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Benefits and challenges to productive use of off-grid rural electrification: The case of mini-hydropower in Bulongwa-Tanzania

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ABSTRACT

This paper presents a case study of a minigrid powered by a small hydro plant in the southern highlands of Tanzania. The approach was chosen to provide in-depth understanding on benefits and challenges facing a rural minigrid. The case focuses on productive use; i.e. electricity as a direct input to the production of goods or provision of services. The study applies an interdisciplinary approach consisting of a mix of qualitative and quantitative methods, which included stakeholder and user interviews and measurements of output power and water flow. The analysis shows that certain entrepreneurial activities emerged as an outcome of electricity access thru the minigrid; barber shops, welding machines, mobile phone charging, salons, photo copy, and lighting business centres. Major challenges are related to the initial set up of the mini-hydro power plant, i.e. to only service the hospital, as the idea and need for building a minigrid developed much later. A tentative conclusion is that subsidized electricity will not promote rural businesses unless other criteria are met. Moreover, the minigrid faced a number of technical problems partly because of lack of adequate technical resources such as technicians and spare parts but also from the poor-planning and non-saving culture. The study concludes that the minigrid has led to productive uses that are found elsewhere in grid-connected rural communities. The finite supply of energy however means that there are restrictions using electricity for certain productive use – there is a load shedding schedule in place for some of the power intensive machines - due to overload caused by the load and large number of connections. Finally, there is apparent room for improvement not the least regarding the tariffs, which do not reflect market price and hence may affect the sustainability of the system.

1. Introduction

There are approximately 600 million people who do not have access to electricity in sub-Saharan Africa (WEO (2017)). The overall electricity access is 42% whereas rural access is a mere 22% (WEO, 2017). IEA estimates that the number of people without electricity will remain the same in sub-Saharan Africa by 2030. Even though the overall access rate has reached 60%, high population growth rate will level out the progress.[1] The access to electricity in rural sub-Saharan Africa is viewed as a huge stumbling block to economic development.

Minigrids as the point of departure in this paper is rooted in the failure of grid extension over the last few decades to reach rural Africa. The IEA (2014) found that in order to achieve universal access to electricity in Africa, 40 percent of new power connections would most cost-effectively be provided by mini-grids. IEA's conclusion, mainly from a supply point of view but also taking a user's perspective into account, is that minigrids might be the best option. Minigrids can offer 24/7 service and the capacity to power a range of electrical applications, comparable to those offered by the central power grid (Yadoo & Cruickshank, 2012). The challenge is that Africa alone needs at least 100,000 minigrids to meet the projected demand over the next few years Odarno, Sawe, Swai, Katyega, & Allisson, 2017. There are a number of programmes currently supporting minigrids in sub-Saharan Africa; the GMG MDP initiative by S4All implemented through AfDB, Sida&DfID joint support in Tanzania, DfID&EU support to minigrids in Kenya, and the BRILHO programme in Mozambique.

The recent focus on minigrids – see e.g. IEA (2014), Tenenbaum (2014), GMG MDP (2016) - as a solution for unelectrified areas is in

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[1] The pace of electricity growth has only barely exceeded population growth (IEA (2014) and World Bank (2015)).

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fact a 're-focus' as historically small hydropower plants have existed in southern Africa since the late 19th century, often established by mission stations. They often played an important role, though not well documented, in the provision of electricity to surrounding rural areas. The harnessing of hydropower and establishment of minigrids are therefore of particular interest as it provides a semi-centralized system that could be phased into a future grid extension. Hence, minigrid solutions have emerged as a viable alternative to traditional rural electrification, positioned between large-scale grid extension and smaller stand-alone solutions like solar home systems (Pedersen, 2016). Historically, minigrids commissioned by national utilities have failed in comparison those built by faith-based organisations that have a far better success rate (see Appendix 1 for the case of Tanzania). In a review of the potential benefits and risks of photovoltaic hybrid minigrid systems (Hazelton, 2014), identify the major risks related to community integration, equipment compatibility, and inappropriate business models.

