International Journal of Sustainable Energy Planning and Management Vol. 21 2019 76–92

International Journal of
Sustainable Energy Planning and Management

Socio-economic impacts of rural electrification in Tanzania

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ABSTRACT

Recently, penetration rates of solar PV-systems increased drastically in rural Sub-Saharan Africa, and there will be less areas without electricity access altogether. Simultaneously, mini-grid systems are expected to be key in rural electrification because they allow for higher loads. Eventually, interconnection of national grids with mini-grid systems will gain importance. This case study compares impacts of electrification on households connected to an interconnected 4 MW mini-grid system with effects on households connected to off-grid energy systems in rural Tanzania. Relying on Propensity Score Matching, the analysis detects minor differences regarding usage of electrical equipment and expenditures for energy sources between the comparison groups. As has been expected, it concludes that grid-electrified households have significantly higher mean lumen and lighting hours. However, the case study shows that off-grid technologies, including solar PV-systems, are important sources to bridge and narrow the electricity gap and can already meet a critical level of rural electricity demand of households. Pre-grid-electrified statuses and their socio-economic impacts need to be reflected in research as they build the foundation for further electrification measures.

Keywords:

Socio-economic impacts;
Rural electrification;
Interconnected mini-grid system;
Propensity Score Matching

URL:
http://dx.doi.org/10.5278/ijsepm.2019.21.6

1. Introduction

In the last decade, many achievements have been made in increasing the number of individuals who have access to electricity. Notwithstanding, more than 1 billion of people worldwide still lack access to electricity connections. This is particularly true for rural areas of Sub-Saharan Africa (SSA), where demographic growth is outpacing access gains. At present, 587 million Sub-Saharan Africans do not have access to electricity [1] and this figure is expected to increase by 45 million until 2030 [2].

In Tanzania, which is the focus of the paper, some progress has been made recently, and the access to electricity rate jumped from less than 20% of the population in 2014 to 32.8% in 2016 [3]. At the same time, Tanzania is still one of the poorest countries in the world in terms of GDP per capita (constant 2010 US$) with approximately 867 USD in 2016 [3].

The nexus between electricity consumption and/or access to electricity and economic development has been studied extensively. Payne surveyed international evidence on the relationship between energy consumption and growth [4], whereas Ozturk studied the research done in the field of the energy-growth nexus [5]. Omri [6] analyzed the literature on this relationship by country-specific cases. Notwithstanding, to date there is no clear consensus regarding the causality of the relationship between them.

Studies on micro level also yield mixed results concerning the evidence of socio-economic impacts of (rural) electrification. However, there is no doubt that rural electrification is a critical factor for socio-economic development as identified by Peters et al. [7] and Grimm et al. [8] for SSA countries, and the IEG [9] and Kanagawa et al. [10] for developing countries in

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general. In research on evidence of impacts of (rural) electrification, researchers frequently refer to the theory of change to analyze causal effects of electricity consumption on selected indicators for a defined population (e.g. [11, p. 14] and graphically well illustrated by Peters et al. [7, p. 329]). The framework of the theory of change displays the channels - from inputs to activities to outputs, (intermediate) outcomes, and longer-term goals- through which an input factor or intervention becomes theoretically effective [12, p. 20 f.]. Commonly, researchers study the following final impact indicators of household´s electricity use: Income, education and health. Thereby, they intend to capture the socio-economic situation of households which might have changed through their access to electricity.

In the SSA context, evidence on socio-economic effects of (rural) electrification is inconclusive and patchy in terms of space and time. The majority of studies compares households from either grid-electrified with not (yet) grid-electrified villages, or households from off-grid electrified villages with those from not (yet) electrified areas. However, even in least electrified areas such as in SSA, there will be less and less areas that are still completely without electricity access, as the penetration through off-grid solar based energy systems has accelerated in recent years [13].

As a means to quantify the quality of energy access, the Multi-Tier-Framework from the Energy Sector Management Assistance Program (ESMAP) from the World Bank no longer defines electrification as binary (e.g. whether a household has access to electricity or not) but multi-dimensional [14]. By considering the user´s perspective, the spectrum of service levels and neutrality of technology delivering the service, they strive to capture better the multiple modes of energy access [IBID].

The International Energy Agency (IEA) estimates that a major share of the universal access to electricity by 2030 is expected to be achieved by off-grid technologies such as (isolated) mini-grid systems [15]. Some of these technologies might play a key role to pre-grid-electrify communities, households and enterprises before the national grid arrives and could be interconnected to it at a later point of time. Compared to conventional grid technologies, off-grid systems that are based on renewable energy sources might allow for access to electricity in a more environmentally friendly manner. In light of inadequate grid supply, off-grid systems, such as PV systems, could even meet suburban housing electricity demand in a techno-economically manner (as shown by [16] for the case of Nigeria). Yet, to the disadvantage of sustainable electrification and development, grid-electrification is still most preferred mode of electrification in many SSA countries [17].

The interconnection of mini-grid systems to the national grid may provide a necessary step towards full-scale electrification, until economic and topographical challenges are met while the revenue base increases. On the other hand, interconnection of systems might help to avoid sunk investment costs in mini-grid systems, e.g. when the national grid arrives. Nevertheless, off-grid technologies interconnected with a main grid are rarely studied yet. Additionally, a recently published report on mini-grid system deployment in Tanzania calls for more formal research on analyzing the impacts of mini-grids in Tanzania, as most information on the effects is still “anecdotal” [18] (p.11). As a basis for further proceeding with rural electrification, the quantitative benefits of such need to be understood better.

This paper strives to fill these gaps identified by detecting socio-economic effects of access to an interconnected mini-grid system. Based on a case study in rural Tanzania, it compares off-grid with grid-connected statuses of households. To establish household comparison groups, this study relies on a non-experimental research method, Propensity Score Matching (PSM). PSM allows to address the challenge of identifying an appropriate counterfactual group.

The major share of electricity in rural households in SSA is still used for lighting or illumination purposes as observed by Bernard [11], IEG [9], Lenz et al. [19] and Bensch et al. [20]. Illumination belongs to the most direct impacts of electrification and assumes an intermediary role in promoting effects on final impact indicators. Therefore, this case study puts a special focus on the intermediary outcome of electricity: Lighting and lumen hours (lmhr). To reflect on education, the analysis studies the treatment effects of electricity on children’s home based study time after nightfall. Additionally, the paper investigates the effects of electricity on households’ weekly energy expenditures and consumption of energy sources and daily usage time of the most frequently owned electric appliances in terms of TV, radio and mobile phone. These indicators are assumed to affect household´s health, income and also education.

