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Access to sustainable electrification: Possibilities for rural Mozambique

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Abstract: We assess the sustainability of rural electrification in Manica Province, Mozambique, focusing on different alternatives for mini-grid and off-grid power supply. The qualitative assessment considers four dimensions of sustainability, namely environmental, socio-cultural, economic, and institutional. We argue that small-scale hydropower is the most sustainable alternative for off-grid or mini-grid solutions in rural Manica Province with good possibilities to scale up this to the major parts of rural Mozambique. The investigation shows that social acceptance for small-scale hydropower is high. Environmental sustainability of small-scale hydropower is higher than for PV systems. To speed up the electrification process, efficient rural electrification has to connect policy to local scale and institutional strengthening. The legislation needs to be improved, and there is a need for better institutional coordination for hydropower mini-grids' regulation. Along this line, a national framework to support small and independent power producers is necessary.

Subjects: Heat Transfer; Power & Energy; Electrical & Electronic Engineering; Electromagnetics & Communication; Engineering Economics

Keywords: rural electrification; sustainability; Mozambique; mini-grid hydropower



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PUBLIC INTEREST STATEMENT

Access to affordable, reliable, sustainable, and modern energy is a prerequisite for economic and social development. Electrification is important for income development, healthcare, basic education, and personal safety among other things. In view of this, we investigated the current status and possibilities for sustainable electrification in rural Manica Province, Mozambique, and assess the sustainability of rural mini-grid and off-grid power supply. The study shows that both small-scale hydropower and solar power through family-based photovoltaic systems are feasible in poor areas of rural Mozambique.

1. Introduction

Mozambique is one of the poorest countries in the world. About 54% of the population are below the poverty line and about 70% of approximately 30 million people (2018) live and work in rural areas (World Bank, 2018). Subsistence agriculture occupies about 80% of the labor force (Cuvilas et al., 2010; Mozambique Forest Information and Data, 2011). Mozambique has, however, experienced a strong economic growth during the last two decades. During this period, the average annual GDP growth was 7.4% due to trade, manufacturing, extractive industries, transport, communication, and electricity production (World Bank, 2017). The rapid growth, however, has not resulted in significant poverty reduction. The general electrification rate increased from 5% in 2001 to about 26% in 2016 (Energypedia.info, 2018). However, the electrification as well as the domestic power generation is uneven both socially and spatially (Power & Kirshner, 2018). Access to electricity is mainly focused on urban areas (67%) while only 5.7% use electricity for lighting in rural areas. Forest resources, in general, satisfy more than 95% of energy requirements in rural areas.

The UN Sustainable Development Goal (SDG) 7 states to ensure access to affordable, reliable, sustainable, and modern energy for all (UN, 2016, 2018). Three socio-economic effects of electrification stand out even if it recently has been questioned if these usually results from experiences gained in Asia and Latin America, are fully transferrable to the African context (Peters & Sievert, 2016). Positive effects of electrification are usually stated as educational benefits (IEG, 2008; Sachs et al., 2004), improvements in income (IEG, 2008; Jimenez, 2017), and decrease in respiratory diseases (Fullerton et al., 2009; Lam et al., 2012; McCollum et al., 2018). Thus, electrification and SDG 7 may be seen as enabling factors for achieving a general sustainable development (Alloisio, 2018; International Atomic Energy Agency [IAEA], 2005; Mainali et al., 2018).

In view of the above, the objective of this paper was to investigate the current status and possibilities for sustainable electrification in rural Manica Province, Mozambique, and assess the sustainability of rural mini-grid and off-grid power supply. To the best of our knowledge, this has not been done before for rural Mozambique. We are especially interested to analyze different possibilities to supply rural electrification using renewable energy sources. Indicators for four dimensions of sustainability were used, namely 1) environmental, 2) socio-cultural, 3) economic, and 4) institutional (Feron et al., 2017, 2016; Wate & Mika, 2007).