Traditionally, rural electrification has been assessed in increased access such as number of connections, district towns, villages that are on the national grid. There was less attention on the actual use and transformative impact of electrification. Recently, the focus has turned to so-called productive use.[2] The rationale for the shift draws partly from the role of electricity in alleviating poverty. There is an enhanced understanding that the formation of businesses and their uptake and use of electricity will lead the way in rural development (Dinkelman, 2008; Blimpo & Cosgrove-Davies, 2019).

While electricity is generally regarded as a necessity for rural development, the evidence for such a sweeping statement is still rather poor (Matinga & Annegarn, 2013). There is an on-going debate on the role of rural electrification in triggering economic activities; one strand of literature claims that development follows in the footsteps of electrification whereas others view it more as a substitution of energy sources for already existing activities implying that it is not electricity per se that drives development. There is also a discourse on the complementary role of productive use and access to electricity whereby exposure and learning leads to increased use of electricity.

Literature on the role and impact of electricity access is unfortunately scant, mixed and mostly based on grid access, hence not addressing the specific context of minigrids. Generally, most impact studies focus on households (HHs) rather than productive use Grimm, Munyehirwe, Peters & Sievert, 2017; Peters & Sievert, 2016; Aklin, Bayer, Harish & Urpelainen, 2017; Bos, Chaplin & Mamun, 2018). The overall conclusion from these impact studies is the extremely low electricity consumption in rural households – ranging from 50 to 200 kWh/capita per year, and the relatively slow and low connection rates in electrified areas, a preference for grid connections. These studies define productive use, by and large, as an extension of households' capacity[3] to generate non-farm income earnings. This strand of literature concludes that most households in sub-Saharan Africa hardly use electricity for income generation. Moreover, potentials for rural micro-enterprises to expand their businesses are mainly depending on reaching markets outside the village or small town of operation (Peters & Sievert, 2016). Further, both Grimm et al. (2017) and Aklin et al. (2017) discuss mainly impact at the HH level focusing on lighting needs met by pico-PV lanterns. Hence, there are no direct linkages or impact on productive use discussed because of the technical limitations of pico-PV systems. In addition, Bos et al.'s. (2018) review of relevant literature shows that many studies have demonstrated that households in rural areas of developing countries use electricity primarily for lighting, transitioning away from kerosene, but they rarely use electricity for cooking or for productive uses.

The few studies addressing the impact at enterprise level are not conclusive on the casual relationship between electricity access and business performance. Lenz, Munyehirwe, Peters & Sievert 2016 present qualitative evidence that there are observable changes among micro-enterprises 3–4 years after electrification though rather modest. For example, there was a slight increase in business activities among existing enterprises as well as a modest increase in the number of startups. The main limiting factor for growth was however not access to electricity but access to larger external markets outside the local community (i.e. the village or rural small town) as the purchase power and demand of most local customer was not sufficient for sustained growth.

There is evidence that Kenyan micro-enterprises increased productivity and revenues after accessing electricity thru a community-driven micro-grid Kirubi, Jacobson, Kammen & Mills, 2009. Access to electricity led to productivity gains in the order of 100–200%, while increases in revenues ranged from 20% to 125% (op cit.). A West-African cross-sectional study of micro-enterprises in the informal sector shows that improved access to electricity may contribute significantly in certain sectors and for some types of businesses but it is not the main bottleneck for the informal sector as a whole Grimm, Gubert, Koriko, Lay & Nordman, 2013.

While the body of literature on the impact of electrification has grown considerable, there is still a scarcity of rigorous research addressing the particular transformation taking place in rural enterprises as a result of electrification. Moreover, the few studies identified use quantitative methods rather than case study approaches which may shed different light on our understanding of the transformation processes. In conclusion, adding more qualitative impact research at the enterprise level we believe that it will be possible to address many of the issues related to rural development more directly.

A tentative conclusion, based on literature reviews, is that productive use leading to significant rural development entails an additional set of challenges due to the paucity of markets, purchase power, skilled labour, location, etc. Most rural businesses tend to draw on local market opportunity and the entrepreneur's skills to utilize electricity to meet the demand of rural customers. Hence, it is seldom the access per se that leads to extensive productive use.