1.1. Background and project

Tanzania´s installed power generation capacity is only about 1,500 MW [21]. This low figure is reflected in official indicators on electricity access. Annual electric power consumption per capita amounts to approximately 99 kWh and access to electricity is limited to only 32.8% of the population. In urban areas, approximately 65.3% of the population has access to electricity, whereas in rural parts- where three quarters of the Tanzanian population lives-only 16.9% of the population is connected to electricity [3]. The growing importance of off-grid technologies for rural areas is reflected there. For example, approximately 65% of rural electrified households rely on solar power [22].

In line with these developments, the Investment Prospectus for Rural Electrification estimates that about half of the Tanzanian rural population could be cost-effectively best served by off-grid and/or mini-grid solutions [23]. This corresponds with recommendations from the International Renewable Energy Agency (IRENA) [24], which estimates that more than 60% of rural areas globally should be best served by renewable powered off-grid electrification to achieve universal access by 2030.

With the Electricity Act of 2008, the government introduced comprehensive energy sector reforms including a framework for Small Power Producers (SPPA). The authorities plan to expand generation capacity up to 10,000 MW by 2025 [25]. The 4 MW Mwenga run-of-river Hydro Power project which is the focus of the present study, is one of the first projects under the SPPA scheme, and is a mini-grid system interconnected to the nation’s main grid. The majority of its power generated is sold to the central grid (to the state utility TANESCO), but it also sells power to the local tea industry and the rural community [26]. In 2018, approximately 80% of electricity consumed by the rural community is still on subsistence plateau with less than 50 kWh per month [27].

The project´s location is in Mufindi, one of the three districts of the Iringa Region in the Southern Highlands of Tanzania. The intensively forested and farmed region is the second richest region of Tanzania in terms of GDP per capita (approximately $ 880 USD in 2012 [28]). The Mufindi region lies on an altitude between 1700 m and 2000 m above sea level and is characterized by its hilly topography, long rainfall and short dry seasons.

In Figure 1, the current Mwenga power network system is displayed. Grid-connected areas, mostly located in the south, received access to grid-electricity in 2012. By the end of 2015, when research data was collected, the villages in the north were still not connected to the mini-grid system. The mini-grid extension to the northern villages became operational in 2017.

Figure 1: Map showing sampled grid-electrified and non- grid electrified villages in 2015 Source: Author based on [29]

2. Methodology

This section provides the survey design and implementation as well as the description of Propensity Score Matching (PSM).

2.1. Survey design and implementation

Household surveys with more than 70 detailed questions on socio-economic background and energy use were conducted by the end of 2015. The selection of the four grid connected and two not yet grid-connected villages (see Figure 1, above) was not done randomly. It was intended to select villages that are comparable in terms of their background conditions: Accessibility, existence of complementary infrastructures 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).

Qualitative information on that level has been obtained by consulting local informants like village leaders or project representatives. Additionally, secondary sources such as official reports, other studies and census data supported the selection of the sample villages [30, 31]. Household selection was based on random selection due to the difficulty of detached household locations. In total, 120 households were interviewed in mini-grid-connected and not yet grid-electrified areas. This represents approximately 10% of total households in those villages. Approximately 44% of the households were located in grid-electrified areas, whereas 56% of them were based in off-grid areas. Data collection was based on standardized questionnaires (Author based on [30] and [32]] and the interviewers were trained before taking the surveys. A pre-test of the questionnaires aimed to detect misunderstandings, uncertainties, or other difficulties interviewers and interviewees may encounter.

Daily mean lighting and lumen hours are based on the information provided by the household, on how many lighting hours per day the respective lighting devices are used. The calculation on daily lumen hours is based on assumptions of luminous flux.

Table 1 below indicates lower and higher levels of luminous flux of the most common lighting devices used by households in grid- and non- grid-electrified areas: CFL Energy Saver (30 W), Energy Saver (SHS), Kerosene/Paraffin Wick Lamp, Incandescent Bulbs (40 W), Fluorescent Tube (30 W) and Solar Lamp.

Table 1: Assumptions on luminous flux of lighting tools

	Lower luminous flux [lm]	Higher luminous flux [lm]
CFL Energy Saver (30 W) [34]	1500	2100
Energy Saver (SHS) [33]	210	420
Kerosene Wick Lamp [35]	8	82
Incandescent Bulb (40 W) [36]	400	680
Fluorescent Tube (30 W) [36]	750	3540
Solar Lamp (stored in rechargeable batteries) [35]	25	200

Due to data constraints, mobile, non-solar powered torches and candles are excluded from the analysis on lighting. Firewood is rarely used for lighting and is therefore also excluded. Information on lighting tools has been cross-checked by knowledgeable project partners [33].

It should be noted that firewood, kerosene and paraffin, charcoal, LPG/LNG, Diesel and dry-cell batteries are important energy sources of rural households in SSA. These energy sources could be replaced by access to (grid-) electricity, which is why household´s monthly expenditures and usage of these energy sources will be studied more in detail below.

2.2. Propensity score matching (PSM)

This study examines socio-economic impacts of grid-electrification. These include lighting and lumen hours, children´s study time after nightfall, energy expenditures and usage time of the most frequent appliances used by households in rural Sub-Saharan African areas in terms of TV, mobile phone and radio.

For the purpose of effect analysis, two comparison groups, one of those households being exposed to the invention (here: grid-electrified households) and one of those households not being exposed to it (off-grid households), need to be established. However, the isolation of the genuine effects of grid-electrification might be biased by unobserved influencing parameters researchers cannot control for. Theoretically, the most suitable research design to address bias is randomly chosen research units. However, practical research cannot always achieve this. To tackle biases and influencing factors, this study relies on PSM based on [37]. It is a quasi-experimental method frequently applied in research when the intervention to be studied is not assigned randomly to units as it often happens in rural electrification [38].

To ensure a high matching quality, Genetic matching is applied to establish comparison groups. The calculated mean difference between the outcomes of these two matched groups is then interpreted as the (population) average intervention or treatment effect [37].

However, as the study deals with non-random targeting of electrification, it is restricted to a subsample of the population. Therefore, the analysis considers "alternate treatment effects", the treatment-on-the-treated- effects (TOT) or average treatment effects on the treated (ATT):

$$E(Y_{i1}) \text{ I } z_i = 1 - E(Y_{i0}) \text{ I } z_i = 1; \qquad (1)$$

treatment effect for treated unit i = outcomei (observed) - outcome$_i$ (unobserved) or treatment effect for non-treated unit i = outcomei (unobserved) - outcomei (observed), where only the expected observed and potential outcomes Y of the units being treated $z_i = 1$ are considered [37].

