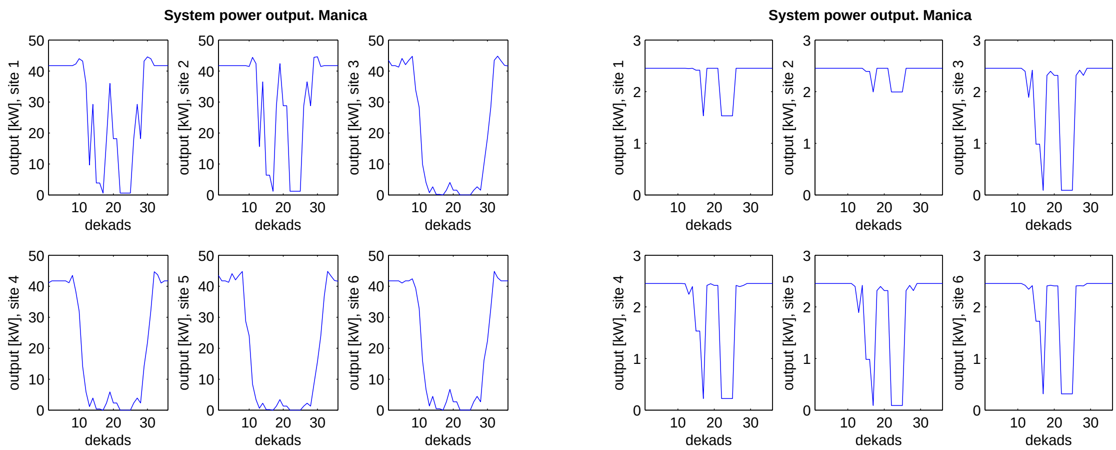
Province	No of sites within head range	
	Crossflow	Pelton
Manica/Tete	17	11
Zambézia	17	9
Niassa	16	3

Zambézia was modeled with head levels 30% lower than Manica, which has caused two of the sites to fall beneath the lowest head limit for Pelton turbines.

The Niassa model, where the head levels have been modeled as 50% lower than in Manica, shows larger differences. All sites but the three with highest head levels have now dropped below the Pelton lowest head limit, and one is even below the head limit of the Crossflow.

5.2.2 Reliability of water resources

A very important aspect to model is reliability of water resources throughout the year, for the different sites. If the flow level is low this affects the power output directly. In addition, if the flow level is far from the rated flow of the turbine, the turbine will be less efficient. An example of the system power output throughout the year for six of the sites is presented in Figure 5.2. The selected sites have a head level suitable for both turbines and an average flow level near 200 l/s (sites 1,2) and near 100 l/s (sites 3-6).

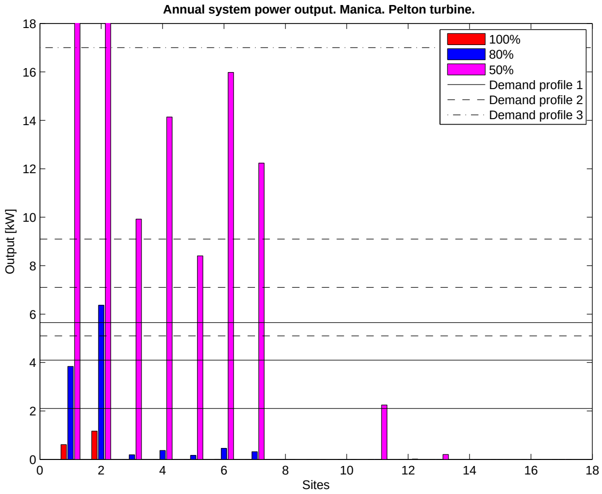


(a) Pelton (b) Crossflow

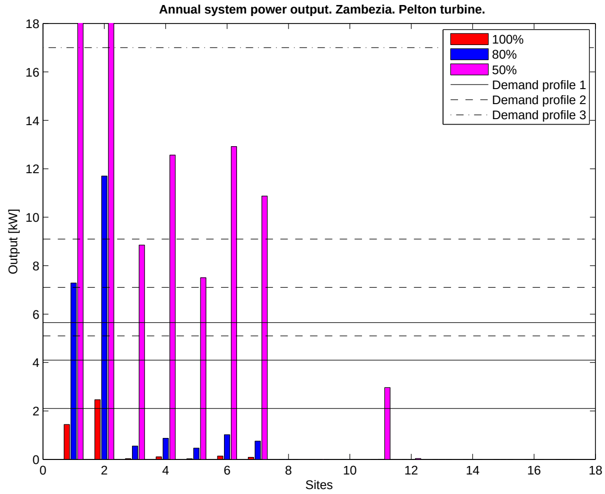
Figure 5.2: The system capacity of six high head/high flow sites in Manica.

The power output when using the Pelton turbine (Figure 5.2a) differs from close to maximum power output during the rainy season, to near zero kilowatts during the dry season. The sites with a lower average flow level are more affected by the dry period. The Crossflow turbine on the other hand (Figure 5.2b) does not require as high flow levels due to its lower rating for flow. The output from the sites with high flow never drop near zero kilowatts and are close to the maximum output for a longer part of the year than the Pelton.

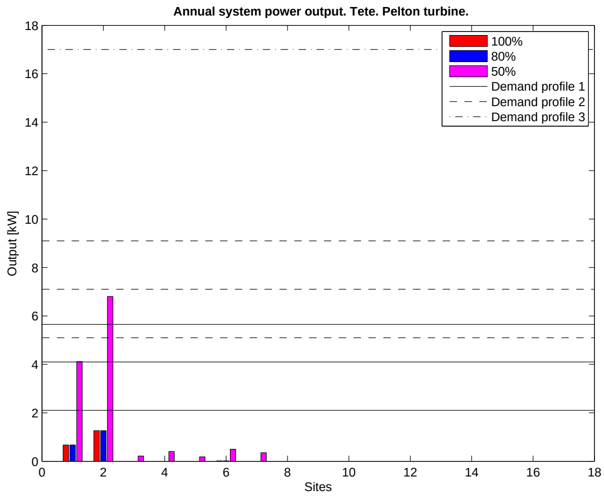
The maximum demand for different load profiles is calculated in the model (Table 4.8). Since the model selects maximum load demand for all 24 hours of a day, and in that sense is not adjusted to realistic load situations, it is not expected that the system supports 100% of the load demand at all times. If the power output available is 50% of the maximum demand, this might be enough for most part of the day. Figure 5.3 shows the minimum guaranteed system power output for 100% of the year, using the Pelton turbine for all the sites. It also shows the minimum output level guaranteed for 80% and 50% of the year. The reached levels can be compared with maximum demand of the three community load profiles with 5, 20 or 80 households respectively. The results for Niassa are similar to those of Tete, but only three sites (1, 2, 11) fall within the head range of the Pelton turbine. Therefore are the results for Niassa not presented.



(a) Manica



(b) Zambézia



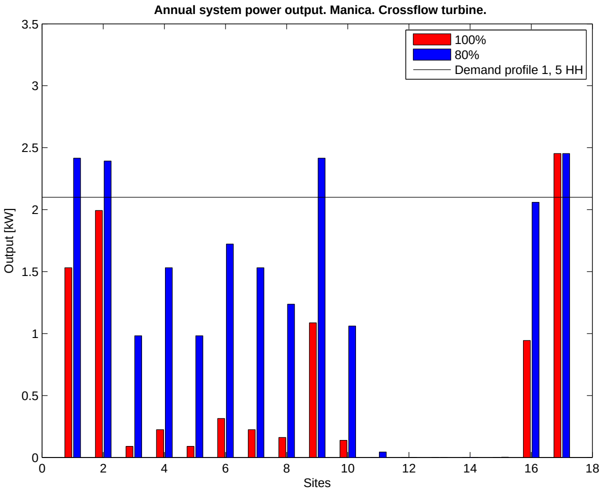
(c) Tete

Figure 5.3: Demand coverage of Manica, Zambézia and Tete sites for the Pelton turbine. The bars represent the lowest demand covered for 100% of the year (red), 80% of the year (blue) and 50% of the year (magenta). Also shown are demand levels of the different community load profiles. The solid lines show load profile 1, the dashed lines show load profile 2, and the dash dotted lines show load profile 3. All profiles show 5, 20 and 80 households respectively where 5 households have the lowest demand.

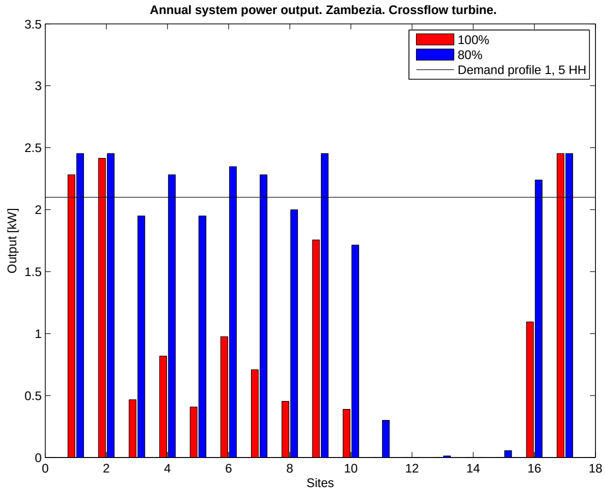
Just studying the Manica sites in Figure 5.3a, the first two sites differ much from the rest. These two sites are the ones with average flow around 200 l/s and head above 80 m (shown in Figure 5.3a). The 100% and 80% bars are not very high, but 50% of the year the sites can provide more than 30 kW (this is outside of the graph to focus on the rest of the sites). Sites 3-7 have a lower flow and head (flow around 100 l/s and head above 40 m), which renders a lower power output. Sites 11-13 have so low average flow levels that the variation in precipitation makes the flow level very small during a part of the year. This keeps the power capacity from reaching the 80% coverage. The rest of the sites have head levels below the rated head of the Pelton turbine.

Comparing the Manica results with the other three provinces, Tete shows a worse result. Not even for 50% of the year can the two most favorable sites reach higher than 4 and 7 kW. For the rest, the result is zero or below 0.5 kW for 50% of the year. Niassa is similar, but with only site 1, 2 and 11 possible for the Pelton head range. In Zambézia the lowest output for 100% and 80% of the year is generally increased, while the lowest output for 50% is decreased for some sites.