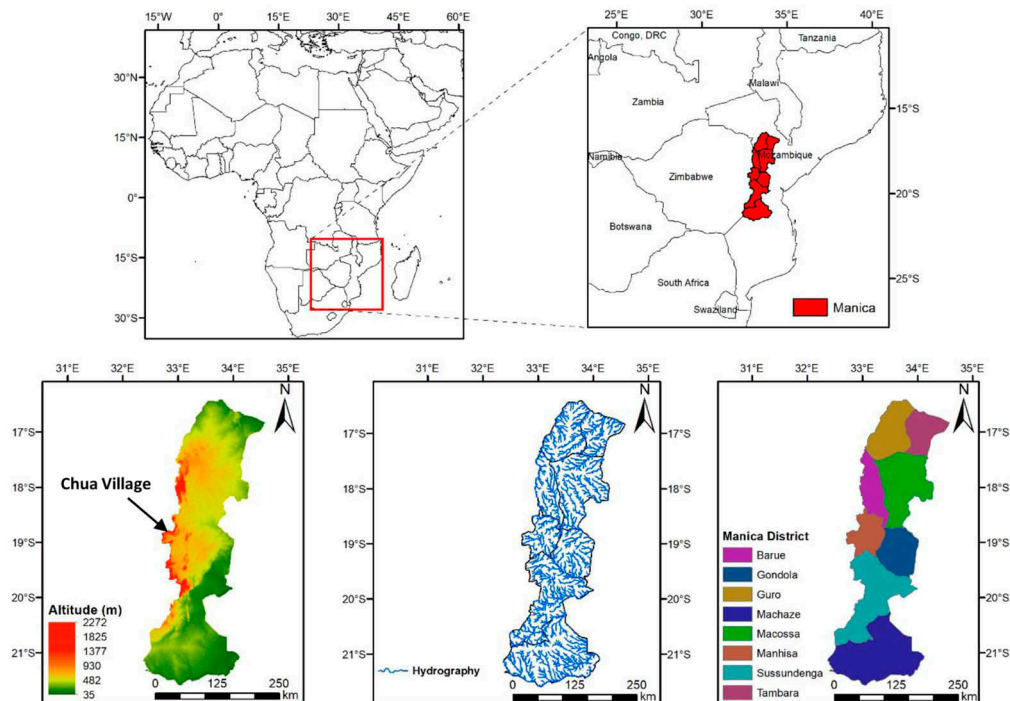
2. Materials and methods

2.1. Area description

Manica Province is located in the central western part of Mozambique, along the border of Zimbabwe, between 21°34 and 16°24 latitude S and 34°01 and 32°42 longitude W (Wate & Mika, 2007) (Figure 1). The province has an area of 61,661 km², representing approximately 7.7% of the total area of Mozambique. The climate is tropical, modified by the altitude with a tendency of hot and humid weather. Two distinct seasons are present: a rainy season, from September to March, and a dry season, from April to August. The average annual rainfall is about 1,400 mm. In dryer regions, the annual rainfall is no more than 700 mm and in the highlands of the interior, it can reach 1,800 mm (Wate & Mika, 2007).

Manica Province has plenty of water and high agricultural potential. Over 90% of 2.4 million population are engaged in subsistence agriculture (2017 census) (Instituto Nacional de Estatística Moçambique [INE], 2017). Poverty of the area is high, though, and the people suffer from recurrent high levels of malnutrition. Staple food crops are constituted by maize, sorghum, pulses, and groundnuts. The province was severely affected by the 16-year civil war that ended in 1992. Almost all social and economic infrastructure was destroyed during the war (Wate & Mika, 2007). Health service is scarce and of poor quality. Due to bad infrastructure and long distances, access to education is unsatisfactory, especially for girls. The literacy level is about 56%.

Figure 1. Manica Province physiography, administrative borders, and location of Chua Village. Source: own illustration.



About 77% of the area is covered by forest and forest resources plus charcoal constitute 80–90% of the energy consumed. The area has many perennial rivers and streams and the potential for micro and small-scale hydroelectric dams is high. Solar energy is as well of high potential with an average insolation of about 5.4 kWh/day (INE, 2017).

Chua Village along the Chua River was used for detailed interview studies of potential local electricity consumers (Figure 1). Chua Village has about 3,000 inhabitants and is located in Maridza administrative post in the vicinity to Manica City in the Manica District and Province. The village lies in the upstream parts of the Pungwe River Basin at the border to Zimbabwe in the central western part of Manica Province (21°34'–16°24' latitude S and 34°01'–32°42' longitude W) (Figure 1). Families in the area typically live at small farmhouses quite remote from each other. Families' main income is from agriculture, livestock, and artisanal gold mining.

More than half of the Chua Village population are illiterate (Bensch et al., 2010; Republic of Mozambique & accessed on, 2018). About 38% suffer from malaria and 32% from respiratory diseases (Bensch et al., 2010). Chua Village may be regarded as the representative for the Manica Province in terms of size, demographic and socioeconomic patterns, and general physiographical environment (Bensch et al., 2010). The village covers two valleys and surrounding mountains with households generally located at large distance from each other. Households usually contain 5.5 individuals (Bensch et al., 2010). In 2003, about 74% had access to radio, 25% had television set, and 30% had mobile phones. There is, however, no grid connection (Republic of Mozambique & accessed on, 2018). Access to electricity is achieved through solar panels, car batteries, or diesel generators.

2.2. Methods

The methodology to assess the sustainability of rural electrification in Manica Province followed four dimensions of sustainability indicators, namely environmental, socio-cultural, economic, and institutional (Table 1) (Feron & Cordero, 2018; Feron et al., 2017, 2016). Environmental indicators

reflect awareness of the population and impact of applied technology on environment. An important environmental aspect of applied technology is the ability to contribute to societal resilience against climate change. Socio-cultural indicators show the degree of equity regarding energy provided to different societal groups partly through accessibility. Social acceptance implies a participatory and inclusive approach. Cultural justice refers to justice through participation, mutual learning, and knowledge sharing (Feron et al., 2016). Important aspects regarding economic sustainability are indicated by cost-effectiveness, reliability, and funding. Cost-effectiveness is a measure of how efficiently monetary resources are spent on a certain technology. Reliability is a measure of how operational the technology is in time. Funding depends on both investment costs and operation and maintenance costs. In turn, this is determined by both public and private spending. Institutional sustainability provides a stable and dependable framework through which individuals and organizations can interact. Decentralization is important as it gives legacy to, e.g., national policies to be implemented at a local scale. Adaptability is a measure of institutions' ability to adapt to the needs of a population in terms of flexibility and decentralization. Stability or durability defines the strength of the institution and is also related to the general reliability (Feron et al., 2016).