The types of treatment effects could differ significantly due to the aforementioned presence of hidden and non-observed biases. This is also why the subsequent sensitivity analysis is of crucial importance to undermine the detected effects [39] based on [40] and [41]. The sensitivity analysis is based on the Wilcoxon-signed ranks test as suggested by [42]. The whole analysis is conducted in R [43] and follows the structure as suggested by Leite et al. [39].

3. Empirical results

This section provides descriptive statistics and the steps involved in PSM. Descriptive statistics allow the reader to get an understanding of important socio-economic characteristics and conditions of households in the study area. This part further contrasts household´s ownership and usage of electric appliances as well as expenditures on and usage of energy sources. Moreover, it also contains information regarding illumination before matching analysis is undertaken. PSM includes the identification of covariates for model specification encompassing checks on model quality, the estimation of the effects of electrification and a subsequent sensitivity analysis.

3.1. Descriptive statistics

Data analysis from the survey before the matching procedure indicates that households from both areas have similar living conditions in terms of a large part of their characteristics and irrespective of their grid-connection status. In Table 2 below, the characteristics of households are presented with respect to their grid-connection status. In addition, Table 2 displays the corresponding test statistic (t-statistic or chi-square ($\chi 2$)).

It can be noted that the means and shares of households do not differ statistically significantly in terms of household size, number of household members contributing to the household income household´s head education, age and gender.

Additionally, households from off-grid areas have comparable access to formal financial services, ownerships of buildings and farm land. Yet, there are statistically significant differences in terms of use of formal financial services, primary source of drinking water, toilet type facility and number of rooms, as well as floor type in a household´s main building. The differing primary sources of drinking water reflect the fact that public water pumps were available in not yet grid-connected villages.

As presented in Table 2, it can be noted that almost half of the households (47%) in the not yet grid-connected villages use Solar Home Systems and there is an evident difference in usage of Solar Home System between households from the grid-electrified (8%) and not yet grid-electrified villages. Thus, almost half of the not yet grid-connected households are already electrified in terms of access to solar based technologies. In 2009, only 4% of the not yet connected households reported to own Solar Home Systems [31]. This finding underlines the significantly increased importance of solar powered technologies and the pre-grid electrification status of off-grid households in this region.

Conversely, some households in the grid-connected areas reported to have had access to solar power before the grid arrived, and still use it. Individual generators are rarely used in both areas and some few households also use batteries to power their homes. However, results suggest that some households combine multiple electricity resources, instead of only relying on one electricity resource. On the other hand, firewood is the main energy source for cooking for households (93% in grid-electrified household compared to 99% in not yet grid-electrified households).

As Table 3 below shows, households differ significantly in their weekly mean expenditure on electricity, kerosene and paraffin, dry-cell batteries and candles.

Table 2: Descriptive statistics on surveyed households from grid- connected and not yet grid connected areas

	Grid-electrified households (sample size = 40)	Not yet grid-electrified households (sample size = 66)	Test statistic
Average household size	4.5	4.5	t = 0.13
Share of male household heads [%]	80	82	$X^2 = 6.71$
Average household head´s education [in yr]	7	7	t = 0.26
Average age of household head [in yr]	43	41	t = 0.77
Average no. of household members contributing to household income	2	2	t = 1.1
Household has access to formal financial services [%]	77.5	87.9	$X^2 = 1.29$
Household uses formal financial services [%]	72.5	87.9	$X^2 = 3.03$*
Share of households owning farm land [%]	97.5	100	$X^2 = 0.06$
No. of buildings a household owns	2	2	t = 0.12
No. of rooms in household´s main building	7	6	t = 1.96*
Wall material of main building (baked bricks) [%]	77.5	74.2	$X^2 = 0.02$
Floor material of main building (cement) [%]	55	74.2	$X^2 = 3.35$*
Roof top material of main building (iron) [%]	100	98.5	$X^2 = 0.0$
Household´s toilet facility (without drainage) [%]	85	100	$X^2 = 7.87$***
Household´s source of drinking water (unprotected spring) [%]	92.5	50	$X^2 = 18.21$***
Firewood is the main energy source for cooking [%]	93	99	$X^2 = 2.4567$
Usage of Solar Home System [%]	8	47	$X^2 = 17.80$***
Usage of car battery for electric purposes [%]	8	2	$X^2 = 0.296$
Usage of individual generator [%]	0	0	NA

***, **, * indicate 1%, 5% and 10% level of significance

Table 3: Weekly energy related expenditures (in Tanzanian shilling) per household in grid and not yet grid-connected villages

	Grid-electrified households	Not yet grid-electrified households	Test statistic
Electricity	1040	0	t = 10.71***
Kerosene, Paraffin	70	625	t = –3.17***
Diesel	0	0	NA
LPG/LNG	0	0	NA
Charcoal	275	38	t = 1.10
Candles	308	85	t = 1.79*
Dry-cell batteries	139	1274	t = –4.72***
Firewood	437	38	t = 1.57

***, **, * indicate 1%, 5% and 10% level of significance

In the not yet grid-electrified villages, households do not incur any electricity costs. It is evident that their average expenditures for kerosene, paraffin and batteries are significantly higher.

Conversely, households in grid-electrified villages have higher weekly average costs for candles. Differences were also identified in firewood and charcoal expenditures. However, these differences are statistically not significant. It should be noted that most households collect firewood which is free of charge. Among the negligible expenditure items of households are LPG/LNG and diesel.

However, it should be noted that prices of the different energy sources might differ, which might affect the level of expenditure. For this reason, the study took into account the quantities of different energy sources that a household consumes on a weekly basis. The analysis is limited to those energy expenditures (apart from elasticity and firewood) that were significantly different before (see in Table 3 before). As shown in Table 4 below, the households differ significantly in terms of weekly average usage of kerosene and paraffin and dry-cell batteries. No significant differences can be identified in terms of weekly average usage of candles.

Table 5 below displays ownership and daily usage of electric appliances in the analyzed households. Households from both areas are similar regarding radio and mobile phone usage and ownership. These are the most possessed and used technologies.