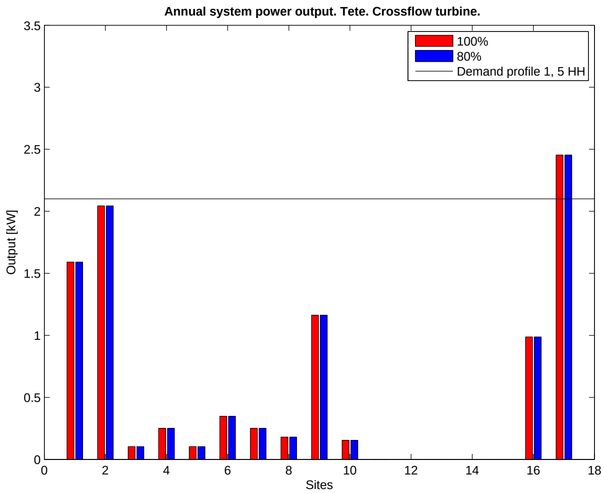
In Figure 5.4 the provinces are compared in the same way as in Figure 5.3, but using the Crossflow turbine. Here, the system power output is of course lower than for the Pelton, and only the lowest load profile is included for comparison. Since a larger part of the maximum power output is covered for 100% and 80% of the year, the 50% bars are not included. The Niassa results are very similar to the Tete results, although somewhat lower and with site 16 excluded because it is out of Crossflow head range.



(a) Manica



(b) Zambézia



(c) Tete

Figure 5.4: Demand coverage of Manica, Zambézia and Tete sites for the Crossflow turbine. The bars represent the lowest demand covered for 100% of the year (blue) and 80% of the year (red). Also shown is demand level of load profile 1, for 5 households.

Using the Crossflow turbine in Manica (Figure 5.4a) it is only the sites with the lowest average flow (sites 11-15) that show zero or a very low result for 100% and 80% of the year. The high flow sites 16 and 17 are within the Crossflow head range and can therefore provide close to (or more than) maximum power demand for these two sites. The five sites with the highest flow (1,2, 9, 16, 17) all provide maximum or close to maximum power output for 80% of the year. For the rest of the sites there is a large difference between the complete yearly coverage and the output level for 80% of the year, which indicates a short period of low flow every year.

The Tete results (and Niassa), are very similar to Manica for 100% of the year. But where Manica shows a higher power output for 80% of the year than what can be provided 100% of the year, in Tete the power output for 80% follows that for 100%. In Zambézia, the results are higher for all sites except site 9.

5.2.3 Installation cost

Installation costs are calculated for Manica province starting with total installation costs, cost per household and finally cost per kilowatt.

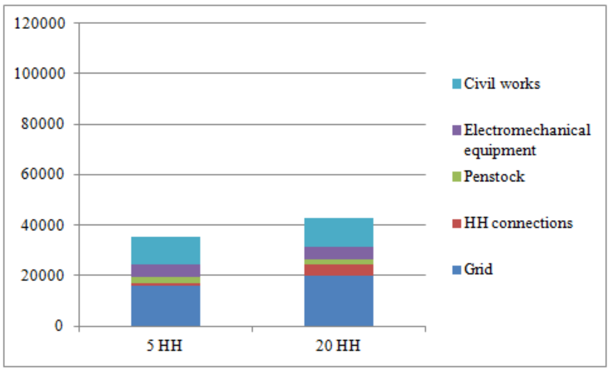
Total installation cost

Total installation cost is calculated for two scenarios, the scenario with no community contribution to the civil works, and the scenario where community contribution corresponds to 50% of the civil works cost. Table 5.14 shows the total installation costs for Crossflow and Pelton turbines, rounded to the nearest 100 USD, based on the cost estimates in Table 4.9. The cost for a Crossflow turbine supporting 80 households is disregarded since the small turbine cannot support even 50% of the demand from an 80 household community. The cost for electromechanical equipment for the Crossflow is based on individual costs for generator, turbine and Electric load controller, (ELC). In the Pelton case the cost is based on a total cost for electromechanical equipment, see Table 4.9. The length of the penstock is set to 300 m. All costs are presented rounded to the nearest 100 USD.

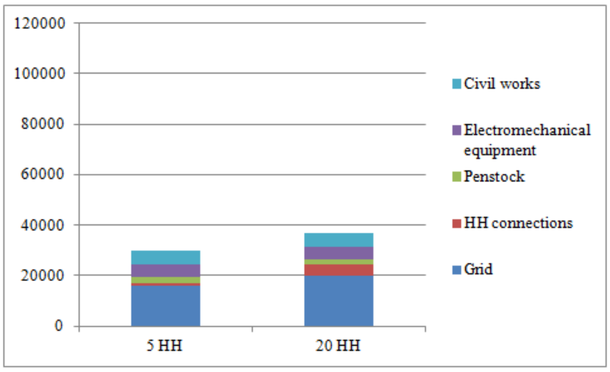
Table 5.14: Total installation costs for a system with a Crossflow (3kW) or a Pelton turbine (50kW), for 5, 20 or 80 HH. The costs are presented for the case with no community contribution to the civil works, and community contribution corresponding to 50% of the civil works cost.

Households	Installation cost [USD]			
	Crossflow [3kW]		Pelton [50kW]	
	no contribution	50% contribution	no contribution	50% contribution
5	35 500	29 800	93 000	64 700
20	42 600	37 000	100 200	71 800
80	-	-	114 000	85 600

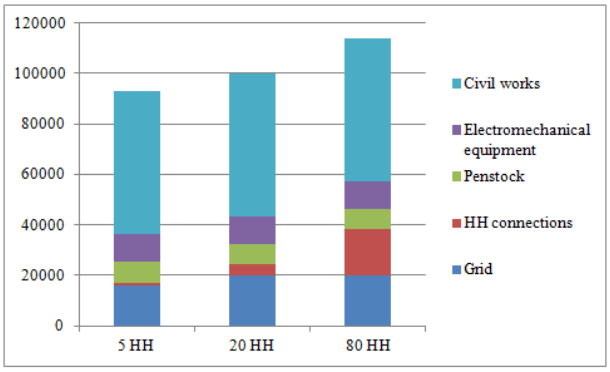
The distribution of costs is shown in Figure 5.5. The two factors contributing most to the cost are the grid cost and cost for the civil works. The civil works is the major contribution for the larger Pelton scheme, while the grid is the most costly considering the smaller Crossflow scheme.



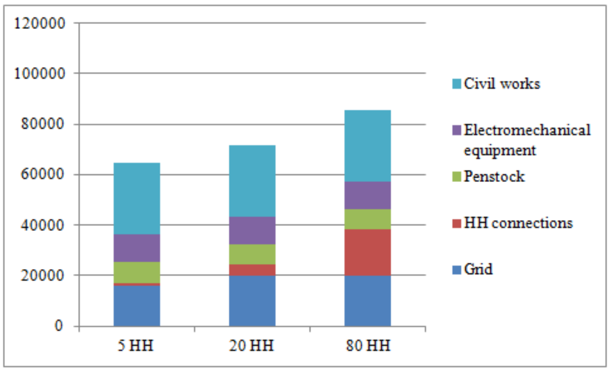
(a) 3kW scheme. No community contribution.



(b) 3kW scheme. 50 % community contribution.



(c) 50kW scheme. No community contribution.



(d) 50kW scheme. 50 % community contribution.

Figure 5.5: Cost components of the installation cost for the 3 kW Crossflow scheme and the 50 kW Pelton scheme with no community contribution to the civil works and community contribution corresponding to 50 % of the cost of the civil works.

Costs per household

The costs per household is not dependent on the system capacity. Table 5.15 shows the cost per household for the two turbines.. The cost of the Crossflow turbine for 80 households has not been included, since there is no case where the system can meet even 50 % of the maximum load demand.

Table 5.15: Cost per household in USD.

Households [HH]	Crossflow, 3 kW [USD/HH]		Pelton, 50 kW [USD/HH]	
	no local contribution	50% local contribution	no local contribution	50% local contribution
5	7 100	6 000	18 600	12 900
20	2 100	1 900	5 000	3 500
80	-	-	1 400	1 100

Cost per kilowatt

Two tables are submitted for installation cost reference. Table 5.16 shows the cost per kilowatt from the model. The cost per kilowatt is based on modeled maximum demand (see Table 4.8), not on the installation capacity of the two turbines.

$$Cost\ per\ kilowatt = \frac{Total\ installation\ cost}{Maximum\ demand}$$

For the cases where the Crossflow turbine cannot support the load demand, the price is disregarded. The table show results for a scenario with no community contribution to the civil works, and scenario with community labor covering 50% of the costs for civil works.

Table 5.16: Installation costs per kilowatt for ideal systems (Crossflow 3 kW and Pelton 50kW) based on maximum demand for nine different demand profiles. The costs are presented in the unit [USD/kW] for a scenario with no community contribution to the civil works and a scenario with community contribution corresponding to 50 % of the cost of the civil works.

(a) Cost per kW. Model outcome. Low consumption scenario.

	Low consumption				
HH	Demand	Crossflow		Pelton	
	[kW]	no contr.	50% contr.	no contr.	50% contr.
5	2.1	16 900	14 200	44 300	30 800
20	5.1	-	-	19 700	14 100
80	17	-	-	6 700	5 000

	Medium consumption			
HH	Demand	Crossflow	Pelton	
	[kW]	-	no contr.	50% contr.
5	4.1	-	22 700	16 800
20	7.1	-	14 100	10 100
80	19	-	6 000	4 500

(b) Cost per kW. Model outcome. Medium consumption scenario.

	High consumption			
HH	Demand	Crossflow	Pelton	
	[kW]	-	no contr.	50% contr.
5	5.7	-	16 300	11 400
20	9.1	-	11 000	7 900
80	29	-	5 700	4 300

(c) Cost per kW. Model outcome. High consumption scenario.

Table 5.17 shows examples of the approximate installation cost for a GIZ project, based on the same maximum demand. In the GIZ example, the number of households is estimated to 80 households for the large system and five for the small. The difference between model outcome and GIZ data is most likely explained by different ways of including equipment and labour in the calculations. The data for a GIZ project was not specified in terms of included equipment and labour, which makes it less reliable to use as a comparison to the model outcome. However, concerning a comparison of the two different turbines, the GIZ data can be seen as a more reliable source, since all data comes from the same person.

Table 5.17: GIZ installation cost per kW.

