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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Groth, Annika (2020). Overcoming one-way impact evaluation of rural electrification projects. In: International Journal of Energy Economics and Policy 10 (2), S. 464 - 476.
https://www.econjournals.com/index.php/ijeep/article/download/8941/4920.
doi:10.32479/ijeep.8941.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2020, 10(2), 464-476.

Overcoming One-way Impact Evaluation of Rural Electrification Projects

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Received: 05 November 2019 **Accepted:** 08 January 2020 **DOI:** https://doi.org/10.32479/ijeep.8941

ABSTRACT

Impact evaluation in rural electrification research usually studies the effects under the framework of a one-dimensional approach from electrification to socio-economic development and/or vice versa. Recent research identifies the need for more research uncovering reverse feedback and complexities of rural electrification projects. For planners, regulators and investors, it is very important to know about the dynamics to facilitate their planning. This paper assesses effects of electrification on daily lighting, lumen and operating hours of micro enterprises. It is based on a case study of a with the main grid interconnected mini-grid project located in Southern Tanzania. Propensity score matching method is applied to identify control and research groups. Furthermore, qualitative data allows for a comprehensive overview on dynamic interactions between electricity demand and the local market structure. The study reveals that mini-grid-electricity has significant impacts on the quality of illumination in micro enterprises, but no evidence of impacts on lighting and operation hours can be identified. Off-grid systems, mainly consisting of solar technologies, might already meet a major share of electricity demand and do not necessarily have to compete with grid power supply, but can complement it. Complementary activities and infrastructures are needed to stimulate electricity demand and business development.

Keywords: Rural Electrification, Impact Evaluation, Propensity Score Matching, Micro Enterprises, Sub-Saharan Africa
JEL Classifications: C21, I32, O12, Q42

1. INTRODUCTION

Since the year 2000, great progress in electrification has been made and 1.2 billion people have gained access to electricity. However, with 1 billion of people without access to electricity, the gap to reach the Sustainable Development Goal 7.1 (SDG 7.1) (UNDESA, 2018) - universal access to electricity - in 2030 is still pronounced (IEA, 2017). Whereas grid extension remains the preferred option to electrify particularly more densely populated areas, the role of off-grid systems for electrification, such as mini-grid systems, should not be underestimated. This is especially true for less densely populated and remote areas with difficult terrain. The international energy agency (IEA) estimates that approximately 60% of rural electrification is cost-effectively best met by decentralized systems (IEA, 2017). However, recent IEA forecasts further estimate that by 2030 there will still be 600 million people without access to electricity, which is mainly due to population growth and uneven progress.

Tanzania, which is in the focus of the present study, is one of the least electrified and poorest countries in the world, but has experienced fast progress in electrification and economic growth in the recent years. Nowadays, more than a third of its total population has access to electricity. This is mainly attributed to the enabling environment for off-grid systems: Solar PV systems serve about a quarter of households with access to electricity (IEA, 2017. p. 84) based on (TMEM, 2017). These developments must be taken into account in research on impacts of (rural) electrification.

The widespread hope associated with electrification is to boost the socio-economic development; there is a consensus that electricity is a critical but not sufficient input factor for development. Yet, the direction of causality between electric power consumption and economic output expansion remains unclear (Omri, 2014; Menegaki, 2014). As will be discussed below, evidence of impacts of rural electrification on income, employment, education and health in the Sub-Saharan African context remains thin even when dealing with the evaluation of large-scale electrification projects (Peters and Sievert, 2016; Odarno et al., 2017; Lenz et al., 2017). In many rural cases, electricity consumption levels are still low and electricity is mainly used for lighting purposes (Peters and Sievert, 2016; Lenz et al., 2017). In their recent paper, Riva et al. (2018) developed a complex framework on the (causal) interactions between electricity use and development in rural areas from the global South to provide guidelines that can support rural electricity planning. They pointed out that the relationships are very context- and time-specific and that feedbacks should be studied as well because they might have both; positive and negative implications for development. Riva et al. (2018) consider positive interactions possible only if complementary services and infrastructures are also taken into account.

For the purpose of analysis, the present paper studies the dynamics between electricity demand and local market production with a focus on the effects of grid-electrification on micro enterprises in Mufindi in the Southern Highlands of Tanzania. To reflect electricity demand, daily average lighting hours of micro enterprises in grid-connected and non-grid-connected but pre-grid-electrified villages are studied. The analysis further compares daily average consumption of lumen hours of micro enterprises and their average operation hours during times of darkness. Electric lighting is a clean lighting source defined as an intermediary outcome, and is said to have an impact on several socio-economic outcome indicators, such as health, education and income (Jimenez and Alberto, 2017). Lumen hours could be an indicator for quality and convenience of lighting (Bhatia and Angelou, 2015). The analysis on the dynamics is based on qualitative analysis, whereas propensity score matching (PSM in the following) is applied to study the average treatment effects ("ATT") of grid-electrification on lighting and lumen hours as well as on the extension of operation hours of businesses.