Data and information collection were performed during two monthly study visits to Manica Province and Chua Village in July 2015 and June 2016. Data scarcity and lack of information regarding rural conditions are general problems in Mozambique. A law to provide free access to information, however, was approved in 2014 (Law on freedom of information) (freedominfo.org, 2018). For this reason, data and information used in the present paper could partly be collected from official documents. Initial literature surveys and qualitative document analyses (Ritchie et al., 2013) were combined with semi-structured interviews (Bernhardt, 2015) in Chua Village and Manica Province during the study visits. Literature surveys and document analyses gave important insights on national electrification policies of Mozambique that could be compared to at-site conditions and interview results with different stakeholders such as experts from different ministries and authorities, national and international organizations, energy companies, local power plant managers, and potential local energy consumers in Chua Village and Manica Province. Study visits and interviews were made with key professionals at the GIZ offices in Chimoio the capital of Manica Province. As mentioned above, GIZ is responsible for financing projects concerning renewable hydropower energy produced in this region of Mozambique. Other institutions that provided us with information were EDM (Electricidade de Moçambique), UNIDO (United Nations Industrial Development Organization), Ministry of Energy of Mozambique, and FUNAE (Fundo de Energia). Five local hydropower operators in Manica Province were interviewed during the study visits. In each interview, questions were asked to elucidate institutional and organizational conditions, economic aspects, environmental conditions, and socio-cultural features. Deeper literature surveys on sustainability gave input to the methodology that was used to understand relationships between electrification and sustainability goals (Heinrichs & Laws, 2014; Hugé et al., 2015; Ilskog, 2008; Nguyen-Trinh & Ha-Duong, 2015).

Specific interviews were made with villagers in Chua Village. The objective was to analyze the local needs of electricity and how these match possible supply. Totally, 50 face-to-face interviews with mixed-electrified/non-electrified household representatives were conducted in order to understand the local sustainability of different electricity alternatives in the area. The results gave insights on five key demand areas in the village, namely households, public infrastructure, small trade, small industry, and leisure activities. The village head was interviewed to get an overall assessment of village functions and public electricity needs. Interviews were recorded by taking handwritten notes during the interviews, supplemented by further notes after the interview events. A checklist was used to find answers concerning the household structure and basic needs of electricity such as how lighting is used, health status, general water use, washing and cleaning, refrigerator needs, cooking requirements, leisure activities, and appliances uses. Enquiries were also made regarding public lighting, local hospital use, village administration, primary school conditions, and business opportunities.

Table 1. Indicators of four sustainability dimensions used in this study

Environmental	Socio-cultural	Economic	Institutional
Environmental awareness	Accessibility	Cost effectiveness	Decentralization
Environmental impact	Social acceptance	Reliability	Adaptability
Resilience to climate change Cultural justice	Funding	Stability	

The information gathered through document analyses and interviews was used to address the four dimensions of sustainability according to Table 1. The assessment is based on the group of indicators (Table 1) that were evaluated relative to an ideal situation. Particularly, we wanted to assess the sustainability of mini-grid and off-grid solutions using different possibilities to supply rural Manica Province with electricity from renewable energy sources.

3. Results and discussion

Governmental electrification policies and programs are implemented at the local scale. Hence, it is of specific importance to evaluate effects on the local user-scale when addressing sustainability. For this reason, special emphasis on the interview work was allotted to the Chua villagers. The Chua Village is in many respects representative of socioeconomic and physiographical properties of Manica Province (Bensch et al., 2010). The interviews in Chua Village identified potential consumers of electricity according to Table 2. In general, villagers with access to electricity agreed upon that electricity had done much to change their lives for the better. The rural household representatives were pleased to have electricity to light their homes, watching television, listening to radio, and different leisure activities, as well as for cooking and making life in general easier. Most villagers, however, are still not connected to safe and reliable power. Candles, kerosene, batteries, and wood are still to a main extent used as energy sources. Many families have a solar panel or a generator sometimes in combination with a car battery. According to the village head, about 520 households are in need of safe and reliable electricity. Other important communal infrastructure is a hospital, a primary school, and a church. Besides these, there are four small shops, one administrative office, two grain mills, and two bars. The village head emphasized prioritizing the hospital, primary school, and church besides the households. The shops, administrative office, grain mills, and bars have access to electricity through solar panels, batteries, or diesel generators. One of the grain mills is an old hybrid type used for both electricity generation and grain milling. The identified main potential uses of electricity in Chua Village are providing lighting of houses at night, as well as for television, charging small appliances and mobile phones, water supply, refrigeration, and food conservation.

Table 2. Potential consumers of electricity in Chua Village

Type	Consumer	Total
Private home	Households	520
Small business	Shops	4
Public infrastructure	Hospital	1
	Primary school	1
	Church	1
	Administrative office	1
Small industry	Grain mills	2
Leisure	Bars	2

3.1. Environmental sustainability

Environmental sustainability and electrification of rural areas in developing countries are strongly connected to several SDGs (UN, 2016). At present, there are some 1.75 million people in Manica who still do not have access to safe and reliable electricity (about 8% supplied by modern electricity) (International Energy Agency [IEA], 2017). Besides household uses of electricity, services such as safe water supply and sanitation, lighting in schools and public spaces, and health care are important considerations for improved quality of life in rural Manica.