Households	Low consumption			Medium consumption			High consumption		
	Demand	Crossflow	Pelton	Demand	Crossflow	Pelton	Demand	Crossflow	Pelton
5	2.1 kW	4 200	-	4.1 kW	-	-	5.7 kW	-	-
80	17 kW	-	2 900	19 kW	-	2 600	29 kW	-	1 700

5.2.4 Validation of system power output

Figure 5.6 shows the system power output of the modeled Ndirire station. The system output is set to 26 kW, which is shown as the line in the figure. The committee member interviewed, stated that the problems with too low power output was mainly in October (dekad 28-30 on the x-axis). If the precipitation data is correct, October is the month directly after a longer period with low precipitation. This indicates that a direct relation with low precipitation and low system capacity, is not entirely accurate. If the problems with the water flow is only in the three dekads of October, the flow modeling shows a lower system power output than the station in fact possesses.

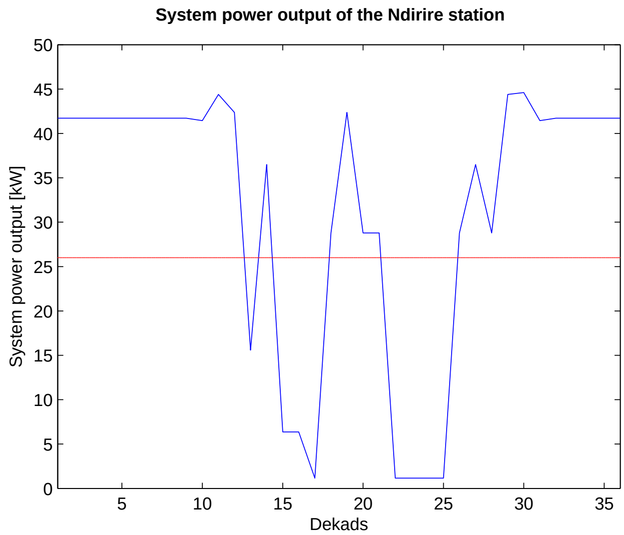


Figure 5.6: System power output with parameters close to the community Ndirire in Manica province.

5.2.5 Sensitivity analysis

A change of flow data for three sites in Manica, affects the modeled power capacity of the system. Annual flow data is first increased and then decreased by 10% for the three sites to analyze the sensitivity of the model. The change in power output is observed dekad by dekad. For some parts of the year the change in power output is 10% or less, which would be expected. But for other parts of the year, the power output changes more than 10%. Due to this the model is considered sensitive to changes in the flow. Table 5.18shows for how large part of the year the power output changes less than 10% due to the change in flow.

Table 5.18: Sensitivity analysis of flow. Part of the year where the system power output changes less than 10% ±10% change in flow levels.

	Part of the year with system power output change less than 10% [%]		
	Low flow site	Medium flow site	High flow site
Crossflow (increased flow)	81	86	100
Crossflow (decreased flow)	78	86	100
Pelton (increased flow)	42	53	64
Pelton, (decreased flow)	39	53	64

Table 5.19 shows how the system capacity is affected if the spread in flow level is increased or decreased. The method of measuring sensitivity is the same as when varying the flow level.

Table 5.19: Sensitivity analysis of spread of flow. The table shows part of the year where the system power output changes less than 10 % ±10% change in spread of flow.

	Part of the year with system power output change less than 10% [%]		
	Low flow site	Medium flow site	High flow site
Crossflow (increased flow spread)	58	78	81
Crossflow (decreased flow spread)	78	86	100
Pelton (increased flow spread)	52	53	47
Pelton, (decreased flow spread)	52	53	47

Increasing or decreasing the head data shows the sensitivity of the set head range in the model. Table 5.20 shows how many sites that fall within the head range when head level of all sites is raised or lowered by a certain percentage.

Table 5.20: Head sensitivity analysis - sites within the head range in the model.

Head	Crossflow	Pelton
0	17	11
+10%	17	12
+20%	17	14
+30%	17	15
+40%	17	15
+50%	17	15
-10%	17	10
-20%	17	10
-30%	17	9
-40%	17	7
-50%	16	3
-60%	15	3

Chapter 6

Analysis

The results from interviews and modeling are analyzed, in relation to the research questions, in the analysis chapter. First the barriers are analyzed in order of relevance. This is followed by an analysis of the results of the technological and resource potential evaluation.

6.1 Barriers to pico and micro hydropower

Main barriers and most mentioned barriers are described and analyzed together with mentioned ways of overcoming barriers in this section. Comparisons with barriers from literature are done when relevant.

6.1.1 Main barriers and most mentioned barriers

The four barriers most respondents have mentioned are *Lack of access to finance*, *Lack of grid code and feed-in tariffs*, *Lack of proper maintenance* and *Poor knowledge management*. Lack of access to finance, Lack of proper maintenance and Lack of grid code and feed-in tariffs are also selected as main barriers by some respondents. Other main barriers are *Limited rural infrastructure*, *Lack of access to spare parts*, *Lack of local involvement*, *Poor design*, *Scattered population in communities*, *Lack of investor interest*, *Lack of supporting legislation*, *Poor payment management*, *Lack of water resources* and *Long distance transmission*. Results concerning these barriers are analyzed below. It is important to keep in mind that many of the barriers are connected, impacting each other.

The opinions concerning funding are the most unanimous; half of the respondents have described the lack of access to finance or lack of interest from investors as one of the main challenges for pico and micro hydropower. Finding finance is a major problem for all instances.

The hope lies in FUNAE or banks to provide loans and grants to private operators. But both the banks and FUNAE are perceived as unwilling to provide funding by requiring guarantees. The National Directorate for New and Renewable Energy tries to attract investors to gain more finance for FUNAE. If the idea of FUNAE as a credit agency gains support, that function could be facilitated by using for example a local micro finance institute or a bank as an intermediate point.

A future connection to the main grid is a potential way of increasing investors' interest, in many respondents opinion. Therefore, barriers against grid connection are seen as barriers against hydropower development even for off-grid application. A feed-in tariff program for renewable energy will be introduced in a foreseeable future which obliges EdM to buy electricity at a set price. The interest from private operators is believed to increase with this in place. Similar programs are already in place in other countries like Rwanda and Kenya. In Rwanda, the change in legislation was made this year (RURA, 2012) and the effects are yet to be shown, however in Kenya it has resulted in stimulation of new hydropower stations (Hankins, 2008). However, the lack of feed-in tariffs, hindering private sector participation is an issue addressed only by stakeholders in Maputo. Stakeholders in Manica either express grid connection as a less important issue or have the perception that the problem is already solved with feed-in tariffs on its way.

Consultants and donors discuss ways of lowering the administrative costs to make pico and micro hydro projects interesting for international funding agencies. The alternative of not providing more funding at all, but instead capacitate FUNAE so that the finance management is more effective, is presented. This discussion is not brought up by FUNAE itself.

One of the reasons for the lack of interest from banks is presented as their unawareness of the benefits of pico and micro hydropower. This corresponds well with the stakeholders' general perception of the level of common knowledge of pico and micro hydropower in Mozambique today. Most stakeholders claim the common knowledge level is low. As mentioned in literature, lack of awareness of a technology is considered hindering the development. With low awareness banks are more unwilling to provide funding and consumers are skeptical to the new technology.

To increase the awareness of pico and micro hydropower, knowledge needs to be spread. Not many of the barriers to spreading knowledge have been stressed by more than one stakeholder, pointing at a lower relevance, or a barrier yet to be discovered. Stakeholders see different weaknesses in the process, but at the same time they present ways to overcome the barrier by suggesting alternative ways of spreading the knowledge. The lack of a body for meeting and sharing information is expressed, along with the need for proper documentation. This is mentioned in earlier studies of barriers to pico and micro hydro development (FAO, 2008), and considered important for knowledge spread. A problem only brought up by international consultants, and not by Mozambicans, is the risk of educated people advancing and moving abroad to obtain higher salaries where the presented solution is to offer higher salaries.

The strategies on how to spread the knowledge are many. The NDRE plans to do a road show and inform people about the technology. Many positive experiences have been lifted during interviews, of study visits to other countries or to communities with hydropower stations in operation. Some of the active organizations share an office in Chimoio, which facilitates knowledge sharing. The plans of a "Centre of excellence", to educate designers of pico and micro hydropower stations, is welcome. The local NGO intend to improve their documentation routines together with the international governmental entity, to ensure the knowledge remains. If the universities cooperate around the "Centre of excellence" this will also prevent the valuable experiences from disappearing with the international organizations and donors. However, most suggestions for spreading knowledge are focused on Manica province. None of the respondents have mentioned if it will spread to the rest of the country.

Lack of proper training of operators is the last aspect brought up while discussing knowledge diffusion, where poor spread of knowledge leads to failure of power stations. This has only been addressed by two stakeholders. Others say sharing knowledge with operators has worked well. Good training is manageable, although quite difficult.

This could be contradicted by the fact that most stakeholders discuss lack of sufficient maintenance as a barrier. Three of the stakeholders see lack of proper maintenance as one of the main barriers. Damaged equipment and station break downs due to mismanagement have occurred. However, there are more factors influencing the quality of maintenance than operator training. Some bring up lack of understanding the purpose of maintenance as a cultural problem, lack of finance to buy spare parts and problems with administrating funds for maintenance. Lack of access to spare parts is not seen as a main factor hindering maintenance, although it is seen as a main barrier by one of the respondents, which indicates it might be of extra importance. The same respondent explains it can be overcome by holding a stock of spares though it would add an extra cost component. In addition, privately owned hydropower stations do not often use additional equipment like meters. A decision to add more advanced electric equipment could make lack of access to spare parts more crucial.

If the electricity prices are too low to reflect the true cost of running a pico or micro hydro station, that could lead to poor maintenance, as experienced in Kenya (Kirubi, 2009). The stakeholders express problems with tariffs set too low to cover maintenance and operation costs, indicating a similar situation. No clear solution is brought up to this problem.

Many are aware of the fact that mismanagement of the power stations imposes a great risk, and suggest ways to ensure well functioning maintenance. One suggestion is to do capacity building of local manufacturers who could support maintenance of the power stations. Another is to keep the design of the system at a basic level, which would decrease the level of technical expertise needed to operate the station. It is brought up as an important factor to reduce the number of mechanically advanced components and bearings. To ensure basic design is seen as a major challenge by one stakeholder. However, he has no personal experience of pico and micro hydropower and merely speculates what level of technical expertise is required for such a system.