Thus, the objective of this study is to illustrate and assess how electricity is used by businesses in a minigrid system in rural Africa, how this electricity use develops over time and impacts village businesses, and to discuss challenges. Despite the importance of the topic, there is hardly any published qualitative studies addressing these topics, and this study thus aims to fill this gap and to add field data and experience. Although our work was inspired by (Kirubi et al., 2009), the study of Bulongwa does not provide the before and after scenarios like Kirubi et al.

A case study approach was chosen to provide in-depth understanding of the dynamics present within single settings (see e.g. Eisenhardt, 1989). We chose to carry out the study in Tanzania (in the Bulongwa village) and to focus on a (NFP[4]) micro-hydro supplied minigrid, since these are dominating among the minigrids in Tanzania, which have been in operation for more than five years and

[2] Electricity is normally viewed as having two distinct uses: residential and productive. In emerging views, the distinction between the two is blurred and residential use of electricity – for lighting, charging cell phones, IT, computers – is closely related to development in a broader sense. Many households in sub Saharan Africa are involved in non-farming earnings which predominantly comprise petty trading, charcoal making and selling, agro-processing, financial services, etc. (Haggblade, 2011).

[3] This means productive use is viewed as a part of the household's activities instead of the formation of a separate business entity, like a micro-enterprise.

[4] NFP Not For Profit.

where it thus is possible to address development impacts. The choice of micro-hydro power with its relatively high capacity also allows analysis of relatively high productive use loads (Jacobson, 2007).

The rest of the article is organized as follows: section 2 presents the Case - the Bulongwa village minigrid, followed by Method, then section 4 that provides the Findings such as the results of interviews and visits, which is subject to Analysis in section 5 in terms of productive use, benefits and challenges and section 6 concludes.

2. The case – the Bulongwa mini-grid

Bulongwa is a small village within the Makete district in the Njombe region; population of around 2000. It is situated in the southern highlands of Tanzania; 110 km from Mbeya city and 130 km from Njombe town. The village is located along the main road between Mbeya and Njombe. The population of the Njombe region is about 700,000 (according to the national census of 2012). Njombe is one of the five regions in the southern highlands where there is a number of waterfalls in the rivers directing water to Lake Nyasa and Indian Ocean and thus many potential sites for development of small-scale hydropower. Thus, the selected case is well representative for minigrids in Tanzania which have been in operation for a number of years since they are generally micro-hydro based, organized by the missions and located in the highlands.

The Evangelical Lutheran Church had been in Bulongwa since the 19th century, originally brought there by Germany missionaries while after World War II Swedish missionaries took over. Most missionaries had apart from their main mission an interest in developing the nearby communities by for instance providing social services. Thus, Bulongwa Lutheran Hospital was one of the health facilities established by missionaries in the early 1960s with the goal of providing health services. Since its establishment, the Bulongwa mission has solicited help/aids from various donors around the world, including support for the hospital facilities and from experts from abroad. The hospital also used to provide services to the nearby towns and districts.

Electricity access was one of the requirements deemed necessary for the hospital operations since the main facilities of the hospital use electricity and Bulongwa was identified as a village with considerable hydropower resources. The idea of establishing a mini-hydro power plant thus seemed as the most suitable option given the off-grid location of the hospital and village. The first power plant was built in parallel with the construction of the hospital buildings in the late 1950s. In 1962, the first hydro power plant was already installed (while the hospital was not officially inaugurated until in 1968). However, it did not work for long since a large part of the machinery was swept away by the river already at its first trial. Thus, from that time diesel generators were used to generate power for its electrical appliances until 1994 when they started to use electricity from the newly refurbished hydropower plant.[5]

In the first few years after starting operation in 1994, the plant only supplied electricity to the hospital. Later, the diocese offices were also connected. In the early 2000 the hospital management requested a permit from Tanzania Electric Supply Company (TANESCO) for supplying electricity to other users as the generation was far beyond the hospital's consumption. Although at that time the regulation of allowing individual power producers (IPPs) was not yet released, they were granted a permit similar to the ones introduced in 2009 and known as Standardized Power Producers Agreement (SPPA).

