Chapter 11
Impacts of Electrification Under the Perspective of the Multi-Tier-Framework in Southern Tanzania

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Abstract Off-grid areas in many African countries do not necessarily lack access to electricity. In the last decade, energy technologies based on solar power achieved higher penetration rates, also in rural areas of Sub-Saharan Africa. Mini-grid technologies are expected to play a key role in expanding the access to electricity. However, grid extension is still the preferred technology to enhance electrification rates. Taking into account the Multi-Tier-Framework (MTF) by the World Bank, electricity access is no longer a binary metric but a multi-dimensional phenomena. Reliability is one of the criteria considered in the new framework. This study strives to reflect enhanced reliability through an interconnected mini-grid system by comparing the effects of power outages on households in the Southern Tanzanian Region. The focus of this paper is the daily mean lighting hours consumed per household in both a mini-grid-electrified area and none mini-grid electrified areas. Lighting is one of the most important intermediary outcomes of electricity through which households can benefit in many fields. As has been expected, lighting hours consumed by households in mini-grid-connected areas are affected by power outages but are still significantly higher than in not yet grid-connected villages. The analysis underlines the importance of interconnected systems supporting the reliability of electricity access, which is also crucial for productive uses. Additionally, fertile ground for further research is identified. Propensity Score Matching Method is recommended to identify treatment and control group to further study the impacts of interconnected mini-grid electrification.

Keywords Interconnected energy systems · Electricity access · Multi-tier framework · Reliability · Socio-economic impacts · Sub-Saharan Africa

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11.1 Introduction

The relationship between (rural) electrification and socio-economic impacts has been studied widely on macro-economic level. However, up to now, there is no clear consensus regarding the causal direction of this relationship [1]. But the relevance for electrification as one of the drivers for achieving the sustainable development goals is not questioned. Also on micro economic level, there is some evidence that electrification improves living conditions in developing countries [2].

According to the binary definition of "having a connection to electricity or not", the African continent is with 587 million Africans (excluding North Africa) out of more than 900 million people or with 63% of them not having access to electricity in 2014 far away from reaching the UN's development target of universal access by 2030 [3]. Tanzania, which is in the focus of this study, still belongs to one of the 20 least electrified countries in the world and most recent data from 2014 indicates that only approximately 16% of its population is electrified [3].

However, as acknowledged in the recently developed United Nations Sustainable Energy for All Global Tracking Framework the binary definition of electricity access is too narrow to describe the complexity of it. Energy access-which contains the access to electricity—should be adequate, available when needed, reliable, affordable, legal, convenient, healthy and safe for all required energy applications [4].

This study considers the reliability of electricity by taking into account the duration and frequency of power outages and its impacts on lighting hours of households. On the other hand, the analysis studies households from not yet grid connected areas to reflect their "pre-grid electrification status" allowing access to basic electricity services. With worldwide falling prices for solar power based technologies, ex ante grid electricity based on alternatives to for example diesel generators becomes also more accessible for poorer households in rural areas of developing countries. In rural Sub-Saharan regions many of recently electrified households still use electricity mainly for lighting purposes [5, 6]. Lighting is seen as an intermediary outcome of electrification with the potential to improve final outcomes in the field of health, education and income in the long run.

In the next section, the article reviews research done in the field before it reflects the methodology applied and discusses the results. Finally, it concludes and gives an outlook on further research.

11.2 Background

Tanzania belongs to one of the African countries with a stable economic growth rate of 7% annually in the last decade [7]. The agricultural sector is the backbone of the economy employing more than two thirds of the population [8] which amounts to 55.6 million people in 2016 [7]. The country is still one of the poorest countries in the world, reflected in position number 151 out of 188 countries in the Human

Development Index (HDI) [9] and the Multi-Dimensional Poverty Index (MPI), which defines 66.4% of the Tanzanian population as multi-dimensionally poor in terms of education, health and standard of living [9].

This is also reflected in the official electrification rate, which defines that only 16% of the population is electrified. Per capita electric power consumption amounts to approximately 99 kWh [7]. Installed power generation capacity is low with only 1564 MW [10], whereby approximately 10% of it is attributed to mainly fossil fuel powered mini-grid systems [11].

However, the Tanzanian energy sector is frequently affected by power generation outages, which can be attributed to chronic underinvestment and weak technical as well as financial performance [12] but also to climatic conditions due to its high dependence on hydro power (more than 30% of total generation capacity) [13]. In 2014, approximately 18% of electric power transmission and distribution has been lost [7].