The most important component of successful maintenance brought up by most stakeholders, apart from proper training, is that community members and operators should be closely involved in the whole project process and see the benefits of it. This is supported by literature (Alzola, 2009; Murphy, 2001; Maher, 2003). There is an awareness that community involvement is necessary for the sustainability of the projects. The importance of a feeling of ownership and lack thereof is discussed in relation to this. Many of the stakeholders have described a change in opinion on the importance of these matters. Stakeholders' personal experiences as well as shared experience from projects, where lack of focus on community involvement to make local people feel like owners leads to project failure, has put the issue on the agenda. Today stakeholders seem to discuss, to a larger extent, how to increase local participation.

Three of the respondents see mobilization of communities, when initializing a pico or micro hydro project, as a main challenge. These are the two donors and NGO B employees. NGO B employees have much experience in the field and covered the subject thoroughly since part of the NGO hydro project is to show different ownership models in use. However, identified barriers connected to community relations mainly originate from using community owned models which are uncommon in Mozambique.

The choice of ownership model is seen as essential. Respondents have mentioned earlier experiences with projects failing or being delayed due to difficulties to manage maintenance or problems with community conflicts. It is in some cases difficult to say how much of the experience comes from projects in Mozambique and other countries respectively. The interviews show most respondents advocate a private owner model. This might be based on earlier experience of community based projects with sustainability problems. The political changes Mozambique has gone through, since the country's socialistic past, could also be a factor of influence. A private owner model might be favored due to mistrust in the community owned models associated with socialism.

No barriers specifically originating from a private owner model have been brought up during the interviews in Mozambique. Although when discussing payment barriers, some mention the risk for the operator to be unable to pay back loans for the equipment. It is unclear if this risk is considered when the equipment is community owned. The employees from the international NGO say the model is preferable from a sustainability perspective once the hydro station is in place. However, the construction phase is difficult since it is the owner who mobilizes the community. One reason to why no other respondent has mentioned any barriers connected to community relations within a private owner project can be lack of experience.

Relations with, and relations within, a community with a private owned model are mentioned in several circumstances, like management of maintenance and availability of funds. However it has never been expressed that the owner model in itself is the problem. Stakeholders working with private operators have strategies where previous knowledge of the operator is highly valued and used to motivate for further development of the power station. So far, the respondents seem to agree this is a successful concept.

To hand over both ownership and management of hydropower stations to small local companies situated in rural areas on a "fee-for-service" programme, as experienced in Zambia (Ellegård et al., 2004), has been discussed concerning FUNAE's projects. In Zambia it was considered as a way to facilitate access to finance. With a similar financial situation in Mozambique, where banks are uninterested, this could be an alternative. However, it relies on companies, capable of taking this role, being present in rural areas.

It is often mentioned how, if a system fails to deliver continuous electricity, the customers get disappointed. In addition, when the word of well functioning systems spreads, many expect this will increase investors' interest. From a system design point of view, two respondents see the poor quality of system design and feasibility studies as main barriers to the development. There are examples where stations have stopped running, or not even been completed, due to poor studies in early stages of projects.

The continuous delivery of electricity also depends on year-round water supply. Two respondents see lack of water resources as a main barrier. None of the respondents have mentioned the problem of rivers originating from outside of Mozambique, increasing the vulnerability of the water resources. Problems have however been observed locally when a dam built by FUNAE reduced the water flow for a pico scheme down streams. The reason for this is unclear, but it might indicate the importance of communication between entities within the country. If pico and micro hydropower spreads, problems with activities out of Mozambican control could pose a barrier. What has been mentioned by a few respondents are other uses of the water resource competing with hydropower. For example irrigation could be a down stream activity, which is affected by the power station.

Using multiple-jet turbines, or other designs to increase the part flow efficiency, is not mentioned. To choose a low rated flow for the turbine limits the output capacity the whole year around. A higher rated flow with increased part flow efficiency could maybe be a better alternative. Using alternative renewable techniques as a complement, like solar PVs, to secure the yearly electricity supply, has not been mentioned either. The only suggestion brought up to have continuous electricity supply was to add a diesel generator to the system, as a back-up during the dry season.

The problem with climate change, and how this makes flow forecasts unsure, is only discussed by the international NGO. This could be because there is not much reliable flow data in Mozambique to start with. Improving the availability of high quality data will of course make it easier to select potential sites. To select sites based on political preferences rather than data, as could be the case today, could result in unsuitable schemes and bad examples for future investors.

The barrier concerning the location of the river is mentioned in literature, but only considered by a few respondents. There is an awareness that not all parts of the country are suitable for implementing hydropower, so the specific barrier of long river - community distance could be included in these discussions. It could in any case be important to consider, since a respondent describes how the problems are specific for Mozambique due to seasonal flooding.

The Mozambican geography and demography cause a problem. Opinions accord with those found in literature on the importance of existence of infrastructure and conditions of roads in remote areas. However, the opinion on the magnitude of the problem varies significantly. Either it is seen as part of infrastructure development, where roads need to be built to reach these remote areas nevertheless. Or it is seen as a factor influencing the potential of the technology since building a road adds a cost component to an already high investment cost. All stakeholders agree accessing a site cause difficulties, however only stakeholders situated in Maputo consider it a barrier to the development.

Many of the stakeholders see the low population density in Mozambique as problematic. However, similarly to the issue of improving poor infrastructure, some see urban planning as part of the development of a community. For those who don't want to move, an alternative mentioned is a battery charging station centrally situated. Two of the stakeholders see scattered communities as a main barrier, however they do not have specific experience of micro and pico hydro and it may therefore be considered a more general barrier to rural electrification.

It is apparent that the awareness of the laws and policies relevant for pico and micro hydropower is not enough, or at least that the perceptions differ. The local NGO finds it a main challenge that the government is not visible enough in the work with electrifying Mozambique by initiation of hydro projects. The respondent who tells of supportive policies just waiting to be used for doing wonders, probably has a closer cooperation with governmental employees than the local NGO. Governmental visibility could be improved to increase the awareness.

The choice of payment system affects the sustainability of a hydropower project. On one hand the customers should be able to afford electricity. The correlation between electricity use and price should be reasonable. The unfairness of the flat rate system is even brought up as a main barrier by FUNAE B. On the other hand the operator needs some sort of guarantee that the revenue will be enough to pay off the loans for the equipment. There, the prepaid system can introduce a difficulty. EdM has had a lower income from introducing prepaid meters. The baseline study needs to be done properly to ensure enough demand for the fund generating mechanism to hold.

The level of problems with payment probably reflects the general attitude in the community. NGO B employees have experience of different communities in several countries. They describe how they can solve all problems in some communities during meetings, while in other communities they are not even told what the problem is. The example of breached meters was handled by the community itself with help from the district council.

Barriers mentioned connected to demand correspond well to those discussed in literature. The general low demand in rural areas and difficulties to find and promote productive use in the areas, are both discussed by many respondents. Two reasons for a low level of productive use have been mentioned; directing electricity use to productive use has not been prioritized and a general difficulty of finding productive use activities in the surroundings of the power station.

Local stakeholders, who work directly with communities that have pico and micro hydro, say there are ways to increase productive use, like promoting industrial agriculture. Stakeholders in Maputo that have mentioned increase of productive use claim it is a difficult task that needs legislative support from other ministries than Ministry of Energy.

Well corresponding with the perception of a low demand in Mozambique is the fact that no stakeholders say the power stations have a too low capacity. Consumers use less electricity than expected. NGOs working with the hydro projects express a concern that over sized systems are common, where the cost of the projects is not justified by the low demand.

Many stakeholders believe in a future increase of demand for electricity, though the opinion varies on whether it is difficult to increase the capacity of a system or not. This could be because stakeholders discuss different sizes of the power systems. Also, experience of expanding systems is low. It is associated with a cost and an increased level of technical expertise needed to operate and maintain the system.

If electricity for cooking would spread in Mozambique, this would lead to an increase in demand. Despite a low demand in rural areas none of the respondents have pointed out lack of demand as a main barrier to pico and micro hydro.

FUNAE and the local NGO (NGO A) have opposite ways of managing their funds, for which both have been criticized. Choosing not to reinforce the canal has lowered the reliability of water resources of the power station in Ndirire, since water is allowed to leak out. But there are funds left to provide another community with electricity. Since a way of spreading knowledge about pico and micro hydropower is inviting other communities to see functioning stations, it can be argued that the stations should be made as reliable as possible. But semi-functional examples with a lower investment cost could perhaps also be interesting to communities with low investment capacity.

6.1.2 Less mentioned barriers

The relatively high investment cost associated with pico and micro hydropower is not brought up by any of the respondents when discussing main barriers, although this is described in literature as a cause for financiers to exclude pico and micro hydro in their funding programs (WB, 2008). This could be interpreted as if the investment problems are rather seen as lack of finance than too expensive equipment. However, ways to reduce the costs are still discussed. Respondents with experience from Zimbabwe and the shareholder model consider the communities contribution a way to lower the costs for construction work and materials. The same reasoning is found in pico and micro hydropower projects in Kenya (Maher, 2003). Those who have experience of the private owner model do not discuss this, but if the operator could hire community members as construction workers, maybe this would still have an effect on the investment cost. In the Ndirire example the operator constructed the canal all by himself, which must have saved money.

The general ability to pay is by some considered very low. However, some respondents perceive that the social benefits gained by electricity have such a great impact, that the willingness to pay is high.

Low quality of locally produced equipment is the most common barrier associated with availability of equipment. It is brought up by many of the respondents working closely to the small hydro projects. Despite disadvantages of using low quality equipment, locally produced equipment is considered a good alternative, since it creates work opportunities, increases the knowledge of the technology on a local level and is the low cost alternative. Locally situated representatives of both FUNAE and EdM encourage the use of locally produced equipment, even though it is not used in governmentally initiated projects. No direct solutions on how to increase the quality of locally produced equipment have been brought up during the interviews. However, the quality is said to have increased with time which suggests that it is a matter of learning in progress.

The alternative to import equipment is argued a good solution to ensure a high quality. However, the high import duty is considered a barrier since it adds an extra cost which can be unfavorable where high investment costs are already a problem. The government is aware of this but no solution or plans to lower the duties like in other countries have been mentioned by any of the governmental representatives interviewed. Still, they mention it as disadvantage, showing it is not a hidden problem.