It should be noted that mobile phone usage may reflect charging with electricity, whereby the operation of radios could also be based on dry-cell batteries. In

Table 4: Weekly consumed amount of energy sources per household in grid and not yet grid-connected villages

	Grid-electrified households	Not yet grid-electrified households	Test statistic
Kerosene, Paraffin [in ltr]	0.04	0.2	t = –2.57**
Candles	0.7	0.2	t = 1.59
Dry-cell batteries	0.2	1.9	t = –5.16***

***, **, * indicate 1%, 5% and 10% level of significance

Table 5: Ownership (share in%) and daily mean usage of electric appliances (in minutes) of grid and not yet grid-connected households

	Grid-electrified households	Not yet grid-electrified households	Test statistic
Radio	90	86	X^2 = 0.3
Radio usage	210	242	t = -0.934
Mobile phone	95	80	X^2= 4.42*
Mobile phone usage	128.6	35.4	t = 1.244
TV	50	15	X^2 = 13.23***
TV usage	85	26.1	t = 3.025***
Computer	13	1.5	X^2 = 5.628**
Computer usage	22.5	1	t = 1.871**
Water heater	5	0	X^2 = 3.364
Mill	5	0	X^2 = 3.364
Iron	18	9	X^2 = 1.636
Refrigerator	3	0	X^2 = 1.665
Internet facility	5	0	X^2 = 3.364
Power tiller	0	1.5	X^2 = 0.612
Washing machine	0	0	NA
Sewing machine	0	0	NA
Water pump	0	0	NA
Fan	0	0	NA

***, **, * indicate 1%, 5% and 10% level of significance

Table 6: Average consumption of lighting and lumen hours (lmhr) in grid and not yet grid-connected households

	Grid-electrified households	Not yet grid-electrified households	Test statistic
Average total lmhr consumed, lower level assumed	44924	4096	t = 8.72***
Average total lmhr consumed, higher level assumed	65288	8785	t = 8.2***
Average lighting hours per day	32.95	23.94	t = 2.01**

***, **, * indicate 1%, 5% and 10% level of significance

Table 7: Daily average study time of children at home after nightfall in grid and not yet grid-connected households

	Grid-electrified households	Not yet grid-electrified households	Test statistic
Home-based study time of children (after nightfall) [in min]	46.5	57.9	t = –1.01

***, **, * indicate 1%, 5% and 10% level of significance

terms of TV and computer ownership, it can be noted that households differ significantly. In addition, there is a statistically significantly higher usage of TVs or computers in grid-electrified households.

However, computers are generally less widespread than TVs. Moreover, only a minor share of grid-connected households owns an internet facility. This is also why the study does not consider the usage of computers in the PSM below.

In addition, very few households own an iron, a mill, a power tiller, a water heater, or a refrigerator, which is why their usage- despite their productive potential- is not studied more in detail in the following. No household possesses a washing or a sewing machine, a water pump or a fan. Overall, it should be noted that most of the differences observed are not statistically significant. This underlines the similarities of households regarding electric appliance ownership.

As previously described, the study distinguishes between lower and higher levels of lumen of the most frequent lighting tools applied. It is not possible to reflect the real lumen power of all the lighting tools available in a household because different levels of lumen might be combined within a household. However, the lower lumen ranges, as specified in section 2.1 in Table 1 above, describe the lowest lumen power possible, whereas the highest lumen levels represent the highest possible lumen regarding the different lighting tools used in a household. Lighting hours refer to the sum of usage time per day across all lamps in a household.

The mean values in daily lighting and lumen hours (lower and higher levels assumed) differ between the households from the mini-grid-electrified and off-grid-electrified villages (see Table 6 above). It is evident that households the grid-electrified area have significantly higher daily mean lighting (32.95 hours per day compared to 23.94 hours per day) and lumen hours (44924 lmhr or 65288 lmhr compared to 4096 or 8785 lmhr, respectively). In terms of daily lighting hours, the discrepancies are not too high. However, in terms of lumen hours, the differences are substantial. Although households from not yet grid-connected villages also have access to (electric) light sources their lighting quality is significantly lower.

Based on the significant results regarding illumination, in the following, the study examines whether the extended and improved illumination has an effect on the daily home-based study time of children after nightfall, which could impact their education. As can be noted in see Table 7 above, on average, children of not yet grid-villages study more after nightfall than children from grid-electrified villages (57.9 minutes compared to 46.5 minutes, respectively). However, the differences are minor and statistically not significant.

3.2. Identification of covariates for PSM

The selection of covariates for the final model to estimate the propensity scores draws on former research and previous statistical checks [19,20,44]. As shown in Table 8 below, covariates include gender and educational level of the household head. Further, the study considers the number of household members and members contributing to income as well as the main source of household drinking water. Related to a household´s main building characteristics, the analysis respects floor type.

The visual diagnostic on propensity score estimation quality (in Figure 2 below) confirms that there is enough support to estimate mean treatment effects of grid-electrification by the specified model.

Furthermore, as presented in Table 9 below, there is sufficient performance in covariate balance. Genetic matching procedure yields high degrees of covariate balance across all outcome variables. The lowest maximum absolute standardized mean differences (MASMD) is in all cases is less than 0.1. Thus, the propensity score estimation method performs adequately,

Table 8: Model for propensity score estimation

Covariate selection	Coefficient
Gender of household head	0.39631
Educational background of household head [in yr]	0.11582
Household size	–0.12781
No. of household members contributing to income	0.52198
Main source of drinking water	2.61968***
Main building´s floor type	–0.99278 **

***, **, * indicate 1%, 5% and 10% level of significance

Table 9: Covariate balance of Genetic matching

	MASMD	Covariates with MASMD above 0.25
Daily lighting hours	0.08	0 (0%)
Daily lower lmhr	0.06	0 (0%)
Daily higher lmhr	0.08	0 (0%)
Daily children´s home-based study time (after nightfall)	0.08	0 (0%)
Daily TV usage	0.07	0 (0%)
Daily radio usage	0.08	0 (0%)
Daily mobile phone usage	0.06	0 (0%)
Weekly expenditures for paraffin /kerosene	0.08	0 (0%)
Weekly consumed amount of dry-cell batteries	0.08	0 (0%)
Weekly expenditures for dry-cell batteries	0.08	0 (0%)
Weekly consumed amount of dry-cell batteries	0.08	0 (0%)
Weekly expenditures for candles	0.06	0 (0%)
Weekly consumed amount of candles	0.08	0 (0%)
Weekly expenditures for charcoal	0.08	0 (0%)
Weekly expenditures for firewood	0.08	0 (0%)