After being given the permit to supply electricity to external users the hospital management in collaboration with villagers established a mechanism of controlling the supply. Representatives from the five electrified areas (Mahulu, Katenga, Kitula, Mwakavuta and Madihani) were elected and in collaboration with the BLH management took the responsibility of processing applications for new customers and disseminate information from BLH management to customers. BLH has no formal contracts with users as the agreement is based on a written application, only. The hospital has managed to connect to 264 residential customers and 82 businesses of different demand categories such as business centres, milling and carpentry workshops, office buildings and home usage and it is estimated that this corresponds to an 80% electrification of the village (Amani, 2015).

3. Method

This case study is based on field studies and employs a combination of quantitative and qualitative approaches. Qualitative methods were chosen as they are suitable for dealing directly with perceptions of the respondents (Sovacool, 2013) while quantitative methods were used to complement findings from the interviews. This kind of mixed methodological approach has been used widely in business-related studies (Harrison, 2013). Finally, general observations were made including observations of the environment surrounding the plant. The main field study was conducted over a period of four weeks in 2014 complemented by one week in 2015.

Benefits are here defined as an advantage gained by the user in performing its daily duties, such as laboratory works, laundry activities, lighting; advantages for businesses related to enhancing income generating activities (such as powering business centres, use of modern tools), and related to villagers with regards to socio-economic development such as students being able to read during night, and powering entertainment appliances.

Interviews were carried out with a vast range of persons including technical staff, watchmen, hospital management staff and customers. Four technical staff, who maintain the plant and deal with routine service, six watchmen who oversee day-to-day operation and 20 electricity customers from the four subdivisions of Bulongwa village connected with electricity were interviewed. The hospital management team that includes dentist, medical doctors, matron, and accountants were also interviewed. The interviews were guided by an interview manual and follow-up questions were asked depending on the respondent's answers. These respondents were also asked about when their houses were connected with electricity from BLH, and how many electrical appliances that are available in their residence (although the main focus is on productive use, the access to electricity would benefit households as well).

In total, 15 business establishments using electricity were visited and interviewed. Productive use was addressed by verifying if there were any income generating activities requiring electricity. Issues about satisfaction regarding payment and tariffs were also asked. Further, respondents were asked to compare the amount they were paying and the one they used to pay when they were connected with meter. Questions as satisfactions with the system and questions relating to tariff and reliability were also asked. Further, the hydropower plant and its operations were observed in-depth. The hydro plant was visited three times to study how it was operating and if there were any major technical challenges.

4. Findings

In this section we report the outcomes of the interviews and visits to businesses, the hospital and the plant in the Bulongwa village. The presentation is divided into four themes: Use of electricity, Tariffs, Technical issues, and Miscellaneous issues.

[5] Constructed by a Swedish engineer.

4.1. Use of electricity

Access to electricity in Bulongwa village is reflected in various productive uses; there are milling machines, welding machines, battery charging and various services at the enterprise centres such as barber shops, photo copying, printing and CD&DVD shops. The local pubs and hotels offer additional services using electricity (TV, warm water, lighting, cold drinks).

Up to the time of the data collection (2014-15) there were 264 residential customers – read households - connected to the system with a total peak load of 33 kW. In addition, there are six milling machines with a total capacity of 92 kW, and two welding machines with a total estimated capacity of 2 kW (they were locally manufactured and thus it was difficult to get exact information of their rated power). There are also two carpentry workshops with machines with a total capacity of 10 kW. Lastly, the total capacity demand of the hospital facilities was estimated to be 20 kW. Taking into account the total loads (approximately 150 kW), the power plant generation capacity (120 kW or often less, around 100 kW) is clearly lower than the total peak demand (see Table 1 below).

The Bulongwa Lutheran Hospital is the owner of the power plant and they have the mandate of connecting electricity to new customers. New customers have to pay an application fee of 160,000 TZS, plus 15,000 TZS to BLH for a technician and, in addition, to purchase all required materials such as poles and transmission wires. Thus, all the connection expenses are covered by the user. This also implies that the quality of the materials used is not well controlled.