3.1.1. Environmental awareness

Interviews indicated that environmental awareness is quite limited in Manica Province and Chua Village. Weak implementation of environmental laws was given as a main reason in interviews with experts. As the illiteracy level is high in Manica Province and poverty is widespread, environmental issues are generally of secondary concern. In Chua Village, as in many other places in Manica Province, deforestation and illegal logging are major problems. Deforestation is related to biomass burning but also to artisanal gold mining. Small-scale and informal artisanal gold mining is the second largest sector of employment after agriculture in Manica Province (UniZambeze & Mining Development Fund, 2012). In Chua Village, 30% of all male adults are involved in gold mining as a primary occupation (Bensch et al., 2010). This gives households an important extra income to the subsistence agriculture. However, it also creates erosion of sediments causing siltation in downstream reservoirs. The inappropriate use of mercury in the gold amalgamation process causes serious pollution of soils, crops, and downstream water (UniZambeze & Mining Development Fund, 2012). Authorities and environmental organizations need thus, to set up a framework for these activities that are obviously not sustainable.

FUNAE is giving priority to solar home systems (SHSs) for the production of household electricity in rural areas (FUNAE complements EDM by promoting rural electrification where EDM does not provide service by the national grid due to too high costs). The SHSs consist of a PV panel, charge controller, wiring, and a battery (BRFR, 2016; FUNAE, 2015). This can, e.g., provide sufficient electricity needed for a television set, mobile phone, refrigerator, and some LED lamps. The overall solar power use is quite small at present but growing steadily in rural areas due to general affordability, ease of use, and simple installment. Solar power systems, however, contain hazardous constituents and batteries such as, e.g., heavy metals. There is no system or infrastructure for re-use or collection of old batteries and other parts of used solar panels in rural areas of Mozambique. This, in combination with low environmental awareness and the rather short lifespan of solar panel components, will likely result in used batteries and solar panel parts ending up in the general waste deposits of rural villages.

3.1.2. Environmental impact

The renewable energy potential in Manica Province has been identified as 1,941 MW from hydropower, 25 MW from solar, and 187 MW from biomass (FUNAE, 2013). It is the region that is best suited for small-scale hydropower. However, so far only a few small and micro-scale hydropower projects have been implemented in Manica. The reason for this is the lack of capacity to implement small-scale hydropower projects, lack of clear process, and lack of focus of the sector (Hankins, 2009; Wolfgang Mostert Associates, 2006). Medium-sized hydropower plants may be defined as 10–100 MW. Some research defines renewable hydropower as less than 10 MW due to the fact that large reservoirs often carry negative environmental impact (Hankins, 2009). Up to now, large-scale hydropower projects have been prioritized due to the fact that consumers have primarily been industry and export to SAPP. However, in order to supply rural consumers with electricity, small-scale hydropower may be necessary through off-grid or mini-grid solutions. Off-grid systems such as solar PV and small hydropower plants represent renewable solutions to the needs at hand that display cost-efficient power supply with better developmental, social, health, and environmental performance as compared to traditional-centralized power supply.

Figure 2. Examples of electrification of rural areas in Mozambique using on-grid system in (a) and (c) by EDM and using an off-grid PV system for water supply by FUNAE (b) (photo by Miguel M. Uamusse).



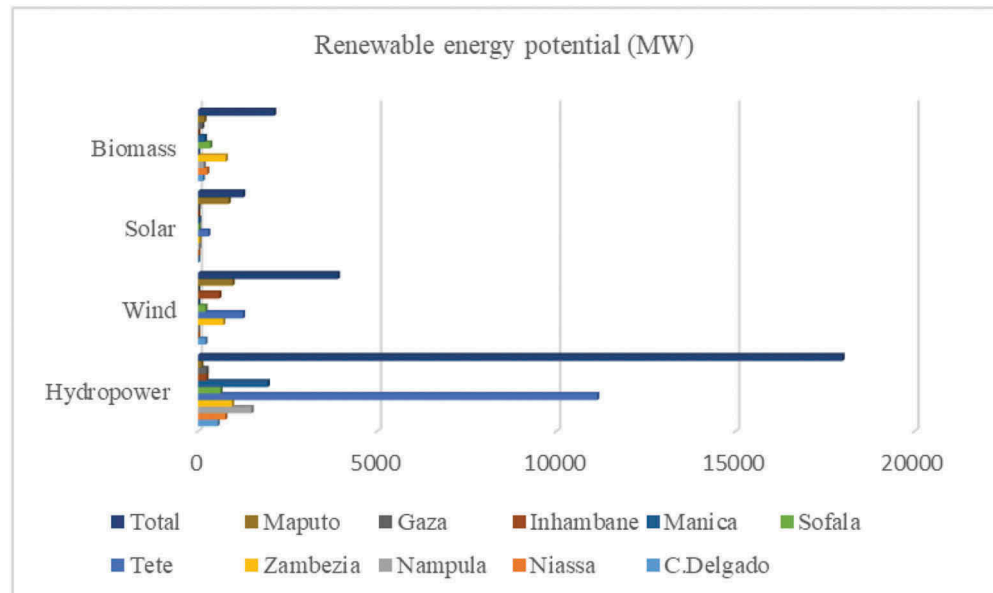
An example of transition to sustainable rural electrification is the 40.5 MW solar power plant under construction by the Norwegian energy producer Scatec Solar in Mocuba in the Zambezia Province (Broto et al., 2018; FUNAE, 2018). The potential power production is 77,000 MWh per year that is equivalent to delivering power to 175,000 households. The total investment is 76 USD million of which 55 million come from the International Finance Corporation (ICF) and the remaining funds from EDM (Broto et al., 2018; Frey, 2017). Generally speaking, solar energy development in Mozambique as a whole encourages the use of renewable and clean energy production to reduce dependence upon fossil fuels, as well as reducing deforestation and emission of greenhouse gases. Figure 2 shows examples of rural electrification in Manica developed by EDM in an on-grid system with the use of electricity from hydropower and an off-grid system developed by FUNAE for rural water supply making use of the PV solar system.