There are some barriers the literature describes as main barriers, which Mozambican stakeholders mention but do not consider as main barriers. Lack of adequate data on hydro resources and lack of awareness of the technology are two of them. Concerning lack of awareness, the stakeholders have focused more on the barrier of lack of investor interest, where lack of awareness of the technology is mentioned as part of the problem. In addition, poor knowledge management is indeed influencing the level of awareness in the country today and in the future. Stakeholders express a demand for more awareness, even though they do not see the current level of knowledge as a major problem.

Concerning data collection, there is no database for potential hydropower sites in Mozambique. However, not many stakeholders have mentioned this explicitly as a problem. Instead each organization describe how they gather data. FUNAE representatives say there is data, but it is scattered which makes it difficult to retrieve. To overcome the lack of data, FUNAE does measurements for a hydro atlas. Google Earth facilitates the selection of sites. However, on a local level there is no one doing measurements continuously. The stakeholders talk about activities in Manica province to improve the data collection, like involving universities. Since only few have said explicitly that there is a lack of data, the barriers might rather be longer handling times, where the need for one year measurements slows down the development and collection of already existing data is time consuming. This is interesting since hydropower development is highly dependent on the access to measurement data.

6.2 Technological and resource potential model

In this section are the results from the model analyzed. The results from the interview section can in some cases be used as a reference to the results. First, the reliability of the water resources when using a Pelton turbine (50 kW) is analyzed, to see on what level continuous electricity supply can be provided throughout the year. Next is analyzed the ability of the locally manufactured Crossflow turbine (3 kW), to complement the Pelton already in use in Manica province.

6.2.1 Pelton turbine

The results from modeling the Manica sites using the Pelton turbine show how the annual dry periods of Mozambique could be a problem for all the sites. The model is over all very sensitive to variations in precipitation, and renders zero or a very low output when the precipitation is low. In reality the water flow will be less sensitive to precipitation. Due to periods of very low precipitation, the sites with low average flow cannot cover any load continuously. Communities with load profiles 1 and 2 will have their maximum demand covered only half of the year for the sites with the highest flow. The best result is from sites 1 and 2, which are the sites with the highest head and flow combination.

The respondents value reliability of water resources. A hydropower station must produce enough electricity for the customers to appreciate it. Using this model, the 50 kW Pelton would not be a very good choice of turbine, not for the low flow sites, but hardly for the high flow sites either. This is, assuming that the flow is directly proportional to the precipitation.

Estimating the results for Niassa, Tete and Zambézia, the higher precipitation in Zambézia is visible for some sites. But still, to consider the Pelton turbine the communities would have to be satisfied with electricity during only half of the year. Tete province is modeled with the same head levels as Manica, but the results still differ a lot from Manica, due to the difference in precipitation levels.

6.2.2 Crossflow turbine

The Crossflow turbine is different from the Pelton turbine both in function and in size. All Manica sites are within the head range of the turbine, which allows for all sites with high flow to produce maximum power for at least 80% of the year. The rated flow level is low for this smaller turbine, which means it is not as sensitive to flow variations as the Pelton. This results in a longer period of the year with a power output above half of the demand, for some sites. The maximum output of the Crossflow turbine can only cover the lowest load profile. In Manica, the Crossflow turbine fully covers this demand for two sites, and partly covers it (80% of the year) for four sites.

6.2.3 Comparison of the two turbines

Comparing the two turbines, the Pelton can have a much higher power output, but only for half of the year. There are no sites where the Pelton covers the lowest demand fully, and only two sites where it covers the lowest demand 80% of the year. The results for Zambézia, Tete and Niassa show a similar pattern. So installing a small turbine gives a higher power output than a large one, if the flow is low.

For a community with a low demand where the maximum output of a small turbine is enough, it is better with a small turbine than a large one. The large turbine has a higher rated flow which makes it inefficient when the flow is lower. For sites with low head, it is better with a Crossflow turbine. The head range of the Pelton excludes sites that might instead be suitable for a Crossflow turbine.

Using the model to find ways to improve the potential for pico and micro hydropower, it is clear that an important turbine parameter is the rated flow. If the turbine is designed for a flow level that is too far from the actual flow in the system, the output power is affected considerably. Since the flow levels vary significantly in all four provinces, using a turbine with a boosted part-flow efficiency would improve the efficiency of the system. To use several Crossflow turbines could be an alternative to one Pelton, since this would increase the capacity during higher flow and still cover important loads during low flow.

6.2.4 Installation cost

The outcome of the cost part of the model can be compared with examples from literature and interviews. The Ndirire case described in Subsection 4.2.3 *Field surveys*, has a cost of 650 USD/HH, which is less than the results obtained with the model for a Pelton turbine in a community of 80 households in a high consumption community profile. This is true for both a scenario with no community contribution to the civil works and when the community contributes with 50% of the cost. However, the civil works is the major part of the installation cost for the 50 kW Pelton system and both the canal and forebay tank of the Ndirire station was constructed by the operator, which could have corresponded to more than 50 % of the civil works cost. Stakeholders have suggested larger contribution from the communities in the construction phase to lower costs. It would be considered a good strategy according to the cost calculations. To capacitate the community members to do civil works properly reduces the total cost of the hydro scheme. The reference data from FUNAE indicates the cost would be 6 300 USD/HH, which indicates the two cost calculations are based on different cost components.

The cost per kilowatt from the Ndirire example is stated as 1 900 USD/kW if the output capacity is assumed to be 26 kW all of the time. This is comparable to the high consumption case of 80 households in Table 5.16 with a cost of 4 300 USD/kW or 5 700 USD/kW with or without community contribution respectively. The cost is calculated based on a demand equal to maximum demand of the high consuming 80 household case, 29 kW. Once again, the high cost of the civil works could be a reason for the difference in price. Furthermore, the cost per kilowatt is in the range of the examples in the IRENA work paper (IRENA, 2012b) for the Ndirire case. The cost calculations for 3kW system in the low consumption case of 5 households are fairly high compared to literature. The grid cost is the highest cost, as mentioned by many stakeholders. It indicates it is an important field to do further studies. With an optimized grid design, the costs can be reduced. The grid model also poses an uncertainty to the result since it is a simplified model.

According to the results of the installation cost modeling, the least expensive system per household would be to share a large system for many households. It encourages to ensure a high demand at a site when selecting it. If the demand is as low as 2 kW, the Crossflow system with a low output capacity is a better selection from a installation cost perspective than the Pelton system, both according to the model and the reference data from FUNAE, (even though the costs are different among themselves). Especially if the grid cost can be reduced by selection of a good grid design. However, an important factor not to neglect is that a small system with less customers generates less revenue from the customers to the operator. A larger system might be favourable even if the installation cost is higher if it guarantees a revenue to the operator to pay for operation and maintenance costs. However, it assumes the hydropower station can run during most part of the year. More detailed calculations of cost per kWh, where the time perspective is included, would be needed to draw any conclusions concerning this.

Chapter 7

Discussion

In this section the relevance and credibility of the method and results are discussed, and further studies are suggested.

The field trip to Mozambique has been of great value for the modeling of technological, geographical and demographical factors of the pico and micro hydropower potential in the country, as well as the mapping of barriers. An awareness of the work done by involved stakeholders was obtained, concerning the current technologies preferred and the available equipment. The data provided in interviews and visits has been a good reference when comparing data from articles of hydro projects.

A first selection of respondents was done before arrival in Mozambique. The selection was based on knowledge of the power sector structure and what actors could be considered as important stakeholders. However, most respondents were defined in the capacity of their roles, for instance *private actor*, without specifying a company. Instead, the final selection was decided upon arrival in the country. The first interviews were facilitated by Prof. Cuamba at the Eduardo Mondlane University, and thereafter respondents were asked for examples on who to talk to next. The strength in this method is that it lowers the risk of leaving an important stakeholder out due to lack of previous knowledge.

The selection of stakeholders closest involved in the development of the technology, may present a polarization of the results, since respondents convinced of the advantages of the technology might miss some of the barriers. All respondents were from the capital, or areas in Mozambique and Zimbabwe, where pico and micro hydropower was implemented. Further research could be to compare the perception of these respondents with the opinions of stakeholders from other provinces.

Using semi structured interviews with open-ended questions opens up for the respondents to direct the discussion. Not all themes are covered to the same extent in the interviews, which may have lead to some barriers being left out by stakeholders. Other sources of uncertainty in the results are misunderstandings due to miscommunication. In addition, the interpreter used in three of the interviews was not professional, increasing the risk of misunderstandings in these interviews. To minimize the number of misunderstandings, additional questions to clarify were asked as often as possible.

The content of the interview guide was updated after each interview, to improve the quality of the questions and minimize the risk of leaving out subjects where barriers could be brought up. Furthermore, no standard questions addressing ways to overcome barriers were included in the guide to not influence what barriers where expressed by the stakeholders. Instead, the ways to overcome barriers were asked for as follow up questions to the extent it was possible. This could have lead to less examples of ways to overcome barriers addressed.

The choice of codes used in the analysis has affected the results. Some codes address barriers which can be part of a larger barrier, for example where lack of access to spare parts can be one reason to poor maintenance. This choice was made to give a more detailed mapping of the barriers. In those cases where barriers depend on each other they are analyzed together.

The assumptions and limitations of the model used in this thesis, are stated in the method section. However, some areas require further discussion.

The flow is modeled based on the precipitation data of the respective provinces, and it has been stated in the method section that the behavior of water on the ground has not been taken into account. Although it is clear that the level of flow in rivers does not have a linear relation with the level of precipitation in an entire province, the sensitivity of the flow data can still be studied. The importance of the rated flow of the turbine is clearly shown, and the extrapolations indicate conditions for the provinces, relative to Manica province. This comparison should still hold, if there are no other major differences between the provinces that would have an influence on the flow, for example the presence of water storing cavities.

The potential shown can, due to the flow modeling, be considered a worst case scenario. Since the system capacity in real schemes will probably not be as much affected by low precipitation levels as indicated in this thesis, the potential should be generally higher.

The comparison between turbines of both different functions and sizes limited the conclusions possible to make, since the qualities were difficult to separate. Having modeled the smaller Pelton turbine would have given more information. This was not considered in the work process, but can be suggested for future studies.

The load profiles were designed with electrical application data from Tanzania, estimating the usage of these applications with reference to the field survey to Ndirire. Only using one example of load profile can be considered insufficient, but the use of electricity can be expected to change in time, so accurate estimations would still have a short life length. The power levels modeled are clearly stated and more emphasis is put in exemplifying possible applications of the kilowatts obtained, than ensuring there are communities with this demand profile.