This supply-demand mismatch, mainly originating from the presence of the six milling machines, has led to an agreement regulating the use, implying that only three of them may be in operation during a single day. Thus, the agreement allows three machines to be run on Mondays, Wednesdays and Fridays, and the other three on Tuesdays, Thursdays, and Saturdays. Hence, each milling machine has a limited weekly load but the power shedding has in fact contributed to multiple suppliers and increased competition. Two milling machine operators have both electric and diesel machines but the diesel machines (no electricity generation, only mechanical power) seems not to be running much due to high cost. Hospital machines and those at the orphanage centre are allowed to run anytime when there is need of doing so. Table 1 shows the main load and productive use of the minigrid (user type 8 and 9 are not productive use).

The heavy users of electricity are the milling and carpentry workshops though from a revenue perspective, households represent 50% due to the flat tariff structure (i.e. subsidizing heavy users rather than HHs). There was no active push by BLH to promote productive use per se as business start-ups and the uptake and shift to electricity as an energy source has been driven by the entrepreneurs themselves. Most of the productive use businesses were started after the minigrid was established. There were 2–3 millers operating prior to the minigrid using diesel generators and/or diesel-powered machines.

The heavy users totally depending on access to electricity are the wood working industries (sawing, planning, carpentry, etc.). In addition, there is a tyre repair workshop which operates on electricity. Several businesses had backup diesel generators because of power cuts in the minigrid, e.g. photocopying, millers. Many businesses such as groceries and convenient stores mainly benefit from longer opening hours in the evenings as the productive use linked to the actual business is limited. Hotels, guest houses, bars gain a competitive advantage to those establishments with no access by offering lighting, TV, cold drinks, etc. Some services delivered, as a result of the mini grid, are new to the community, e.g. hair salons, barber shops, welding, music & DVD sales, and cold drinks, as other off-grid power technologies were not used for these purposes prior to establishment of the minigrid.

Furthermore, the electricity provision makes some services more affordable to community members, for instance the milling machine charged 700/- per tin as compared to 1000/- shillings or 1500 in some places if the machines would run on diesel.

How the dependency on electricity has developed was shown when the system failed in 2012. As a result, after half a year the number of patients at the hospital dropped from more than 250 to less than 150 per month. The income of the hospital dropped to an extent that it failed to pay monthly salaries to casual labours for about six months since they were using minigrid revenues for running the hospital as overseas contributions and grants from e.g. the Lutheran church have decreased a lot. Furthermore, a number of business centres were closed down during this period and some entrepreneurs moved to a nearby town.

There is also anecdotal evidence of the role of electricity access. The orthopaedic technician narrated that without electricity he cannot do any activity in his workshop as all the machines are powered with electricity. A laboratory technician also pointed out that when the hospital is disconnected from power, specimen testing becomes difficult and other activities impossible; sometimes it is not worth to run the generator just for testing one specimen so the patient has to wait till there are accumulative activities and the generator may be switched on. The matron who is in charge of supervision of the nurses and all the ward activities reiterated further that, electricity at the hospital is required for daily sterilization of medical equipment and laundry activities; for lighting at least there is back up of a solar system.

4.2. Tariffs

Currently, the tariff structure applied is based on a flat rate depending on customer category, billed on a monthly basis. This means that the different categories of users each has a set tariff

Table 1
Estimated load, productive use and tariff of the minigrid.

#	Type of load	Units	Capacity/ Load (kW)	Tariff	TZS/month	Remarks
1	Milling machines	6	92	30,000	180,000	M/c owned by Orphanage centre was excluded
2	Welding machines	2	2	25,000	50,000	Load estimated
3	Water heater	1	1	0	0	Excluded from tariff
4	Sunflower oil processing machine	1	5	0	0	Excluded from tariff
5	Workshops	16	10	25,000	400,000	This includes carpentry workshops and garages
6	Shops, groceries (lighting mostly)	33	1	10,000	330,000	
7	Medium businesses (barber, photocopying, guest house, bars, etc)	26	1.5	12,000	312,000	
8	Hospital facilities		20	0	0	
9	Households	264[a]	33	7000	1,057,000	
Totals connected to the system			**153**		**2,439,000**	

[a] Assumed average load is 125 W for all residential customers. However, this load tends to peak in morning hours and in evenings.

regardless of consumption. Hence, tariffs basically differ with respect to the type of consumer; household or business. They have also changed over time. In the first decade (2000–2010), the first 170 customers were supplied with meters (from Sweden) and payment was according to actual usage but the consumption was very low. The BLH cashier, who is responsible for collecting monthly bills from customers, pointed out that the collections were less than Ths 600,000 per month when they relied on meter readings.