To address these constraints, the Tanzanian government put ambitious reforms into place which include a higher participation of independent power producers (IPP) and small power producers (SPPs) in the power generation sector. The Mwenga Hydro Power Project (Mwenga in the following), which is in the focus of this study, is a 4 MW hydro power based interconnected mini-grid system and falls under the umbrella of a "special regulatory framework with simplified procedures and standardized contracts" [10]. The majority of its power is sold to the main grid (the national utility called Tanesco). The rest of the power generated is distributed within the mini-grid system which encompasses the local tea industry and surrounding rural villages. The shares of what is distributed within the mini-grid or sold to the national grid fluctuates depending on season.

Commonly, research done in the field of impact evaluation of (rural) electrification is on different levels: macro and/or micro level. Irrespective of research level, it focusses mainly on off-grid or grid electrification and rarely studies the effects of interconnected electrification projects. Additionally, the impacts of power outages on (intermediary) impact indicators—such as lighting hours—have been studied less, especially in the Sub-Saharan context.

11.3 Methodology

In 2015, 327 households and enterprises were interviewed in mini-grid connected or not yet mini-grid connected areas in the Mufindi Region in Iringa located in the Southern Tanzanian Highlands [14]. By that time the Mwenga Project already operated for three years. The surveys contained more than 70 detailed questions on socio-economic conditions and energy use. For the purpose of this study, questions related to households' sources of energy use and daily average usage in hours were analyzed. An overview on these questions can be found in the Annex in Tables 11.4 and 11.5.

Household and enterprise selection was based on simple random selection. However, the selection of villages was not randomized because the author wanted to ensure that the villages share most of their background characteristics to enhance comparability between households from the mini-grid connected and not yet mini-grid electrified villages. For that purpose, the village selection procedure considered accessibility of villages, the existence of complementary infrastructure and context characteristics such as topography, distance to bigger cities and towns, educational services, health services (regular) markets in the village, (formal) financial services, mobile phone network, main income sources and presence of other development projects. To get a comprehensive overview on the background characteristics information from different sources was collected and combined. These included local informants like village leaders or representatives from the Mwenga Project and secondary information like official reports [15, 16] and other studies [17].

The present study limits its analysis on 40 mini-grid connected households relying solely on electricity for lighting purposes and 68 households from not yet grid electrified villages.

The concept of reliability of electricity is based on the definition of the World Bank within the Multi-Tier-Framework [4]. In accordance with this concept a non-reliable electricity access is understood here as the time electricity distribution of the mini-grid system is interrupted. The higher the frequency and time of interruptions the more unreliable the supply of electricity becomes.

Data on mini-grid power outages is based on information from project representatives [18]. Power outages refer to the time mini-grid distribution of electricity is interrupted, thus no power is delivered to the end consumers (to the mini-grid connected villagers and to the main grid), irrespective on mini-grid running mode—interconnected or island mode. Thus, power outages from the main grid are not reflected totally because the interconnected system is able to disconnect from the main grid and to switch on isolate mode to further distribute to the villages. Especially planned power outages by the main grid are therefore not reflected here because the system is prepared to switch to isolate mode. However, the data describes unplanned power outages and the time needed to switch the operation to an isolate operation of the mini-grid. Power outages due to occurrences within the Mwenga system are reflected totally. For the purpose of this analysis mini-grid power outages attributable to Tanesco or Mwenga are calculated in average hours per day between 7 p.m. and 6 a.m. on a yearly basis first (see Table 11.1). It is assumed that within that time frame household's lighting hours might be impacted by power outages. At this stage of research, no impacts of seasons or other parameters affecting mini-grid power distribution are reflected.

To better reflect seasonal fluctuations and extraordinary events affecting power generation and distribution, average power outages per day between 7 p.m. and 6 a.m. are also displayed on monthly basis (see Fig. 11.1). The estimations on yearly and monthly basis assume that power outages take place every day- an assumption that might be too strong to reflect reality, but is needed to study impacts on daily lighting usage of households.

To address these constraints, the study further includes average outage frequency per month between 7 p.m. and 6 a.m. (see Table 11.3), which is calculated on yearly basis. Additionally, this study displays average daily distribution in kWh within the mini-grid system between 7 p.m. and 6 a.m. to illustrate the effect of power outages on electricity distribution.

Table 11.1 Average power outage duration in hours per day from 7 p.m. to 6 a.m. in 2015 and 2016

	2015 (h)	2016 (h)
Mwenga	0.51	0.19
Tanesco	0.53	0.25
Both combined	1.04	0.44

Source Own elaboration based on [18]