***, **, * indicate 1%, 5% and 10% level of significance

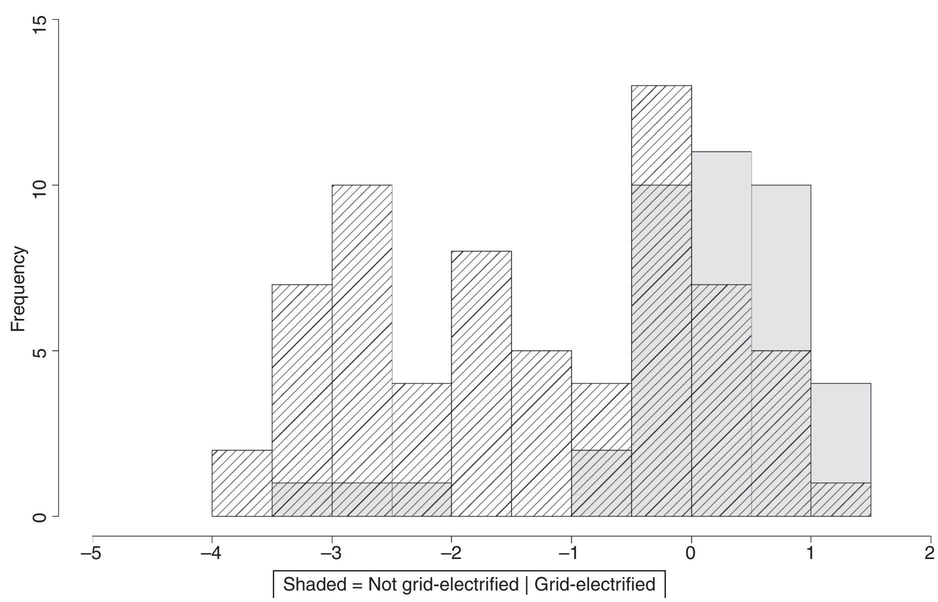

Figure 2: Distribution of linear propensity scores

Source: Author

which is why the model can be applied to estimate treatment effects.

3.3. Estimation of treatment effects and sensitivity analysis

As displayed in Table 10 below, it is evident that access to grid-electricity has a significant impact on average total lighting and lumen hours of households. Grid-connected households have significantly higher lighting hours (ATT = 18.38) and lmhr per day on average than households from off-grid areas (ATT = 42044 and ATT = 59583, respectively).

However, extended lighting hours through grid-electricity do not have an impact on daily home-based study time of children after nightfall. The ATT of -11.9 is not significant. On the contrary, in terms of watching TV, the households differ significantly. After matching, the estimated average treatment effect is 59.1 at conventional significant level. This implies that grid-electrified households watch almost one hour more TV per day than not yet grid-electrified households. The estimated treatment effects of grid-electricity on daily radio and mobile phone usage (ATT = 13.2 and ATT = 91.8, respectively) are not significant.

Regarding the weekly expenditures for and amount of energy sources consumed, the output suggests that access to grid-electricity has a significant impact on the spending on and usage of dry-cell batteries. Grid-electrified households consume and spend significantly less money on dry-cell batteries in a week (ATT = –1.06 and ATT = –608.9, respectively) than not yet grid electrified households.

No impact of grid-electricity on expenses for charcoal or firewood can be detected. Moreover, treatments analysis suggests that grid-electrification has no impact on households' weekly consumption and expenditures

Table 10. Average treatment effects (ATT)

	ATT	t-statistic	AI S.E. †	Critical Gamma Γ Lower bound †† (hidden bias)	Critical Gamma Γ Upper bound †† (hidden bias)
Daily lighting hours	18.38	3.22***	5.72	> 3	> 2.0
Daily lower lmhr	42044	6.95***	6045.4	> 3	> 3
Daily higher lmhr	59583	6.55***	9090.3	> 3	> 3
Daily children´s home-based study time (after nightfall) [in min]	–11.9	–0.79	15.14	1	< 1.4
Daily TV usage [in min]	59.1	1.91**	30.91	> 3	> 1.8
Daily radio usage [in min]	13.2	0.28	47.62	< 1.2	< 1.1
Daily mobile phone usage [in min]	91.8	0.92	99.84	> 1.3	> 3
Weekly expenditures for paraffin/kerosene [in Tshs]	–171.6	–1.378	124.4	1	< 1.1
Weekly consumed amount of paraffin/kerosene [in ltr]	–0.11	–1.49	0.07	1	< 1.8
Weekly expenditures for dry-cell batteries [in Tshs]	–608.9	–1.82*	334.21	> 3	> 3
Weekly consumed amount of dry-cell batteries [in Tshs]	–1.06	–1.9*	0.56	> 3	> 3
Weekly expenditures for candles [in Tshs]	54.19	0.21	260.26	1	< 2
Weekly consumed amount of candles [in Tshs]	0.10	0.16	0.64	1	< 2
Weekly expenditures for charcoal [in Tshs]	240	0.83	288.57	> 3	> 3
Weekly expenditures for firewood [in Tshs]	309.3	0.95	324.19	> 1	> 3

***, **, * indicate 1%, 5% and 10% levels of significance
† Standard error based on AI estimator
†† Wilcoxon Signed Rank p-values based on [42]

for paraffin/kerosene and candles. Sensitivity analysis indicates that most of the results are robust and not sensitive to hidden bias by the influence of unobserved confounders at comparatively high Gamma (Γ) values at conventional significant levels. However, findings related to daily radio and mobile phone usage as well as on households' weekly consumption and expenditures for paraffin and kerosene and candles need to be interpreted with caution because inference might change at low values of Γ due to their vulnerability to the presence of hidden bias.

4. Conclusion and discussion

This case study analyses the impacts of grid-electrification compared to pre-grid-electrification on households in Mufindi, in rural Southern Tanzania. In 2015, the year of data collection, the grid-connected households had access to grid electricity for three years. By relying on the Propensity Score Matching (PSM) procedure, the undertaken analysis indicates that socio-economic impacts of grid-electrification on households are limited. Overall, three years after grid-electrification, acquisition and usage of electric appliances in households remained relatively low. In most of the cases, grid-connected and off-grid but potentially pre-grid-electrified households do not differ much in terms of ownership of electric appliances. The most significant effects of grid-electrification can be identified in relation to lighting and quality of lighting. Average lighting and lumen hours per day are significantly higher in the interconnected mini-grid- connected areas than in off-grid but pre-grid electrified areas. This means that access to grid-electricity compared to access to off-grid electricity is at the front in terms of enhancing the quality of life of households. The positive impact of grid-electricity on lighting usage, and thereby on households´ quality of life, has also been confirmed by other researchers dealing with the Sub-Saharan African context: Bensch et al. [20] for the case of Rwanda, Bensch et al. [44] and Chaplin et al. [45] for the case of Tanzania.