The remainder of the paper is organized as follows: The next section reviews the literature. Section 3 deals with a description of the background and the project on which the case study in based on. The methodology is outlined in section 4, while in section 5 the results will be presented and discussed. Section 6 concludes and gives an outlook and recommendations for future research.

2. LITERATURE REVIEW

At macroeconomic level, the causal relationship between electricity demand and economic output has been studied extensively. This has been done not only for developed countries (Shahbaz et al., 2011; Vaona, 2012; Shahbaz et al., 2012) but also for countries from the global South (Bélaïd and Abderrahmani, 2013; Esso, 2010; Hamit-Haggar, 2016). Yet, until now, there is no consensus regarding the direction of causality between these two variables. Also at the microeconomic level, evidence regarding the impacts of electrification on socio-economic indicators remains weak and is in many cases of "anecdotal nature" (Odarno et al., 2017. p. 85), particularly in the Sub-Saharan African context (Lenz et al., 2017; Bernard, 2012; Bos et al., 2018).

One of the most influential studies in the field is the study from the Independent Evaluation Group (IEG) from 2008 (IEG, 2008). At that time, only weak evidence was detected, and connection costs were identified as a major barrier for poor households to become connected to electricity. Nowadays, a decade after publication of the IEG study, some off-grid technologies have become more affordable, which is why the situation might have changed since then.

Impact evaluation of rural electrification faces many methodological challenges because simple with and without-or before and after-approaches are susceptible to biases (Bernard, 2012; Ravallion, 2007). However, current research is increasingly using advanced methods to study the effects of electrification (Jimenez and Alberto, 2017; Bernard, 2012; Dinkelman, 2011).

Using an instrumental variable approach and community's land gradient as a predictor of electrification, Dinkelman (2011) studied the impact of electrification on women´s participation in the labor market in South Africa. She studied the reallocation of time due to having access to electricity. Dinkelman (2011) observed that women's time spent on fuel collection could be shifted and dedicated to more productive activities.

In their 2011 paper, Peters et al. (2011), studied the impacts of electrification on firm performance in Benin by relying on PSM. They identified an increase in enterprise creation and higher profits for newly created firms (after electrification). However, they claim that these profits might crow out earnings from other businesses and limit the net effects on the local economy. They were not able to determine beneficial impacts for existing firms through electrification. They call for complementary measures that address the problem of the "electrification trap," which describes the problem of micro enterprises that decide to become grid-electrified because they overestimate the expected profits of grid-electrification (Peters et al., 2011. p. 780).

In their recently published report, Chaplin et al. (2017) studied the benefits and challenges of grid extension in Tanzania. By using a difference-in-differences approach, they determined limited socio-economic impacts of grid-electrification on households: Increased ownership of electric appliances, enhanced income generating activities that rely on electricity, more time spent watching TV, increased perceived household safety and consumption of grid-electricity.

Chaplin et al. (2017) stimulate a debate on the reduction of grid connection costs, which could increase the grid-electricity access rate. They also encourage to carefully weigh up the effects of increased time spent watching TV against educational outcomes and identify greater need for action in the reduction of indoor pollution through the usage of polluting fuels. However, in terms of indoor pollution through polluting lighting devices, Bensch et al. (2017) see less need to act in the African context, because the usage of light-emitting diodes (LED) lamps is already widespread and has replaced kerosene lamps and candles in many African rural areas. On the other hand, they point out that the increase of dry-cell batteries running LED lamps can lead to massive environmental problems if they are not disposed of properly.

By relying on a difference-in-difference approach, Lenz et al. (2017) evaluate the effects of a roll-out of a large-scale electrification project in Rwanda. In the case of households, they determined increased ownership of electric devices and lighting usage, as well as shifting of some activities from daytime to night-time and reduced energy costs, e.g., through lower consumption of kerosene. However, they further established that electricity consumption levels and productive effects of electrification remain low. In case of micro enterprises, they observed a slight increase of enterprise activities. They however, once again, observed income effects remain limited, which they also trace back to the lack of access to markets outside the communities. Lenz et al. (2017) also address the difficulties associated with grid-connection costs and call for more research on the willingness-to-pay for the different electrification options because off-grid solutions might already meet household´s demand on electricity, at least in the short time.

This is in line with the recent review from Peters and Sievert (2016) on research on socio-economic impacts of rural electrification in African countries. They ascertain that electricity consumption needs and levels of households in grid-covered areas might already be met by off-grid systems. Peters and Sievert (2016) see that also confirmed by the fact many households in grid-connected villages do not connect to the grid (based on (IEG, 2008; Golumbeanu and Barnes, 2013). They observe that also at the level of small and micro enterprises, the proof of evidence of the impacts of rural electrification on employment, wages and firm growth is still weak, and call for more research regarding willingness-to-pay for electricity, grid-connection costs and the role of access to (international) markets.