There were however customers who complained that their meter readings were higher than their actual consumption but there was never any technical evidence that proved this claim. From 2010, BLH decided to apply flat rate tariffs but with different monthly tariff levels according to usage category. 7000 TZS was charged for household users defined as users using electricity for domestic purposes such as lighting and electrified entertainment appliances. Electrified business centres paid 10,000 TZS while companies with milling machines were charged 30,000 per month and small workshops and welding machines were paying 25,000 TZS. Business such as barber shops, bars and photocopying were also charged 12,000 TZS. Table 1 summarizes the various tariffs. The number of customers connected had in 2016 reached 264 households and 82 businesses of various categories; from these connections the centre can collect up to 2,299,000 TZS per month.

The amount collected is partly used for maintaining the machines but mostly to meet operational cost in the hospital. Although the amount is not sufficient to meet all needs, it has assisted the hospital to meet some of its needs.

The applied business tariff implies that users with machines pay a considerably higher tariff – reflecting the load - but also have restrictions on running hours and days of the week. Considering the heavy load of these users, their bills would be substantially higher if based on their real consumption. Most of the respondents had very little knowledge of their consumption and thought that a meter-based system would lead to reduced costs for them. E.g. one carpentry workshop which believed that the monthly flat rate of 25,000 was overbilling would actually have a bill ten times higher if on a TANESCO meter rate.[6]

4.3. Technical issues

The power supplied from the plant is not sufficient to provide all customers connected to the minigrid 24/7 services. This is in particular critical during evening hours, which results in frequent system failures, see Table 2. Despite the restrictions on electricity use for large consumers such as milling machines in the evening hours the plant seems to be overloaded. Power cuts occur almost once or twice daily and mostly within the interval 19:00–20:30.

The plant is mainly taken care of by one technician who has a certificate in electrical installation acquired from a vocational training centre but much of his skills were acquired from the Swedish engineers who he used to work with during installation of the power plant. After the plant inauguration in 1994 it was operating very well without major breakdowns up to 2010. Lately, however, there have been frequent bearing failures and breakdown of the turbine shaft. The main cause of these failures was sand that rubbed the rubber bearing and the shaft. This kind of failure brought a new technical challenge to the maintenance team. Filters were introduced to purify the water that lubricates the rubber bearings but due to frequent blockages caused by sand and mud they did not function for longer periods of time. Another maintenance challenge faced was the unavailability of rubber bearings; when ordered from the manufacturer, they were told that the plant was no longer producing such kind of bearings. This was eventually solved by the introduction of a greasing mechanism and the provision of a bearing case providing protection from water but it is requiring weekly lubrication of the bearings.

Table 2
Daily electricity cut-off tracking.

Date	Frequency	Total (min)
11/09/2013	2	18
13/09/2013	1	19
15/09/2013	1	07
17/09/2013	2	24
18/09/2013	3	34
19/09/2013	1	04

Up-stream activities along the river banks such as cattle grazing, cultivation, and clearing of land by fires are also impacting the operation of the mini-hydro plant due to erosion caused by land and soil degradation. The erosion leads to nixing of soil and sand into the flowing water causing direct damage (wear) to the machine bearings. In some instances this lead to the requirement of replacement of bearings.

4.4. Miscellaneous issues

The local community seemed to be very keen on seeing the system running. An example of this; in the year 2012, a transformer was blown out because of overheating caused by lack of cooling oil due to night-time theft of the oil. After struggling for almost ten months repairing the burnt-out transformer, villagers currently living in Dar es Salaam raised enough money to buy a new transformer at a cost of almost 15 million TZS. During this period the issue of ownership was brought forward. Community members were asked to assist in ensuring that the system is kept operational. Establishment of area representative groups were introduced so as to ensure that villagers would be informed about BLH management decisions.

5. Analysis of productive use, benefits and challenges

In the following section, we analyse our empirical findings in the light of research questions that focus on productive use, benefits and challenges for users and minigrid operators/owners.