The data supporting the modeling of the installation costs are gathered from different examples of projects. Some costs were more aggregated than others, which introduces an uncertainty in the calculations. The results deviate from references provided by the FUNAE employee, which indicates that there are costs not accounted for in this report, such as transport, salaries and the difference in civil works between the different sizes of schemes. To include transport would add a variable of remoteness to the model, which could be considered in future work.

Even though it is unclear what costs were included in the presentation of the Ndirire scheme, this investment cost is closer to that of the model outcome for the Ndirire site.

There are several parameters discussed in this report that could change in a long term perspective. Some respondents hope that the electricity demand will increase in rural areas, and if this happens the limited power output from the rivers could be too small to meet the demand. The river flow could be affected by climate change, making it difficult to choose a suitable system.

The most important delimitations to keep in mind when studying the conclusions of this report, is firstly that there is very little data to base calculations on. Secondly, since the model assumes linearity between precipitation and river flow, the real power output is probably higher than the calculated. This demands further studies to come nearer the actual potential for pico and micro hydro, but it can be concluded that in some cases the calculated output is enough to cover a certain low demand.

For future research, the investigation of other types of turbines is interesting. The ability to more efficiently use the power available in rivers would be interesting for investors and possible operators in Mozambique. One way of doing this is maybe by using part-flow efficiency raising techniques like multi-jet Peltons or Crossflows with divided nozzle. An alternative could be to investigate the potential, in Mozambique, for Integrated Renewable Energy Systems (IRES)[1], where hydropower is complemented by other sources of energy, for example solar.

[1] Integrated Renewable Energy Systems utilizes different renewable energy resources such as hydro, wind, solar radiation and biomass with different conversion technologies and end-use technologies to met energy needs (Ramakumar, 2012)

Chapter 8

Conclusion

The aim of this report was to investigate the potential for utilizing pico and micro hydropower to boost electrification in remote areas of Mozambique. Three research questions were used to estimate the potential. The first two research questions were: "What are the stakeholders' opinions on existing barriers for utilizing pico and micro hydropower in rural Mozambique?" and "What are the stakeholders' opinions on the possibility to overcome these barriers?"

18 stakeholders were interviewed during an eight week visit in Mozambique. When analyzing the results from the interviews, three barriers were among the most frequently mentioned and were also addressed as main barriers by the respondents. These barriers are *Lack of access to finance*, *Lack of proper maintenance* and *lack of grid code and feed-in tariffs.* A complete list of main barriers is found in Table 8.1. Some barriers are interrelated, which is described in Chapter 6. There are cases where new barriers are presented to the ways to overcome a barrier, as in the case of increasing interest of investors as a way to facilitate access to finance. Some barriers are more specific to the hydropower technology such as lack of water resources and poor design, although most barriers could be addressed as barriers to rural electrification in general.

A comparison with literature on barriers to pico and micro hydropower development shows stakeholders in Mozambique acknowledge all barriers mentioned in earlier studies. However some barriers are considered main barriers in literature, but not by Mozambican stakeholders. These barriers are the lack of adequate data on hydro resources and lack of awareness of the technology. Lack of data is mentioned as a problem by some, while instead some stakeholders explain new ways on how to collect data. Concerning lack of awareness, the stakeholders have focused more on the barrier of lack of investor interest, where lack of awareness is mentioned as part of the problem. In addition, poor knowledge management is indeed influencing the level of awareness in the country today and in the future. Stakeholders agree that the awareness needs to get higher even though they do not see the current level of knowledge as a major problem.

Barriers connected to the Mozambican geographical and demographical conditions (lack of water resources, scattered houses, lack of infrastructure) are only brought up as main barriers by two stakeholders without personal experience of pico and micro hydropower.

From the model results, it is shown that there is potential for pico and micro hydropower in Zambézia. Even though the head levels are set lower than in Manica, the measured precipitation is higher for a longer period of time, which compensates for the head loss.

Lack of water resources is mentioned as a main barrier to pico and micro hydropower development. The results from the model show that annual reliability can be achieved by the pico Crossflow turbine. The demand can of course not be larger than the maximum output of the turbine. Since respondents experience a low demand, specific for rural Mozambique due to low interest in using electricity for e.g. cooking, a pico scheme could be sufficient for many communities.

The potential for utilizing pico and micro hydropower to boost electrification of remote areas of Mozambique depends on many factors. Barriers are recognized by stakeholders, and several ways of overcoming them are presented. Of the solutions presented to overcome important barriers, some are already started or at least planned. The Ministry of Energy is negotiating for feed-in tariffs that are believed to increase the investors' interest for hydro. A "Centre of excellence" is started by foreign actors together with four universities in Mozambique, to increase the technical expertise and awareness of the technology. Hopefully, this will also lead to an increased capability of selecting sites for schemes, which will add to the number of functioning schemes. Local manufacturers get capacity building from organizations,

Table 8.1: Barriers to pico and micro hydropower development and ways to overcome these barriers. Text in italic shows solutions only brought up by one respondent. *Some respondents say the problem does not exist.

Barrier	Ways to overcome barriers
Lack of access to finance	increase interest of investors provision of loans and grants from FUNAE *lower administrative costs* *capacity building of FUNAE*
Poor knowledge management	proper documentation introduce a body for meetings make study visits offer higher salaries to keep educated personnel increase university involvement
Lack of proper maintenance	capacity building of local companies or manufacturers *ensure electricity prices reflect operational costs* *hold a stack of spares* ensure basic design increase local involvement
Lack of water resources	*combine with diesel generator system*
Limited rural infrastructure	include infrastructure in project proposal
Scattered population in communities	urbanize community structure *include battery charging system*
Lack of supporting legislation*	no solution mentioned
Poor payment management	let electricity prices reflect electricity use
Low demand and low level of productive use*	promote industrial agriculture *give fiscal benefits to small industries*
Lack of investor interest	enable future connection to main grid promote and display functioning cases increase awareness of the technology
Lack of local involvement	adequate choice of ownership model value previous knowledge of operators ensure community participation during the construction phase
Poor design (complexity)	minimize number of advanced components
Lack of grid code and feed-in tariffs	introduction of feed-in tariffs

to provide an alternative to expensive imported equipment, and possibly create a continuous access to repair and maintenance resources. NGOs and organizations discuss payment administration and different owner models, and they make study visits to share experiences and knowledge.

Barriers not addressed with a solution from the respondents, might pose a threat to the potential of pico and micro hydropower. Respondents not working closely with the government experience a low political interest. This must be met with an increased visibility of policies and legislation. Projects stopping due to administrative conflicts or misunderstandings delay the development of the technology. To increase the investor interest of pico and micro hydropower, functioning schemes must be completed and displayed to stakeholders. Capacitating involved actors in administrating projects, could improve the conditions.

Future studies proposed, based on the results in this report, are for example to compare the perception, expressed by the stakeholders in Manica province, of the potential for pico and micro hydropower, with stakeholders from other provinces. It would also be of interest to do more studies on increasing the reliability of the water resources. An alternative could be to investigate the potential, in Mozambique, for Integrated Renewable Energy Systems (IRES), where hydropower is complemented by other sources of energy, for example solar. Another interesting topic would be to evaluate the possibility to improve designs of local turbines, by increased part-flow efficiency, or by reducing losses in the turbine.

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Appendix A

Interview guide - FUNAE B

Introduce subject

Names

Background: We are doing a study on the potential of using small-scale hydropower in rural areas of Mozambique. The study is a part of the larger project STEEP-RES organized by Swedish SIDA. We would like to ask you about your opinions on small-scale hydropower. And by small-scale we mean pico and micro hydropower stations, with a capacity up to 300 kW. The project is in two parts, one that consists of making interviews and gathering stakeholder opinions, and the other to make a techno-economic model. The questions asked about data are to help us make the model as realistic as possible.

We brought a recorder to be able to listen to the interview afterwards. It is only for us and our project. Is it okay with you that we record the interview?

Introduction questions

1. Would you like to tell us your name and what it is you work with?
2. What is your experience of small-scale hydropower?
3. What is your experience of other types of rural electrification?
4. What are your current projects in Manica Province? For how long?

Economic barriers:

Investments

(Investments available. What attracts investors. Reasonable loan conditions.)

1. Can you get funding for an off-grid small-scale hydro power project? How?
2. What kind of funding? Loans, grant.
3. What would be the normal loan percentage?
4. What would the interest be? Depreciation time?
5. Is there available data on your investment costs for SSH projects? Usual cost? Cost distribution? (civil works, pre-feasibility, design etc)
6. From your point of view, what is interesting in an electrification project? Local investors? Governmental? Foreign?
7. Are there ways to increase investors' interest in small scale hydro?
8. Is small scale hydro a reliable technique?
9. Do you think the decentralization will make a difference? District funds.

Consumer prices

(Consumers having problems paying electricity bills. Consumers willingness to pay.)

1. How do customers pay for electricity from SSH? How much?
2. How have payments worked so far?
3. Are there problems with payment?
4. Do you see any good solutions to problems with payment?
5. Are people in rural areas willing to pay for electricity? Why/Why not?
6. Do you see any way to increase the willingness to pay for electricity?

Technical barriers:

Suitability

(Available sites near villages, suitable topography and hydrology. Suitable village structure.)

1. How much data is available for selection of SSH sites? (hydrology, topography, remoteness, village structure, demand)
2. What areas in Mozambique do you think are suitable SSH? What other areas than Manica Province?
3. How are the houses distributed in the community in those areas? Near or far apart? Most common? How does the investment cost depend on the distance between houses in the community?
4. How much does a 100 m power line cost?
5. How close to the community should the power station be situated? Regarding power losses? Maximum distance? Do you use transformers to reduce power losses?

Availability

(Available suppliers of all types of equipment: turbines, generators, wiring, transformers, safety equipment, low power loads. Importing difficulties.)

1. What turbines and generators do you use? Cost?
2. Where do you get them from?
3. We heard you use synchronous generators. Why not induction generators?
4. How much does the price and availability of the equipment influence the design?
5. Do you include low power loads for the consumers in the projects?
6. Are there possible suppliers available for small-scale hydro equipment? Widespread?
7. How much (electrical, turbines) equipment is made in Mozambique and how much is imported?
8. What are the advantages or disadvantages with importing small scale hydropower equipment compared to local manufacturing?