From 2006 to 2017 FUNAE was in charge of installing 63 solar-powered water pumps in the provinces of Inhambane, Gaza, Zambezia, Sofala, and Manica (ALER, 2017). The projects meant that the inhabitants did not need to travel far for safe water for both drinking and sanitation uses. Thus, the water pumps improved the lives of the communities reached. The water pumps continue to work as planned. However, maintenance and theft threaten the sustainability of the projects. Absence of fees also threatens the sustainability in the long-term perspective (ALER, 2017).

Figure 3 summarizes the potential in terms of renewable energy in Mozambique. It is evident that the supply of renewable energy is huge. Even though large hydropower projects may be seen as non-sustainable with negative environmental impact (Hankins, 2009), there is ample energy to be supplied from small-scale projects. Renewable energy potential in Manica is dominated by hydropower as mentioned above (EDM, 2018).

About 40 million metric tons of carbon dioxide equivalent (about 60% of national release) are released from emissions from land-use change and forestry (USAID, 2017). These emissions stem from agricultural expansion, wildfires, and harvesting for wood fuel including for firewood and charcoal. Emissions from other energy use represent about 6 million metric tons of carbon dioxide equivalent (about 9% of national release). These figures reveal that a substantial part of the CO₂ emissions can be reduced by increasing the share of renewable energy.

Figure 3. Renewable energy potential in Mozambique.
 Source: own elaboration.



PV systems pose specific advantages and the technology is developing quickly with continuously decreasing cost per produced kWh. Solar energy systems are especially suited for off-grid solutions and do not compete with the central grid, instead with the system that uses fuelwood, charcoal, and kerosene (Broto et al., 2018). It is estimated that about 2.2 MW solar power capacity has been installed in the country (Broto et al., 2018; Hussain, 2015). The focus of FUNAE is on solar PV systems even though it has also developed micro-hydro and pilot wind projects.

PV systems have, however, as well some disadvantages compared to other options. Batteries are usually required to store the electricity to maintain power during dark hours (Lahimer et al., 2013; Phuangpornpitak & Kumar, 2007; Raman et al., 2012). These batteries are often expensive and need replacement every 3–5 years. Due to batteries and other components, PV systems have large losses (Lahimer et al., 2013). At the same time, PV systems and batteries contain chemical hazards that need to be treated in a safe way.

3.1.3. Resilience to climate change

Climate change will probably affect future river flow caused by less annual rainfall, increasing inter-annual variability, and less dry season river flow (Andersson et al., 2011). There is a close correlation between climate change and hydropower generation. With higher temperatures, evapotranspiration will increase and reduce runoff in rivers and thus, reduce water levels in reservoirs. From this background, small-scale hydropower is probably more vulnerable due to less storage volumes (less ability to store water from one season to another) and less resilient as compared to large-scale hydropower and other renewables such as PV systems. To increase the resilience against climate change, it would probably be better to have a regional and national mix of renewable energy sources. However, also large hydropower plants such as the HCB are likely to be affected. The electricity output of HCB may be reduced with 20% until 2100 (Uamusse et al., 2019).

3.2. Socio-cultural sustainability

Socio-cultural sustainability is related to individuals' opportunities to fulfil their potential. In essence, this is comprised the SDGs. However, in reality, socio-cultural sustainability is complex dynamics between the individual and society where equity, diversity, social cohesion, quality of life, democracy, and governance are important keywords (Day et al., 2016).

3.2.1. Accessibility

The electricity access today in Mozambique is uneven both between urban and rural areas and social groups of the society. There appears, however, to be a political will to change the uneven accessibility. The electrification of rural Mozambique requires solving complex societal issues with lacking infrastructure, extremely poor population, and funding through national and international organizations. It is obvious that rural Manica Province cannot be connected to the grid due to sparsely populated areas, long distances with inadequate basic infrastructure, and a lack of general investment capital. Thus, the only economically feasible solution is less expensive small-scale off-grid systems (International Renewable Energy Agency [IRENA], 2012). Rural electrification is, however, one of the banners of the energy sector authorities.

Providing rural households with access to electricity is, however, not enough to ensure socio-cultural development in a sustainable manner. To achieve SDG goals regarding poverty, energy is also important for other sectors such as agriculture, industry, and tourism. The current population increase of about 3.9% per year directly affects the size of energy demand. Recent statistics show that the population of Manica increased from 900 thousand in 1997 to about 1.9 million in 2017. The projected population increase needs to be balanced by a corresponding increase in energy, food, and water security (Olsson, 2015). The growth in population will affect the food security, since the food production called for will result in correspondingly greater amounts of water and energy needed (UN, 2013).

Rural electrification is related to basic societal services such as healthcare and schooling. About 100 schools have been electrified during the last two decades in Manica Province contributing markedly to an improvement in the quality of the educational facilities and to attracting a large number of teachers to work in rural areas (Sebastião, 2013). The electrical power provided is helping to encourage young children to attend school and can in combination with other measures reduce school dropouts in Manica (Casey, 2014; Power & Kirshner, 2018). The electrical power that is supplied creates access to basic educational equipment for teaching, such as projectors, photocopying machines, and laboratory equipment. The electricity gives students the opportunity to continue to study and doing homework after school hours and this has a significant impact on what can be attained through attending school. The access to electricity has promoted the education of children both at primary and high school level, in part due to possibilities to extend study hours after sunset. Thus, for rural Mozambique, the percentage of primary school students completing their studies rose from 82% in 2001 to 96% in 2005 (Sebastião, 2013).