A general observation is that productive uses have expanded as a result of the access to electricity. There are in total 85 productive use establishments in Bulongwa that use electricity to varying extent for their services. Of these, a large proportion (almost 40%), mainly small shops, do not depend on electricity per se for the business but benefit from extended operation hours because of lighting. The heavy users, milling, welding, carpentry, etc. comprise 70 per cent of the total load but only 25% of the revenue base. The productive uses as a result from the minigrid are similar as those cited in other studies of productive uses of RE in rural areas Hazelton, Bruce & MacGill, 2014; Kirubi et al., 2009; Lenz et al., 2016).

The causality between access to electricity and economic growth could be assessed by understanding the growth of productive use activities resulting from the minigrid. The Bulongwa is a single case so we will not draw any general conclusions but the case may add some insights on qualitative aspects such as how and why electricity access led to productive use in this particular case.

Considering the number of years the minigrid has been in operation, since year 2000, and that many businesses were started

[6] All users who were connected before the new flat rate was introduced still have their meters running so during data collection a few businesses were checked by the team. The workshop in question had used 24,000 units over 2 years which roughly corresponds to a monthly bill of 300,000 TZS.

after 2010, the adoption has been relatively slow (the business start-up process was however not fully documented). There are scant data from other similar electrification initiatives but turning electricity into productive use is customarily a slow process. It was observed that most of the more complex productive uses such as those with heavy load and solely dependent on electricity were run by entrepreneurs that had lived outside Bulongwa village for extended period of times, particularly in larger towns like Mbeya. Urban – rural migration seems to be a key source of entrepreneur's experience and drive to start small businesses. We did not focus much on this issue but additional insights on the role of migration may explain why certain rural centres grow faster than others. An additional impact of the grid is that employment increases over time due to labour needs of new companies.

However, electricity supplied in a mini-grid powered by a mini-hydro plant, in particular 'run-of-the-river' plants like Bulongwa, comprises special challenges. Lighter productive use and residential use seem to have minor impact on load management whereas heavy users need to be regulated such as illustrated in the case of Bulongwa by enforcing load shedding. Hence, there were restrictions for some of the heavy users. These restrictions did not seem to be a main bottleneck for the businesses as market demand and lack of input resources were cited as the key barriers.

The benefits for users, whether business or residential, seem to fall in the realm of living a more modern life that comes with electrification. The life has changed a lot as a result of having electricity; people can watch and listen to modern entertainment facilities such as TV and radio at low cost. Productive use benefits both the entrepreneurs and the residents of the community who basically is the market for the productive uses. Some services target out-of-community customers such as some of the hotels (travellers between Njombe and Mbeya spend the night in Bulongwa). These findings are the same as those of the study conducted by Kirubi in Kenya (Kirubi et al., 2009) on how electricity from microgrids contributed to rural development.

The owner of the grid, BLH, decided to commission a hydro plant with the intention of powering hospital facilities, now the plant is used as income generating unit as a large part of money collected from customers' tariffs is used for buying hospital consumables, paying salaries, etc. The hospital has become dependent on the revenues for covering operational costs. Further, the micro-hydro and minigrid activities are poorly organized as there is no separate structure for those activities which mean that they are integrated in the hospital's overall management.

The tariff structure has changed over time and today users are charged a flat rate. However, there are two tariff levels; one for households and the other for income generating centres such as milling machines, welding machines and entertainment centres. A first observation is the paradox of switching from a metered tariff to a flat rate, which led to an expected higher consumption but also to a considerable increase in revenues collected by the operator. The meters were disconnected because many customers thought the readings were too high but in hindsight the operators have increased the revenues substantially under the flat rate tariff. Secondly, challenges emerged from the tariff settings. Many households did not comply with the operator's requirement on using energy saving bulbs as they are paying flat rate; the researchers found e.g. that lights were on during day-time hours. Also machine and workshop operators were complaining on the scheduling introduced as hindering factors to achieve their production goals, and we even noticed one milling machine operator running out of his schedule.

The fact that the tariffs collected is not only used for running costs and system maintenance but also for the hospital indicates that this can be considered as an operational profit, which could have been used to cover investment cost, an issue that is discussed in the literature.