Safety

(Associated risks: electrocution, flooding, equipment failure, theft.)

1. What risks do you associate with small scale hydro? Examples?
2. What should be done to prevent the risks? Safety equipment?
3. What safety equipment do you use? How much does it cost?

Quality

(The robustness of equipment. Need for replacement of spare parts.)

1. What is the usual quality of equipment? Is there a difference in quality in imported and locally made?
2. How often does it need maintenance?
3. How much is that compared to other types of systems like diesel generators and Solar PV?
4. How does it work to provide that level of maintenance?

Social barriers:

Education

(Knowledge level. People with knowledge in key positions (investors, legislators, FUNAE, contractors, consumers, EdM. Possibility to teach local workers. Motivation of workers. Information dissemination.)

1. Who does the designs of your SSH stations?
2. What level of technical expertise of SSH is there in Chimoio? Who has it?
3. What level of knowledge of small scale hydropower is there in Chimoio? Who has it? More key positions? (FUNAE, investors, legislators, contractors, consumers, EdM)?
4. How widespread throughout the country is knowledge of small scale hydropower? (FUNAE, investors, legislators, contractors, consumers, EdM)
5. In what way is the knowledge spread today on all levels? Improvements?
6. How has it worked so far with teaching locals how to run a SSH? Examples?
7. What kind of education is needed to run your systems? Basic education needed? Are there schools and teachers?
8. Has there been problems teaching locals how to build and run a small scale hydropower station?
9. Do you see any good solutions?
10. Is there motivation among locals to participate in the construction of a SSHP station? Qualified work like installing and running the system, if they are paid? (If they are not paid?)
11. In your case, what are the wages normally?
12. Is there motivation among locals to participate in civil works, like building canals and poles for the grid, if they are paid? If they are not paid?
13. In your case, what are the wages normally?

Demand

(Demand of productive use. Sizing.)

1. What is the electricity used for on your SSH sites? Household/Productive use? Examples?
2. Is small-scale hydropower suitable for productive use? Why/Why not?
3. Is there a demand for productive use of electricity in areas suitable for small scale hydro?
4. Is the sizing of off-grid system usually adjusted for present or future demand? Oversizing from the beginning? Increasing capacity after some time? Off-grid system in general?
5. How is the sizing calculated? Per consumer? How well do the calculations suit reality?
6. Do you use load and/or generation meters in the communities? How much do they cost?

Administration

(Complicated project structure. Project ownership. Responsibility for maintenance.)

1. With your model using a private owner of the operating the SSH station. How has it worked? What are the advantages/disadvantages with this model?

2. How does the cooperation with NGOs work? As potential owners, as a business partner like AKSM? Local people's role?

3. Are there usually problems with cooperation between different actors in a project? 45. How are the projects to administrate? 46. What could be done to make it easier to administrate such projects?

4. What will happen when the main grid reaches a SSH site? Possible to connect? Coordination between grid extension and off grid projects?

Legislation

(Lack of legal framework. Badly adjusted legal framework.) (Specify laws when we know)

1. What laws are relevant for SSH?

2. In Mozambique today, there is mainly large-scale hydropower. Do the laws and policies that exist now hinder or support small scale hydro projects? Why? How? Since when?

3. Do the laws and/or policies need to be improved? How?

Infrastructure

(Conditions of roads. Bulkiness and sensitivity of equipment. Distance operation.)

1. How does the condition of the roads influence the use of small scale hydropower? Choice of equipment? Choice of area? Maintenance? Examples?

2. Are there means of transport for large heavy equipment? How heavy/large? Examples? (3m turbine)

3. What is the risk of equipment failure during transport?

4. Is there experience of using distance operation of power stations? Would it be an option?

Conclusion:

1. What are the most important problems to solve for small scale hydropower to be attractive?

2. What are your future projects? What will be improved from previous projects?

3. Is there anything that you would like to add?

4. Is there anything that you would like to ask us?

Appendix B

Interview coding

Table B.1 shows an example of how the data from the interviews is condensed and then sorted into a code.

Respondent	Data	Condensation	Code
Gov. ent. employee B	Here in Africa we have one danger. Efficiency we get in the lab and performance in the field. Miles apart. Efficiency and performance are two different things. Especially here. Why? Because we don't have a culture of maintenance. We are playing around with the word maintenance in the local languages. It turns out the word doesn't even exist in some languages. The closest we can get is repair, and that is a totally different story. Maintenance is cleaning you house, making your bed, putting everything in place, that's preventive maintenance. Then you have routine maintenance. This doesn't exist.	They don't have a culture of maintenance.	Maintenance
NGO A	The most critical and weak part of everything we are doing is documentation. We just talk. No one writes or saves anything. We can talk very nicely but if you ask me tomorrow what is written, I say I'm sorry...	"The most critical and weak part of everything we are doing is documentation".	Knowledge management

Table B.1: An example of coding procedure.

Appendix C

Applications for all load profiles

The three different community load profiles have the following applications.

Application	Load [kW]
Shop	0.8
Street light	0.3
Households	0.2 [kW/HH]

(a) Small community profile

Application	Load [kW]
Shop	0.8
Primary school	2
Street light	0.3
Households	0.2 [kW/HH]

(b) Medium community profile

Application	Load [kW]
Shops	1.6
Office	3.15
Street lights	0.9
Households	0.2-0-62 [kW/HH]

(c) Large community profile

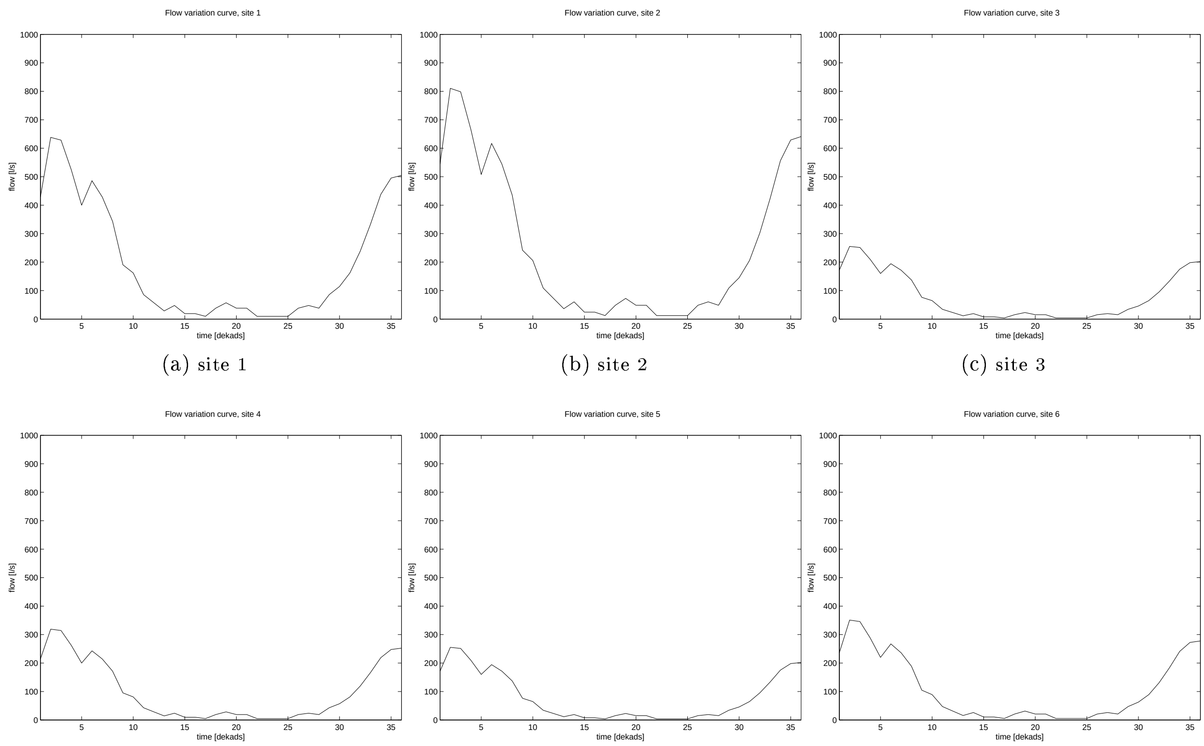
Table C.1: Applications for load profiles.

Appendix D

Site characteristics and flow variation curves

Table D.1: Site characteristics. Head and flow for 17 sites in Manica province.

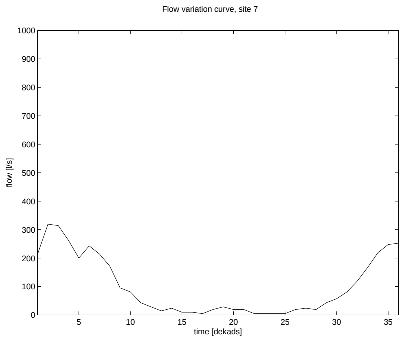
site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
head [m]	86	82	59	52	50	48	45	28.8	25.3	24.7	150	56	40.5	30	25	10	12
flow [l/s]	200	254	80	100	80	110	100	100	200	100	35	12.5	20	10	28	300	1000



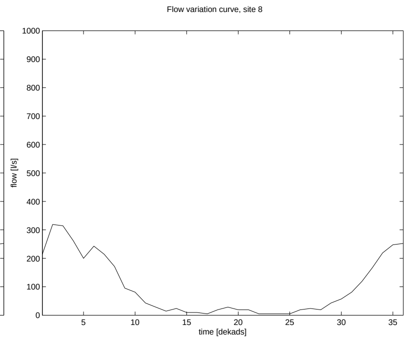
(a) site 1 (b) site 2 (c) site 3

(d) site 4 (e) site 5 (f) site 6

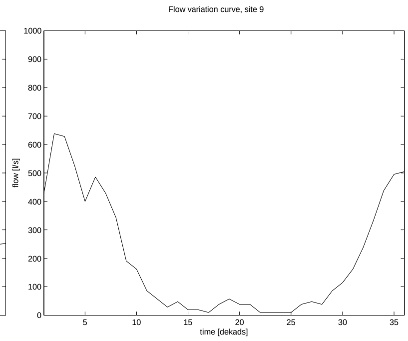
Figure D.1: Flow variation curves.