FUNAE is the most important government partner in promoting energy policy, especially for rural electrification. Thus, its work is to increase the access to modern energy services and promoting the quality of life for the population in Manica Province. The activities have focused on the electrification of offices in the district, post offices, primary and secondary schools, and hospital centers. This has been done in part through PV panel systems, fuel pumps, small mini-, or micro-hydropower plants so that each district has sufficient electrical potential as well as promoting improved biomass use and reducing deforestation.

Increasing access to electricity requires strong and reliable policy development so as to create and support the financial mechanisms needed within the energy sector and expand the access to electricity in rural areas. Research has focused on visualizing policy regulators how the government has reasoned regarding access to electricity during the two decades that the energy sector has been decentralized. The institutional reforms carried out within the energy sector have improved the rate of electrification but at a slow pace. The level of access in Manica Province has just increased from 5% to 8% within a period of two decades. Mulder and Tembe (Power & Kirshner, 2018) argue that the reason for this is the institutional barrier and needs to strengthen the institutional quality. For a developing country like Mozambique, this is a process in time rather than single development. The dependency on foreign actors such as donors, banks, foreign investors adds to the difficulty and complexity of jointly financed electrification programs.

3.2.2. *Social acceptance*

The interviews in Chua Village indicated a unanimous positive view of electrification. Chua Village has, however, a long experience of electrification especially through the work of GIZ. In this respect, the village may not be completely representative for the entire province. It is, however, encouraging that foreign donor work in itself has created a positive view on the electrification process. It is important that the electrification of rural areas involves local stakeholders in a participatory process. This can be done by involving not only households but also small-scale industry at an early stage. In the case of Chua Village, this has been done by developing a hybrid type grain mill used for both electricity generation and grain milling. This arrangement improves the funding of electrification costs and the sustainability.

Through interviews, the identified average potential power need for each person in Chua Village households was approximately 3.0 kWh/day or 1,100 kWh per capita and year. Each household consists of an average of 5.5 persons. Thus, the 520 household village total needs correspond to about 3,100 MWh. Electricity for the hospital, primary school, and church would need to be added to this total. Accordingly, the stated needs for power are approximately twice the average actual consumption of electricity in Manica Province (453 kWh per person) (Nhamire & Mosca, 2014). Thus, the stated potential needs are much larger than existing average use. This indicates that there is a strong social acceptance for the supply of safe and reliable electricity in Chua Village. Potentially, this social acceptance could be translated to the entire Manica Province.

3.2.3. *Cultural justice*

As mentioned previously, cultural justice refers to participation, mutual learning, and knowledge sharing. Up to now, mainly large-scale hydropower projects have been promoted in Mozambique. These have been a priority due to that consumers primarily have been industry and export. Other reasons are lack of capacity to implement small-scale hydropower projects, lack of transparent process, difficulties to involve private investors, and lack of focus of the sector (Hankins, 2009; Wolfgang Mostert Associates, 2006). Small-scale technology is more easily adapted to local conditions and needs. Among the renewable energy alternatives, small-scale hydropower and PV systems are renewables that are easily adapted to local conditions. In Manica Province, FUNAE concentrates on the installation of PV systems in schools, homes of teachers, hospitals and homes of hospital workers, and in public sector services, as well as providing pumping systems for drinking water. Mini-grid systems have been in use for about twenty years in Manica Province and appear to have had positive effects on quality of life here (Sebastião, 2013). Many areas in Manica Province, such as Chua Village, have used small-scale hydropower during long periods of time. Small-scale hydropower is a simple and well-proven technology including few and simple parts. Defective or damaged parts can in most cases be manufactured or repaired by the village smith or other handy villagers. As there is a long practice to use small-scale hydropower in many rural areas of Mozambique, villagers usually have a good understanding of how to plan, build, and maintain small hydropower plants (Uamusse et al., 2019).

The SHSs are used for water supply, pumping of fuel, and for lighting of public buildings (hospitals and schools). Using this technology, four wood industries and 14 villages were electrified through a government project in 2014 (Uamusse et al., 2019). There is ample evidence in Chua Village and Manica Province that the off-grid systems created by FUNAE have improved the quality of life of the local population. Rural electrification, through PV systems and small-scale hydropower, generates improved environment, health, and safety conditions that particularly benefit children and women (Power & Kirshner, 2018). Since FUNAE started its rural electrification in Manica Province, about 200 hospitals have been electrified through PV systems. PV systems are used for illumination, powering of diagnostic machines, and refrigeration of medicines. Access to electrification has improved the quality of health care in rural areas and has contributed to reducing the occurrence of diseases such as HIV and Malaria. This is partly due to educational programs on television and radio.