Results show that radios and mobile phones belong to the most possessed appliances. Matching results suggest that households in grid- and not yet grid-electrified villages do not differ much in terms of their daily usage. Only in terms of TV, matching analysis establishes a significantly higher usage in grid-electrified households. This means that these households have potentially higher access to information and knowledge, which could influence their education or income. However, the effects of TV usage on education or income depend on the content of the TV program but also on the extent to which TV watching comes at the expense of (other) educational or income generating activities. It has also been detected that extended and improved lighting does not lead to a significantly higher study time at home of children in households with grid-electricity. Home based evening study time of children amounts to less than one hour per day in both areas. On the other hand, it should be noted, that children could also study at schools at night, which is not considered in the present analysis. The finding on children´s home based study time contrasts with findings from Bensch et al. for the rural Senegal [46] and for the Rwandan context [20]. They were able to identify significantly higher study times or times spent on educational activities in electrified households.

The relatively low uptake and usage of electric appliances after grid-electrification may reflect household's persistently low power consumption. This is in line with findings from [19] and shows that it indeed may take some time until comprehensive socio-economic effects of rural electrification can be detected. It also may confirm that the enhancement of socio-economic conditions has to be addressed by a comprehensive approach, e.g. by including complementary infrastructures.

For example, no water supply systems were in place in 2015. Therefore, investments of households in sanitary installations or washing machines were not likely. In addition, it has been detected that households still mainly rely on cooking with firewood. Cooking with traditional biomass cookstoves is still and expected to remain a widespread phenomenon in Sub-Saharan Africa [47]. Consequently, significant improvements to health conditions of household members by reducing indoor air pollution may remain limited. It also may imply that the contribution of electrification to environmental protection in terms of reducing land degradation, deforestation, and air pollution is restricted. On the other hand, the development and introduction of new technologies, such as PV-eCook systems, might become competitive and revolutionize cooking within the next years in Sub-Saharan Africa [48] and thereby contribute to health and environmental protection.

Commonly, the lack of electric appliances is associated with availability, affordability, reliability, sustainability and social acceptability of these technologies.

Notwithstanding, it has to be noted that there were some few households possessing electric devices (e.g. computer or mills) that might spur productive activities in the long run. However, while interviewing the households, lack of knowledge with regard to the use of electricity and electric appliances was also noted. To address these constraints, awareness campaigns informing the Mufindi population about electricity usage (e.g. concerning the usage of electric kettles and mills) started in 2016 [33], approximately a year after data collection for this study. Impacts of these initiatives on the acquisition and usage of new electric appliances should be addressed in a future study.

With regard to expenditures on energy sources, matching analysis suggests that only the discrepancy in terms of spending on dry-cell batteries can be attributed grid-electrification. It could indicate that significantly more off-grid households are running radios and lighting tools on dry-cell batteries. The diffusion of dry-cell batteries in rural Sub-Saharan African off-grid areas was also noted by Peters et al. [7] and Bensch et al. [35]. The lower usage of dry-cell batteries in grid-electrified households may suggest that these households are less likely to be exposed to health risks and that their environment is less burdened by inappropriate disposal of batteries. To address these risks in high usage areas, Bensch et al. [35] propose to implement monitoring and waste management systems and call for immediate action to address the inappropriate disposal of dry-cell batteries. This may be also recommendable for the Mufindi region, in particular for off-grid areas.

The non-significant difference in terms of weekly consumption of and expenses for paraffin and kerosene after matching may suggest that these sources are less frequently used for lighting purposes, also in off-grid areas, which might be attributable to the spread of solar based technologies but also to the usage of lighting tools that run with dry-cell batteries. For example, Grimm et al. [8] and Bensch et al. [44] found out that LED technologies are increasingly used by households in rural Tanzania. In many cases these technologies replaced fuel-run lamps and are nowadays affordable even for poor households [44]. Thus, improved efficiency and quality in lighting expressed in lumen hours may not be necessarily related to higher expenditures.

To sum up, results indicate that an important share of rural power consumption may already be met by small-scale and off-grid energy technologies. Nowadays, it is more evident than ever: Penetration rates of solar based technologies, such as solar lanterns and solar home systems, in Sub-Saharan African rural areas accelerated in recent years [13]. This has also been observed in Mufindi. Solar based energy systems can be appropriate means for sustainable rural electrification and development. At least, they can help to pre-grid-electrify households at low costs and meet social and environmental concerns. In this way households can prepare for the arrival of the grid and do not start from the scratch in terms of access to electricity.

However, gaining access to grid-electricity does not automatically imply that households abandon off-grid technologies. On the contrary, results indicate that households rely on multiple electricity sources. This can be beneficial, e.g. to counterbalance the effects of power outages, which was confirmed in another study on this project [49]. The reliance of households on multiple electricity sources after grid-electrification is in line with observations by Enslev et al. [50] (p.135 f.) for the rural Kenyan context: Grid electricity "reorganises and changes the composition of the various energy sources already in use". This reflects the fact that grid-electricity does not encounter a "vacuum" but rather an infrastructure in which certain needs- albeit limited- can already be met.

Evidence from the present study suggests that planners should consider the pre-grid-electrification status of off-grid communities and households to tailor electricity requirements accordingly. It has been observed that rural households` energy consumption follows a complex and dynamic pattern that depends on many factors and does not seem to develop linearly to policy interventions such as grid expansion. On the contrary, nowadays, many households might get access to technologies and electricity without the intervention of any deliberate policy [7].

Therefore, it is of utmost importance that planners take into account available, affordable and rapidly changing technologies driving the energy transition. These include (decentralized) energy systems but also appliances, such as the aforementioned PV eCook systems or LED technologies.

The interconnection of off-grid and grid energy systems can be of crucial importance because it allows to address households' electricity requirements in a more flexible manner. Moreover, planners should keep in mind the possible supportive function of off-grid systems for future interconnections to main grids. The ability to meet future higher loads (more flexible) is certainly one of the main motivations of policy and decision makers to still use grid electrification as the main means of electrification. Nevertheless, there is also a trend towards off-grid electrification in Tanzania. For example, the introduction of the aforementioned SPPA framework contributed to the realization of numerous off-grid projects since 2008 [18].

Based on this study´s findings, there should be more research on the dynamics of rural energy consumption trends and on how to address barriers of higher-level electric appliances adoption, such as recently done by [51]. Moreover, upcoming research should also study the causal effects of blackouts and outages of interconnected systems by also including more (intermediary and final) outcome indicators and research units such as enterprises and/or (public) institutions.