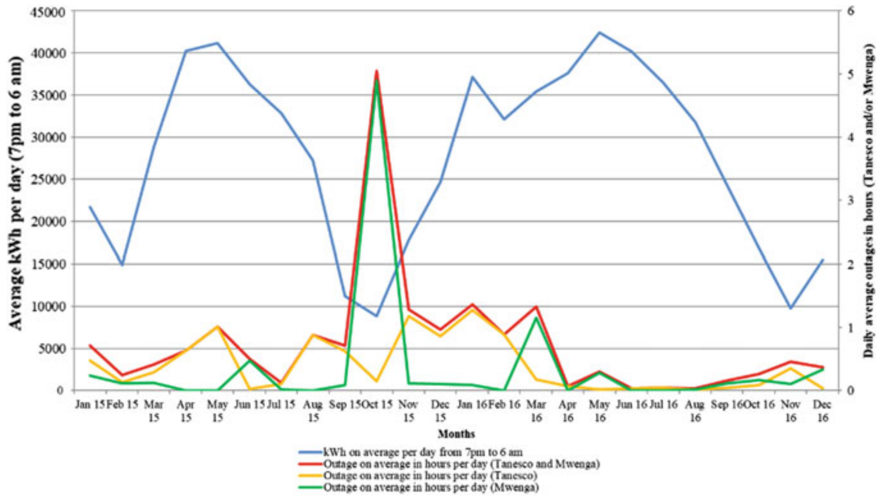

Fig. 11.1 Daily mean power outages in hours and distributed kWh (7 p.m. to 6 a.m.). *Source* Own elaboration based on [18]

Average lighting hours per day are based on estimations of household heads from the non-connected and mini-grid connected villages. Lighting is a direct outcome of electrification because its usage usually starts immediately after electrification when infrastructure and lighting devices are installed. Data has been collected by the end of 2015. For that reason, it was assumed that average lighting usage remained the same for 2016. Lighting hours are based on the daily usage of the most frequent lighting devices or appliances, such as different electric bulb types and wick or gas powered lamps. Due to data constraints mobile torches, such as mobile phone flashlights, and candles have been excluded from the analysis.

11.4 Results and Discussion

As can be seen in Table 11.1, the mean duration of power outages between 7 p.m. and 6 a.m. affecting mini-grid distribution attributed to Mwenga are less compared to those related to Tanesco in 2015 and 2016.

In a worst case scenario, where both power outages would have taken place on the same day but not necessarily at the same time, mini-grid distribution of electricity would have been interrupted by approximately 1 h per day in 2015 and 0.4 h per day in 2016 on average.

With approximately 32.95 mean hours of lighting per day households from mini-grid connected villages consume significantly more lighting hours per day than households from not yet—grid connected areas with 23.94 mean hours per day (see Table 11.2).

On average, mini-grid connected households reported to own 5.3 electric lighting appliances. If their usage in hours is assumed to be equally distributed, this would lead to a usage of each device for approximately 6.2 h per day. For those mini-grid connected households solely relying on electricity from the grid, power outages impact their lighting consumption.

In the worst case scenario, assuming that all lighting devices are running when both power outages take place, this would lead to approximately 31.9 lighting hours per day on average in 2015 and to 32.5 mean lighting hours in 2016.

When distinguished by source of outage, power outages that are attributable to the main grid would have led to 32.42 mean lighting hours in 2015 and 32.7 average lighting hours in 2016.

Conversely, power outages from the Mwenga system would have led to slightly higher mean lighting hours with 32.44 average lighting hours in 2015 and to 32.77 mean lighting hours in 2016. However, the slight differences in average lighting hours are not significant when distinguished by source of outage.

Due to data constraints it is not possible to refine the analysis in terms of a better reflection of real lighting hours diminished by power outages expressed in hours per lighting device. This becomes especially clear, when considering the fact that power outages are not taking place every day. Average outage frequency per month between 7 p.m. and 6 a.m. amounts to 13 in 2015 and to 11 in 2016, which leads to higher average duration per power outage (2.4 h in 2015 and 1.4 h in 2016) and reflects that end users are not affected by daily power outages in a month (see Table 11.3).

However, a comparison with World Bank data on power outages in the national grid in a typical month from 2013 reveals that the interconnected mini-grid system seems to distribute power in a more reliable manner. Tanzanian enterprises reported to be affected by only approximately 9 power outages per month with an average duration of 6.3 h each [19].[1]

The blue line shown in Fig. 11.1 indicates average daily distribution in kWh within the mini-grid system and reflects seasonal and/or extraordinary events and power outages: In dry seasons, from end of June until the end of December, the production from the Mwenga Project and its mini-grid distribution is substantially reduced. In this period, the share of electricity distributed to the village customers (via mini-grid) amounts to approximately 20%, whereas 80% is distributed to the

[1]But in this context, it is important to consider that World Bank's data is based on enterprises surveys and might not reflect power outages within the time frame between 7 p.m. and 6 a.m.