3.3. Economic sustainability

3.3.1. Cost-effectiveness

Potential hydropower in Manica, Zambezia, and Tete at about 23 sites shows that the cost of electricity generation could be low. From feasibility studies in the region, EDM and FUNAE have shown that viable projects could generate a total of 5,000 MW at a CapEx cost of 100 USD/MWh. The majority of the population in rural areas cannot afford payments for the current tariffs, despite the fact that they are highly subsidized. PV systems, are, however, more competitive than hydropower. For example, the solar project Namaacha with a capacity of 30 MW had an investment cost of 68 USD/MWh, Morrumbala with a capacity of 30 MW had an investment cost of 71 USD/MWh, and Lagoa Pathi with a total capacity of 12 MW had an investment cost of 93 USD/MWh. In general, the investment cost is less than 100 USD/MWh. Assuming 500 kWh/person and year as electricity consumption in the Manica province and a need of rural electrification for 2 million people, the total investment cost to supply Manica with electricity would be 100 USD million. Assuming a 6% CapEx-cost per year would result in a cost per person of <3 USD per person and year (US\$6 million/2 million people). It is important to remember that the rural population in Mozambique are low income consumers and have low willingness to pay for energy services (ALER, 2017). On the other hand, Mulder and Tembe (2008) show that rural electrification projects may be commercially viable if they include a key customer such as a small-scale industry or local business (Uamusse et al., 2019).

3.3.2. Reliability

The grid system in Mozambique is in great need of restoration, and thus, the electricity supply is often intermittent. About 25% of power disappear in general transmission losses. As it is not possible to extend the grid to the majority of rural areas, the country will have to rely on off-grid solutions. For Manica Province, small-scale hydropower is a viable option. Small-scale hydropower, as it may be used in hilly Manica Province, has a greater net capacity (ratio of actual electrical energy output to maximum possible electrical energy output over time) than, e.g., solar power. In general, hydropower represents greater efficiency as compared to solar power. In a warmer climate, however, reliability of small hydropower may decrease due to less discharge and greater variation in rainfall. In this regard, large-scale hydropower may be a more resilient alternative.

3.3.3. Funding

Most of the energy sector funds from donor partners in recent years have been addressed to electricity grid projects for the rural areas where population is concentrated. From 2008 to 2013, the Mozambican authorities allocated, through government investments, more than 1.7 billion meticaís (about 27 USD million) to rural electrification. In addition, the Kuwaiti Fund, the Arab Bank for Economic Development in Africa (BADEA), and the Islamic Bank of Development (BID) supported EDM for rural electrification purposes in excess of 27 USD million.

The estimated cost for a main grid system that EDM would need to achieve electrification of 20 million people by 2030 is about 6 USD.6 billion (Table 3). On the other hand, FUNAE has raised funds internally, raised capital from international partners (World Bank, Belgian Cooperation), and

Table 3. Cost of electrification depending on energy type Source: (EDM, 2018; FUNAE, 2018; Nhamire & Mosca, 2014; Power & Kirshner, 2018)

Type of energy	Stakeholder	Type of energy	US\$ Million
On-grid	EDM	Hydro, thermal, solar	6,600.0
Off-grid	FUNAE	PV solar, small hydropower	83.9
Mini-grid	FUNAE	Pico and small hydropower	15.0

played an important role in promoting the electrification of rural areas by developing mini-grid and off-grid systems for sustainable economic, socio-cultural, and environmental development. In any case, the cost for electrification and electricity production indicated in Table 3 must be compared to the gross national income (GNI) in Mozambique. According to World Bank data, the GNI per capita in 2016 was 460 USD. This is a very low income. If the government of Mozambique is to reach universal access to electricity by 2030, additional funding is necessary. Partners such as the European Union, World Bank, Norway, and Sweden have historically been supportive to Mozambique. Including the potential additional electricity from HCB together with an organized exploitation of all energy potentials, there may be a possibility for Mozambique to come closer to reaching universal access to electricity by 2030.

3.4. Institutional sustainability

In general, institutional quality and sustainability are key barriers to promote increased access to electricity to the poor (Cook, 2011; Estache & Fay, 2007; Power & Kirshner, 2018). However, Mozambique is a young country and it is still recovering from the effects of a 16-year civil war that ended in 1992.

3.4.1. Decentralization

Electrification of Manica Province is mainly a scale and institutional process. At the national scale, it is the responsibility of EDM to extend on-grid systems mainly for urban areas. It is the responsibility of FUNAE to plan and supply mini-grid systems for the rural areas. Thus, FUNAE complements EDM by endorsing rural electrification where EDM does not provide service by the national grid due to too high expenditures. At the village scale, GIZ and other donors support micro-grids and individual initiatives (Tomei & Gent, 2015). Due to that FUNAE uses a centralized methodology stressing rural institutions rather than rural dwellers, there is a gap between the national SDGs and the needs of poor rural villagers. Thus, promotion of local ownership, capacity building, and stakeholder empowerment needs further development (Tomei & Gent, 2015). Barrier to small-scale hydropower development is a lacking framework to support small and independent power producers.

3.4.2. Adaptability

The main institutional framework for electrification is the MIREN, CNELEC (will re-organize into ARENE), EDM, and FUNAE. ARENE (Autoridade Regulatoria de Energia) is a new government energy regulator that can provide advice and facilitation regarding energy sector regulation policy and concessional issues (EDM, 2018). ARENE will facilitate setting commercially sustainable (i.e., cost-reflective) energy tariffs. EDM admits that it has a weak institutional framework and a lack of capacity. In general, there is no entity responsible for performing integrated, coordinated planning and monitoring. The role of such an entity is important to promote fair competition among the key players on the energy market and ensure the financial health of the sector. Both EDM and FUNAE struggle with a lack of capacity and funding problems. This creates problems in terms of adaptability from the governmental to the local-scale problem-solving.