References

[1] The World Bank, Sustainable Energy for All 2017- Progress toward Sustainable Energy, The World Bank, Washington DC, USA, 2017. Available: https://www.seforall.org/sites/default/files/eegp17-01_gtf_full_report_final_for_web_posting_0402.pdf

[2] Watkins K, Kende-Robb C, Lights, Power, Action: Electrifying Africa. An in-depth follow up to the 2015 Africa Progress Report, Power, People, Planet: Seizing Africa's Energy and Climate Opportunities, Africa Progress Panel, 2017. Available: http://www.africaprogresspanel.org/policy-papers/lights-power-action-electrifying-africa/

[3] The World Bank. World DataBank: World Development Indicators. Available: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators&preview=on [Accessed on 14.01.2019]

[4] Payne JE, Survey of the international evidence on the causal relationship between energy consumption and growth, Journal of Economic Studies 37(1) (2010) pages 53–95. https://doi.org/10.1108/01443581011012261

[5] Ozturk I, A literature survey on energy–growth nexus, Energy Policy 38(1) (2010) pages 340–9. https://doi.org/10.1016/j.enpol.2009.09.024

[6] Omri A, An international literature survey on energy-economic growth nexus: Evidence from country-specific studies, Renewable and Sustainable Energy Reviews 38 (2014) pages 951–9. https://doi.org/10.1016/j.rser.2014.07.084

[7] Peters J, Sievert M, Impacts of rural electrification revisited – the African context, Journal of Development Effectiveness 8(3) (2016) pages 327–345. https://doi.org/10.1080/19439342.2016.1178320

[8] Grimm M, Munyehirwe A, Peters J, Sievert M, A First Step up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda, The World Bank Economic Review 31(3) (2016) pages 631–649. https://doi.org/10.1093/wber/lhw052

[9] Independent Evaluation Group (IEG), The Welfare Impact of Rural Electrification, The World Bank, Washington DC, USA, 2008. https://doi.org/10.1596/978-0-8213-7367-5

[10] Kanagawa M, Nakata T, Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries, Energy Policy 36(6) (2008) pages 2016–2029. https://doi.org/10.1016/j.enpol.2008.01.041

[11] Bernard T, Impact Analysis of Rural Electrification Projects in Sub-Saharan Africa, The World Bank Research Observer 27(1) (2012) pages 33–51. https://doi.org/10.1093/wbro/lkq008

[12] White H, Raitzer DA, Impact evaluation of development interventions. A practical guide, (2017), Metro Manila, Philippines, Asian Development Bank. Available: http://dx.doi.org/10.22617/TCS179188-2 [Accessed on 17 May 2019]

[13] Lighting Global, International Finance Corporation, The World Bank. Off-Grid Solar Market Trends Report 2018, Washington DC, USA, 2018. Available: https://www.lightingafrica.org/wp-content/uploads/2018/02/2018_Off_Grid_Solar_Market_Trends_Report_Full.pdf [Accessed on 27 January 2019]

[14] Bhatia M, Angelou N, Beyond Connections: Energy Access Redefined, ESMAP Technical Report (2015), 008/15, The World Bank, Washington, DC. Available: https://openknowledge.worldbank.org/handle/10986/24368 [Accessed on 17 May 2019]

[15] International Energy Agency, Energy Access Outlook 2017: From Poverty to Prosperity, International Energy Agency, Paris, 2017. https://doi.org/10.1787/9789264285569-en

[16] Ogundari IO, Akinwale YO, Adepoju AO, Atoyebi MK, Akarakiri JB, Suburban Housing Development and Off-Grid Electric Power Supply Assessment for North-Central Nigeria, Int J Sustain Energy Plan Manag 12 (2017) p 47–63. https://doi.org/10.5278/ijsepm.2017.12.5

[17] Abdallah SM, Bressers H, Clancy JS, Energy reforms in the developing world: Sustainable development compromised?, Int J Sustain Energy Plan Manag 5 (2015) p 41–56. https://doi.org/10.5278/ijsepm.2015.5.5

[18] Odarno L, Sawe E, Swai M, Katyega MJJ Lee, A. Accelerating Mini-grid Deployment in Sub-Saharan Africa: Lessons from

Tanzania. World Resource Institute (WRI), 2017. http://www.wri.org/news/2017/10/release-report-tanzania-mini-grid-sector-doubles-bold-policy-approach [Accessed on 23 April 2018].

[19] Lenz L, Munyehirwe A, Peters J, Sievert M, Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program, World Development 89 (2017) pages 88–110. https://doi.org/10.1016/j.worlddev.2016.08.003

[20] Bensch G, Kluve J, Peters J, Rural electrification in Rwanda. An impact assessment using matching techniques, Ruhr Economic Papers 231 (2010), RWI, Essen. Available: http://hdl.handle.net/10419/45320 [Accessed on 1 July 2018]

[21] USAID, Tanzania Power Africa Fact Sheet, Available: https://www.usaid.gov/powerafrica/tanzania [Accessed on 14 February 2019].

[22] Rural Energy Agency (REA), Energy Access Situation Report, 2016 Tanzania Mainland, National Bureau of Statistics Tanzania, The United Republic of Tanzania, 2017. Available: http://rea.go.tz/DesktopModules/EasyDNNNews/DocumentDownload.ashx?portalid=1&moduleid=639&articleid=91&documentid=100

[23] Innovation Energie Développement (IED), United Republic of Tanzania, National Electrification Program Prospectus, July 2014. Available: https://www.ied-sa.fr/en/documents-and-links/publications/send/3-reports/33-national-electrification-program-prospectus.html

[24] The International Renewable Energy Agency (IRENA), IOREC 2012, International Off-Grid, Renewable Energy Conference, Key Findings and Recommendations, Accra, Ghana, 2012. Available: http://www.irena.org/DocumentDownloads/Publications/IOREC_Key%20Findings%20and%20Recommendations.pdf [Accessed on 15 July 2018]

[25] USAID, Tanzania Power Africa Fact Sheet. Available: https://www.usaid.gov/powerafrica/tanzania [Accessed on 14 December 2017]

[26] Gratwicke M, Rift Valley Energy- Small Hydro Development in Tanzania, ESMAP Knowledge Exchange Forum, The Hague, The Netherlands, 2013. Available: https://www.esmap.org/sites/esmap.org/files/01-KEF2013-REM_Gratwicke_Rift%20Vallery%20Energy.pdf

[27] Hydropower in Tanzania's Rural Highlands (2018), USAID. Available: https://www.usaid.gov/energy/mini-grids/case-studies/tanzania-hydropower/ [Accessed on 17 May 2019]

[28] UNDP, Tanzania Human Development Report 2014, Economic Transformation for Human Development, Tanzania, Tanzania: Economic and Social Research Foundation, United Nations Development Programme, Tanzania Office, Government of the United Republic of Tanzania, Ministry of Finance, 2015. Available: www.hdr.undp.org/sites/default/files/thdr2014-main.pdf

[29] Protas D, Rift Valley Energy, March 2018.