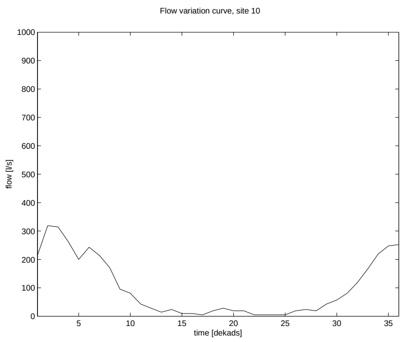
(a) site 7



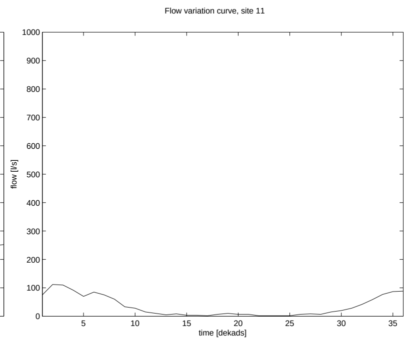
(b) site 8



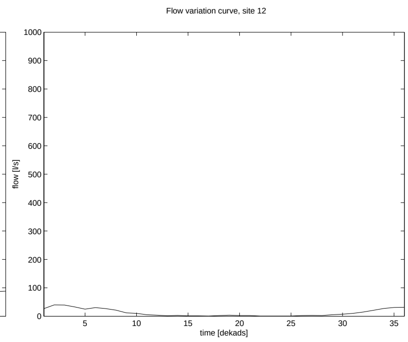
(c) site 9



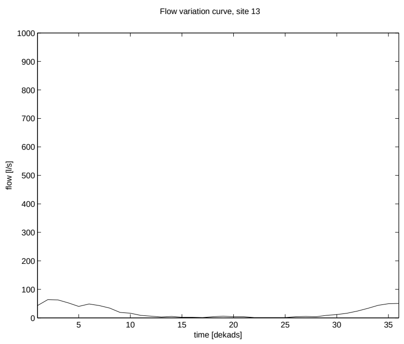
(d) site 10



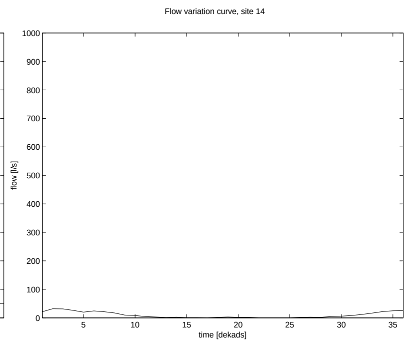
(e) site 11



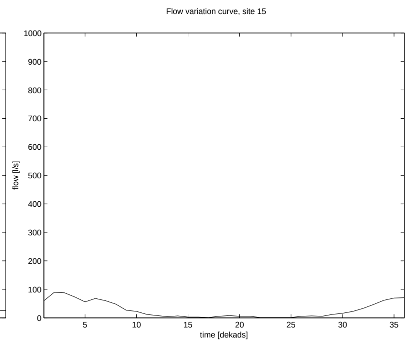
(f) site 12



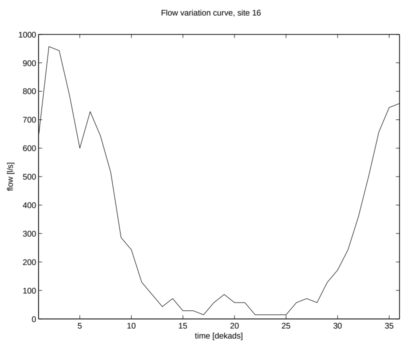
(g) site 13



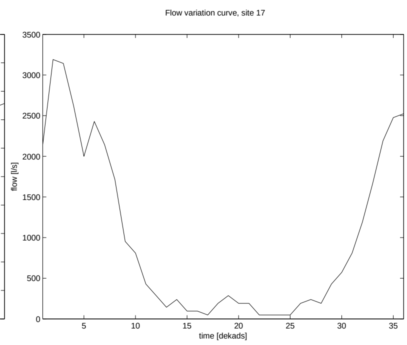
(h) site 14



(i) site 15



(j) site 16



(k) site 17

Figure D.2: Flow variation curves.

Appendix E

Barriers - all respondents

Table E.1 and E.1 show how all respondents mentioned in the report adress barriers. It also includes three respondents that have not been interviewed according to the interview guide. The barriers they mention are simly marked by a vertical line, to show they have been adressed.

Table E.1: Barriers mentioned by all respondents. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply adressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees, 14 - Gov. ent. employee C, 15 - Committee member, 16 - Power system owner.

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Low quality of local products						B		|	|		B	B	B			
High import duties	B O		|	|		|	B			B	|					
Limited rural infrastructure	|	B	B			|	B		|	|						
Lack of access to spare parts		O	B	B O		B							O	|		
Lack of local involvement				B	B						B O	O	B O			
Community relations hinder power station management								B		B	|		B O			
Lack of local contribution											B	O	B			

Table E.2: Barriers mentioned by all respondents. The letter B indicates the respondent considers the matter as a barrier. The letter O indicates a suggestion to overcome barriers, and a vertical line means the subject is simply adressed. 1 - NDRE, 2 - FUNAE A, 3 - EdM A, 4 - Donor A, 5 - Donor B, 6 - Gov. ent. employee A, 7 - Consultants A&B, 8- Consultant C, 9 - FUNAE B, 10 - EdM B, 11 - Gov. ent. employee B, 12 - NGO A, 13 - NGO B employees, 14 - Gov. ent. employee C, 15 - Committee member, 16 - Power system owner.

<table>
<tr><th>Barriers</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th></tr>
<tr><td>Lack of adequate data and measurements</td><td></td><td>B O</td><td>B O</td><td></td><td></td><td></td><td>|</td><td>B O</td><td></td><td></td><td>B O</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Low demand and low level of productive use</td><td></td><td>B</td><td>O</td><td></td><td>B</td><td>|</td><td>B</td><td>|</td><td></td><td></td><td></td><td>B O</td><td>B</td><td></td><td></td><td></td></tr>
<tr><td>Difficulties sizing systems</td><td></td><td></td><td>|</td><td></td><td></td><td>B</td><td>|</td><td>B</td><td></td><td></td><td>B</td><td>|</td><td>B</td><td></td><td></td><td></td></tr>
<tr><td>Poor design</td><td></td><td></td><td></td><td>B</td><td></td><td>B</td><td></td><td></td><td></td><td>B</td><td></td><td>|</td><td>B</td><td></td><td></td><td>|</td></tr>
<tr><td>Lack of proper maintenance</td><td>B</td><td>O</td><td>O</td><td>B O</td><td></td><td>B</td><td>B</td><td>B O</td><td>B O</td><td>B</td><td>B O</td><td>B O</td><td>O</td><td></td><td>|</td><td></td></tr>
<tr><td>Scattered population in communities</td><td>B</td><td></td><td>B O</td><td></td><td></td><td></td><td>B</td><td></td><td>O</td><td></td><td></td><td>B</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lack of access to finance</td><td>B</td><td>B</td><td>B O</td><td>B</td><td></td><td>B</td><td></td><td>B O</td><td></td><td>B</td><td></td><td>B</td><td></td><td></td><td>|</td><td></td></tr>
<tr><td>High investment cost</td><td>|</td><td>B</td><td>O</td><td></td><td></td><td></td><td>B</td><td>B O</td><td>|</td><td>O</td><td></td><td>O</td><td>O</td><td></td><td>|</td><td></td></tr>
<tr><td>Lack of investor interest</td><td>O</td><td>B O</td><td></td><td>|</td><td>|</td><td>O</td><td>B</td><td>|</td><td></td><td></td><td>B O</td><td>B O</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lack of awareness of technology</td><td>B O</td><td>B</td><td></td><td>B</td><td></td><td></td><td>B</td><td></td><td></td><td></td><td></td><td>B</td><td></td><td></td><td></td><td>|</td></tr>
<tr><td>Lack of technical expertise</td><td></td><td>O</td><td>B</td><td></td><td></td><td></td><td>B</td><td>B</td><td></td><td></td><td></td><td>B</td><td></td><td></td><td>|</td><td></td></tr>
<tr><td>Poor knowledge management</td><td>B</td><td>B O</td><td>B O</td><td></td><td></td><td>O</td><td>B O</td><td>B</td><td>O</td><td>O</td><td>B O</td><td>B O</td><td>O</td><td></td><td></td><td></td></tr>
<tr><td>Too low electricity price</td><td></td><td></td><td></td><td></td><td></td><td></td><td>B</td><td>|</td><td></td><td></td><td></td><td>B</td><td>|</td><td></td><td></td><td></td></tr>
<tr><td>Lack of supporting legislation</td><td></td><td>B</td><td></td><td></td><td></td><td>|</td><td></td><td></td><td></td><td></td><td>B</td><td>B</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lack of grid code and feed-in tariffs</td><td>B O</td><td>B</td><td>B</td><td></td><td>B</td><td>B</td><td>B</td><td>B</td><td>|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Low willingness and ability to pay</td><td></td><td>|</td><td>B</td><td>B</td><td>B</td><td></td><td></td><td>|</td><td>B</td><td></td><td></td><td>O</td><td>O</td><td></td><td></td><td></td></tr>
<tr><td>Poor payment management</td><td></td><td>|</td><td>B</td><td>|</td><td></td><td></td><td>B</td><td>B</td><td>B</td><td>|</td><td>O</td><td>B</td><td>B</td><td>|</td><td>|</td><td></td></tr>
<tr><td>Poor project administration</td><td></td><td>B O</td><td></td><td>O</td><td>O</td><td></td><td>O</td><td>O</td><td>B</td><td></td><td>O</td><td></td><td></td><td>|</td><td></td><td>|</td></tr>
<tr><td>Time consuming processes</td><td></td><td>B O</td><td></td><td>B</td><td></td><td></td><td>B</td><td>B</td><td></td><td>B</td><td>|</td><td></td><td>O</td><td></td><td></td><td></td></tr>
<tr><td>Lack of water resources</td><td></td><td></td><td></td><td>B O</td><td></td><td>B</td><td>B</td><td></td><td>B</td><td>|</td><td></td><td></td><td>B</td><td></td><td>|</td><td></td></tr>
<tr><td>Competing resource use</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>B</td><td></td><td></td><td></td><td>B</td><td></td><td></td><td></td></tr>
<tr><td>Long distance transmission</td><td></td><td>B</td><td></td><td></td><td></td><td></td><td>B</td><td>B</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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