Table 11.2 Households average lighting hours per day

	No outages considered	Both outages combined 2015	Both outages combined 2016	Tanesco outage 2015	Mwenga outage 2015	Tanesco outage 2016	Mwenga outage 2016
Mini-grid connected households	32.95	31.9	32.5	32.42	32.44	32.7	32.77
Not yet grid-connected households	23.94 h***	NA	NA	NA	NA	NA	NA

***, **, * indicate 1%, 5% and 10% levels of level of significance respectively
Source Own elaboration based on [14, 18]

Table 11.3 Monthly mini-grid average outage frequency and duration from 7 p.m. to 6 a.m. in 2015 and 2016

	2015	2016
Average frequency	13	11
Average duration	2.4 h	1.4 h

Source Own elaboration based on [18]

main grid. This is mainly attributed to the irrigation practices of the anchor customers from tea production companies during that season.

In wet seasons, from end of December until the end of June, 90% of the electricity produced is distributed to the main grid and the remaining 10% is distributed to the local villages within the mini-grid [18]. Extraordinary events can also be studied in Fig. 11.1. The red, green and yellow lines indicate the daily mean power outage in hours. The green line shows outages from the Mwenga system. Between October and November 2015 comprehensive maintenance work on the system was undertaken which explains the outliers displayed here.

The flexibility in terms of distribution according to seasonal fluctuations illustrates the advantages of an interconnected system which is able to adapt its distribution to seasonal or extraordinary events. A counterbalancing effect can be identified when distribution is maintained in case of failure in one of the interconnected systems. Thereby, reliability of electricity access can be enhanced.

11.5 Conclusion and Recommendations

Interconnection of mini-grid system and main grid can be beneficial for households. This can be achieved through enhanced reliability of electricity by adapting the distribution to seasonal and/or extraordinary events and power outages, e.g. by switching to island mode in case of failure of the main grid. Lighting hours of households are significantly higher in mini-grid connected villages compared to not yet grid-connected areas. However, their lighting hour consumption is limited by frequent power outages which can be counterbalanced by the interconnection of the system. To further study impacts of power outages on the intermediary outcome of lighting, data on power outages from the main grid and households from main grid connected areas could be collected. The application of more profound statistical methods could allow for more robust results, e.g. a propensity score matching analysis could help to identify counterfactual and research groups. Furthermore, more socio-economic indicators could be included in the analysis as well as a study on the effects of power outages and interconnected systems on small and medium enterprises. The inclusion of lumen hours could additionally give a better reflection on the quality of lighting.

Annex

See Tables 11.4 and 11.5.

Table 11.4 Household survey on energy sources and usage

	Q1. Which of the following energy sources does this household use? Multiple entries are possible. READ ENERGY SOURCE. IF ENERGY SOURCE IS USED, ASK Q2-Q5 FOR THIS ENERGY SOURCE BEFORE ASKING Q1 FOR NEXT ENERGY SOURCE												Q2. For which of the following purposes do you use___? Multiple entries are possible. FILL ENERGY SOURCE TAPPED AS INDICATED IN Q1 THEN READ PURPOSE	Q3. Last week or month, roughly how much did this household spend on___? FILL ENERGY SOURCE TAPPED AS INDICATED IN Q1.	Q4. Last week or month, roughly how much did this household use of___? FILL ENERGY SOURCE TAPPED AS INDICATED IN Q1.	Q5. Roughly how many minutes per day or per week does this household spend acquiring ___? FILL ENERGY SOURCE TAPPED AS INDICATED IN Q1.
ENERGY SOURCE *HBW = Home based working	1	2	3	4	5	6	7	8	9	10	11	12				
	Lighting	Cooking	TV	Washing	Radio	Computer	Charging	Water Supply	Timber	Agro –processing	Other (HBW*)	Other				
Dry cell batteries																
Hand-crafted																
Car or other rechargeable battery																
Gas (LPG / LNG)																
Diesel (Non-vehicle-operation-use)																
Petrol (Non-vehicle-operation-use)																
Diesel (vehicle-operation-use)																
Petrol (vehicle-operation-use)																
Paraffin / Kerosene																
Candles																
Biogas																
Charcoal / briquettes																
Crop residue (bought)																
Crop residue (collected)																
Firewood (bought)																
Firewood (collected)																
PV-System (Solar)																
Electricity from mini-grid																
Other																

*Home based work

Source Own elaboration based on [14, 15, 20]

Table 11.5 Household survey on lighting devices and daily average usage

Q1. How many of the following lighting devices does this household use?		Q2. What is the mean number of hours you use this _____ per day? FILL ONLY WITH LIGHTING DEVICE USED AS INDICATED IN Q1
Lighting device	Quantity	Total hours used per day
Energy saver		
Incandescent bulb (<50 W)		
Incandescent bulb ($\geq$ 50 W)		
Fluorescent tube		
Solar lamp		
LED lamp (mobile)		
LED lamp (torches)		
Pressurized lantern		
Wick lamp (paraffin/kerosene)		
Gas lamp		
Candle (per week)		
Other (specify):		

Source Own elaboration based on [14, 15, 20]

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