6. Concluding discussion

To summarize, the study focuses on productive use and challenges faced by operator and businesses. First, the role of access to electricity in forming and sustaining productive use depends on the specific activities requiring electricity. It was noted that most of the heavy machines – milling and carpentry – were earlier run on diesel gen sets which means electricity was merely substituting the earlier energy source. The new businesses established after the minigrid was operational and offered to villagers were mainly using electricity for added value rather than powering the core activity. There were few productive uses solely dependent on the minigrid (the welding, salons). However, profit margins were substantially higher while operating on minigrid electricity as the cost of running diesel generators was much higher (some cases double or more).

The productive use identified and discussed in this study had challenges such as unreliable power supply partly addressed by power shedding. Also, the market was not adequate enough to ensure profitability of the businesses which might be due to low purchasing power in rural areas, thus blocking tariff adjustments. To ensure that revenues for productive use are increased, there should be improvement in productivity in the process of production and creation of new demands (new markets) for products; as most of productive use activities were focusing only on the local market (Bulongwa) which is too small.

There are a number of challenges found in the Bulongwa minigrid: overloading of the power plant as demand keeps increasing without supply side improvements, lack of technical expertise to identify and fix problems once they happen, users with higher usage rate such as milling machines and workshops are restricted, thus limiting productive use which would increase producing in surplus which in turn would trigger searching for new markets. The local community had poor sense of ownership as the plant was regarded as investment for owner's interests, and they even fail to meet agreements with the operator such as not to put on lights on daytime, the use of 100 W incandescent bulbs that were abandoned could still be found in some houses. Connection cost is too high to rural people and hence they opt to use substandard materials such as untreated poles and distribution wires of low quality which may affect users' safety. The supply plant technology is old bringing challenges to find spare parts from manufacturing companies. The operator (hospital) has no saving culture which puts the sustainability of the plant at risk. A plan to connect the village with the central power grid is underway but there is no plan on how this is to be carried out.

There is no obvious justification of the shift from the metering based system to the use of flat rates; as using flat rates consumers become less responsible for controlling their usage; likely this contributed much to overloading the plant while keeping the revenue collection from customers low. Hence, the sustainability of such a tariff model is questionable. The tariff setting does not follow the amount set by the regulator EWURA; the monthly flat rate of 7.000 TZS for households and 25–30,000 for businesses seems to be very low compared to the tariff set by EWURA (2012) under the Standardized Small Power Purchase Tariff for isolated minigrids, which is 480.50 TZS/kWh (about USD 0.25/kWh). It is also below the average monthly expenditure in rural Tanzania which is around 13,000 TZS for HHs (REA, 2017).

This study also highlights the need for proper management of a mini-grid. The BLH micro-hydro power plant may not be optimally managed and operated as the productive uses of electricity from the power plant are not matched with the plant's capacity resulting in frequent power cuts; emphasising the importance of especially proper load management. The flat rate set does not reflect the real consumption, which leads to 'opportunistic' usage which is not sustainable. If the available business centres were charged according to their usage, BLH could collect additional revenues which would help ensure survival of the minihydro plant for the coming years. These findings are in line with (Klunne and Michael, 2010)who emphasize the importance of building capacity that goes beyond maintaining just the hydro power plant. For instance, considering local capability that includes managerial capacity to run the minigrid by involving key stakeholders is critical to sustainability.

From this study it is shown that rural electrification brings a number of benefits to the society which are not easily measured in direct economic output, such as that people can work during night hours and students can benefit from electricity by doing their homework and remedial studies during night. Thus, rural electrification is assisting the community in many aspects including provision of lighting, improvement in the health and education sectors, and it also enhances households' income-generating activities.

Finally, productive uses grew out of independent entrepreneurs' initiative to start a business. In the minigrid we studied, there were no support or sensitization programmes for the community, which had to rely on their own capabilities to organize businesses. However, since successful minigrids, in an entirely different way than with central grid power supply, depend on an integrated operation, meaning that supply and demand aspects are closely connected and interlinked, it is imperative for institutions related with rural electrification programmes to have clear understandings about the challenges faced by minigrid operators and the productive users within rural minigrids.

Conflicts of interest

No conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2019.10.001.

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