3.4.3. Stability

The government has continuously strengthened legislation for rural electrification so as to ensure access to electricity for the entire country (see Table 3) (Cuamba et al., 2013). In 1977, 80% of the population were living without access to electricity. This led to the creation of the government-run EDM, with the purpose of producing, transmitting, and distributing electricity to the country. Since then, the government has introduced reforms and regulations into Law and declared policies for increasing the access to electricity of the population. Through these instruments, the government is able to dictate how the energy sector is managed, pushing the program towards the goal of supplying electricity to each person for the betterment of society. The major reforms in the energy sector started in 1995 with Decree 28/95, defining the role of EDM and establishing its bylaws (Cuamba et al., 2013). In order to more efficiently carry out rural electrification, the government needs to continue to strengthen the institutional framework and work in partnership with stakeholders to provide reliable, sustainable, and affordable electric power.

Figure 4. Summary of sustainability indicators for the investigated four sustainability dimensions. Source: own elaboration.



Figure 4 summarizes the outcome of the four-dimensional sustainability assessment for the rural electrification process in Manica Province. In the graph, the wider each point to the outside, the better the performance. It should be noted that the indicator values are merely indicative and should be interpreted in the relative context of other indicators. In general, the indicators reflect the situation at present for the electrification in Manica Province. Thus, even though renewables like PV systems and small-scale hydropower are suggested in rural electrification programs, the implementation is still in its establishment phase. In view of the interviews in Chua Village, the social acceptance stands out. The interviews with villagers indicated a potential demand of electricity in Chua Village corresponding to approximately twice the average actual consumption of electricity in Manica Province. The communal needs from hospital, school, and church would need to be added to the household demand. Environmental sustainability indicators are somewhat better than average, except for awareness. The potential here for the future is much larger than what is shown in the graph. Institutional sustainability indicators are better than average. Mozambique is a young country that has gone through a prolonged civil war. Thus, institutions and legislations are as well recently established. There appears, however, to be a political will to improve the state of affairs and rural electricity is underway. Economic sustainability is below average. The general funding of rural electrification is a conundrum. Efficient rural electrification has to consider scale and institutional strengthening. Donor organizations such as the GIZ work efficiently at the local scale. A national framework to support small and independent power producers would be necessary. However, at present, there is a lacking capacity for this.

4. Conclusions

Cook (2011) and Estache and Fay (2007) argue that the following prerequisites need to be fulfilled to achieve access of electricity for rural poor, namely 1) instruments to ensure service operators providing access, 2) instruments to reduce connection costs using, e.g., tariff design or direct subsidies within payment plans to favor poor, and 3) instruments to increase the range of suppliers thereby giving alternatives for lower quality service providers. Providing electric power is one of the most dominant resources that the government has for catalyzing societal development within the

country. Through electrification, it is possible to provide better services and job opportunities resulting in an improvement in the quality of life in rural areas (Ahlborg & Hammar, 2014).

The most promising energy sources at present for rural Mozambique have been considered as solar power and small-scale hydropower. Small-scale hydropower is a well-tested technique but needs to be adapted to local conditions and size of the grid. The potential is huge, especially for the Manica Province. Interviews with household representatives in Chua Village show that there is a strong social acceptance to electrification. Simple small-scale hydropower for a community in a village or group of houses can be implemented using knowledge from villagers. Simple turbines and other parts of the generator can often be maintained or repaired by the village smith. Cultural justice is therefore high, especially for small hydropower schemes. Even though solar power represents similar advantages, the negative environmental impact from used batteries and parts and less durability is not favorable. In order to speed up the rural electrification process, legislation needs to be improved, and there is a need for better institutional coordination for hydropower mini-grids' regulation (ALER, 2017). An obvious pre-requisite for successful implementation must always be strong local connection and participation. Mistrust between the government and the rural population will inevitably lead to failed projects.

Other Sub-Saharan countries are struggling in a similar manner as Mozambique. However, on the positive side, Rwanda, with a substantial rural poor population, has displayed positive effects of electrification (Bensch et al., 2011). Similar results have been achieved by South Africa (Dinkelman, 2011) and Cape Verde (Ranaboldo et al., 2014). As well, these countries have displayed the creation of new job opportunities for the people, a clear growth in their economy, improved agricultural technology, educational facilities, and health conditions. In general, the access to electricity reduces the level of poverty and is important for sustainable development. As well, Tanzania has displayed a positive case study for prosperous mini-grid-focused policy measures. Tanzania now has over a hundred operating mini-grids and is one of the leading African countries in this capacity (SEforALL Africa Hub, African Development Bank, 2017). Between 2009 and 2015 a standardized 15-year power purchase agreement program for under 10 MW projects was continuously replaced by a feed-in-tariff, which mitigates high inflation and local currency fluctuations. Tanzania has as well-waived connection costs for poor customers supplied via Rural Energy Agency projects.

Sub-Saharan countries like Gabon, Swaziland, and Kenya have all experienced a rapid growth in electrification. Access rates have increased by more than 50% between 2000 and 2016. Kenya is in the forefront in renewable energy in Africa. It has more than 40% of its electricity coming from non-hydro renewable resources (World Bank, 2018). Thus, there are several good examples of African developing countries where the electrification pace is picking up. In a not too far future, hopefully, they will be joined by Mozambique.

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