[30] The United Republic of Tanzania, Basic Demographic and Socio\Economic Profile, 2012 Population and Housing Census, Detailed Statistical Tables, National Bureau of Statistics, Ministry of Finance, Dar es Salaam, 2014. http://www.nbs.go.tz/nbs/takwimu/census2012/NATIONAL-SOCIO-ECONOMIC%20PROFILE_CENCUS-2012.zip

[31] Tanzanian Tea Research Institute, Mwenga Hydro Power Project Baseline Study, Dar Es Salaam, Tanzania, 2009.

[32] Peters J, Bensch G, Schmidt CM, Impact Monitoring and Evaluation of Productive Electricity Use – An Implementation Guide for Project Managers. In: Mayer-Tasch L, Mukherjee M, Reiche K (eds.), Productive Use of Energy (PRODUSE): Measuring Impacts of Electrification on Micro-Enterprises in Sub-Saharan Africa. Eschborn, 2013. http://www.produse.org/index.php?lang=eng&page=6

[33] Protas D, Rift Valley Energy, June and November 2017. Personal Communication.

[34] Energy Sector Management Assistance Program (ESMAP), CFL Toolkit (Web Version). Available:http://www.esmap.org/sites/esmap.org/files/216201021421_CFL_Toolkit_Web_Version_021610_REVISED.pdf [Accessed on 17 June 2017]

[35] Bensch G, Peters J, Sievert M, The lighting transition in rural Africa — From kerosene to battery-powered LED and the emerging disposal problem, Energy for Sustainable Development 39 (2017) pages 13–20. https://doi.org/10.1016/j.esd.2017.03.004

[36] Aman MM, Jasmon GB, Mokhlis H, Bakar AHA, Analysis of the performance of domestic lighting lamps, Energy Policy 52 (2013) pages 482–500. https://doi.org/10.1016/j.enpol.2012.09.068

[37] Rubin D, Estimating causal effects to treatments in randomised and nonrandomized studies Journal of Educational Psychology 66 (1974) pages 688–701. http://dx.doi.org/10.1037/h0037350

[38] Arraiz I, Calero C, From Candles to Light: The Impact of Rural Electrification, IDB Working Paper Series 599 (2015), Inter-American Development Bank (IDB), Washington DC, USA. Available: http://hdl.handle.net/10419/115541 [Accessed on 11 July 2018]

[39] Leite W, Practical Propensity Score Methods Using R, SAGE Publications Inc: California, USA, 2016, ISBN 978-1-4522-8888-8. https://uk.sagepub.com/en-gb/eur/practical-propensity-score-methods-using-r/book241054

[40] Rosenbaum PR, Rubin DB, The Central Role of the Propensity Score in Observational Studies for Causal Effects, Biometrika 70(1) (1983) pages 41–55. https://dx.doi.org/10.2307/2335942

[41] Rosenbaum PR, Design of observational studies, Springer: New York, USA, 2010, ISBN 978-1-4419-1213-8. https://doi.org/10.1007/978-1-4419-1213-8

[42] Rosenbaum PR, Observational studies, Springer: New York, USA, 2002, ISBN 978-1-4757-3692-2. http://dx.doi.org/10.1007/978-1-4757-3692-2

[43] R Development Core Team R, A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org, 2014.

[44] Bensch G, Kreibaum M, Mbegalo T, Peters J, Wagner N, The status of energy access in three regions of Tanzania, Baseline report for an urban grid upgrading and rural extension project, RWI Leibniz-Institut für Wirtschaftsforschung, RWI Materialien 111 (2016). Available: http://hdl.handle.ne!ra25et/10419/150046 [Accessed on 11 July 2018]

[45] Chaplin D, Mamun A, Protik A, Schurrer J, Vohra D, Bos K, Burak, Meyer H L, Dumitrescu A, Ksoll C, Cook T, Grid Electricity Expansion in Tanzania by MCC: Findings from a Rigorous Impact Evaluation, Report Submitted to the Millennium Challenge Corporation, Mathematica Policy Research, Washington DC, USA, 2017. Available: https://www.mathematica-mpr.com/our-publications-and-findings/publications/grid-electricity-expansion-in-tanzania-by-mcc-findings-from-a-rigorous-impact-evaluation [Accessed on 11 July 2018]

[46] Bensch G, Peters J, Sievert M, Fear of the Dark? How Access to Electric Lighting Affects Security Attitudes and Nighttime Activities in Rural Senegal, Ruhr Economic Paper 369 (2012). http://dx.doi.org/10.2139/ssrn.2159712

[47] SE4All, Tracking SDG7: The Energy Progress Report 2018, The World Bank, Washington DC, USA, 2018. Available: https://www.seforall.org/sites/default/files/tracking_sdg7-the_energy_progress_report_full_report.pdf [Accessed on 24 January 2019].

[48] Batchelor S, Brown E, Leary J, Scott N, Alsop A, Leach, M, Solar electric cooking in Africa: Where will the transition happen first? Energy Research & Social Science 40 (2018) pages 257–272. https://doi.org/10.1016/j.erss.2018.01.019

[49] Groth A, Impacts of Electrification under the perspective of the Multi-Tier-Framework in Southern Tanzania. In: Mpholo M., Steuerwald D., Kukeera T. (eds) Africa-EU Renewable Energy Research and Innovation Symposium 2018 (RERIS 2018). RERIS 2018. Springer Proceedings in Energy. Springer, Cham. https://doi.org/10.1007/978-3-319-93438-9_11

[50] Enslev L, Mirsal L, Winthereik BR, Anticipatory infrastructural practices: The coming of electricity in rural Kenya, Energy Research & Social Science 44 (2018) pages 130-137. https://doi.org/10.1016/j.erss.2018.05.001

[51] Bisaga I, Parikh P, To climb or not to climb? Investigating energy use behaviour among Solar Home System adopters through energy ladder and social practice lens, Energy Research & Social Science 44 (2018) pages 293-303. https://doi.org/10.1016/j.erss.2018.05.019