This is in line with the previously mentioned paper from Riva et al. (2018). Their paper on (causal) socio-economic dynamics of electrification in the global South asks for research that "describes and understands the structure of a system" to capture the "complexity and dynamics" of models on the nexus between electricity use and "multiple dimensions of socio-economic development" (Riva et al., 2018. p. 205). Their work on the interactions between electricity demand and local market production provides the framework of the qualitative analysis (section 5.6) undertaken in the present paper.

3. BACKGROUND AND PROJECT

The United Republic of Tanzania is an East African country with a current population of about approximately 55.6 million people. In the last decade, the Tanzanian economy grew steadily with an average gross domestic product (GDP) growth rate of 7% per year (The World Bank, 2018). Notwithstanding, poverty levels are still high. With a human development index of 0.531 in 2015, Tanzania occupies position 151 out of 188 countries (The United Nations, 2016. p. 200), and according to the multidimensional poverty index (MPI), approximately 66% of the Tanzanian population in 2010 is multi-dimensionally poor in terms of education, health and standard of living (The United Nations, 2016. p. 219).

In 2016, per capita GDP amounted to approximately $ 867 (expressed in constant 2010 US$, The World Bank, 2018). With more than 65% of the work force, the agricultural sector employs majority of the working population and remains the mainstay of the economy. However, the agricultural sector contributes slightly less than one-quarter to the GDP, and approximately half of the economic output is generated in the service sector (CIA, 2018).

Tanzania belongs to one of the least electrified countries in the world. However, recently, some progress has been made in terms of electrification and Tanzania is listed to be one of the countries, which contributed to close the gap of electricity access in Sub-Saharan Africa (IEA, 2017. p. 80). More than a third - approximately 33% of the Tanzanian population - had access to electricity in 2016 (The World Bank, 2018). Notwithstanding, in rural areas, the lack of electricity is still severe, and only 17% of the rural population had access to electricity in 2016 (The World Bank, 2018).

Installed generation capacity of the central grid amounts to approximately 1,500 MW. Most of the power- approximately 99% - is generated by fossil fuels and hydro systems (Odarno et al., 2017). Due to its dependency on hydro, and expensive thermal and emergency generation sources, the energy sector is highly (financially) vulnerable, especially during times of droughts (USAID, 2018). In 2014, electric power transmission and distribution losses amounted to nearly a fifth of the electric output generated (The World Bank, 2018), which might also be credited to the ageing infrastructure.

The government aims to achieve 50% (or 75%) of its population to have access to electricity by 2020 (or 2035, respectively) (IED, 2014). Mini-grid systems, electrical generation and distribution systems of <10 MW, play an important role in electricity access expansion. To enhance the participation of private investors in the energy sector, the government introduced the small power producer (SPP) scheme in 2008. To date, approximately 10% (158 MW) of the installed power capacity is attributed to mini-grid systems, and the role of mini-grid systems in rural electrification is expected to increase.

Since the introduction of the SPP framework in 2008, which was revised in 2015 and again in 2017, the number of mini-grid systems doubled, and sixteen of them are connected to the national grid (Odarno et al., 2017).

The 4 MW Mwenga run-of-river mini grid system, which is in the focus of this study, is one of them. Most 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. The focus of the present paper is on the rural community. Thus, grid electricity describes here the electricity that is generated and distributed by the interconnected mini-grid system. The project is owned and operated by the private company rift valley energy and received grant assistance from the African, Caribbean and Pacific-European Union (ACP EU) energy facility, Tanzania's rural energy agency, and the Tanzanian energy development and access project facility from the World Bank-thus has been publicly and privately financed-before starting its operation in 2012 (Gratwicke, 2013; Protas, 2018b).

In 2015, the year of data collection, 17 villages of the surrounding community were connected to the mini-grid. Meanwhile, 32 villages are connected to the Mwenga network. Approximately 62% of the interviewed micro enterprises from the off-grid Mufindi region reported to use solar PV-systems. In mini-grid electrified regions, 97% of the micro enterprises indicated to rely on grid-electricity, and 11% of them combine it with the usage of solar PV-systems. These results contrast with findings from the baseline study from 2009, when the mini-grid system was not yet operational. Only about 3% of the interviewees reported to rely on solar power for lighting purposes (TESRF, 2015. p. 41). The Mwenga hydro project is located in Mufindi in the Iringa region in the Southern Highlands of Tanzania. With a per capita GDP of $880 USD in 2012, the region is classified as the second richest region of Tanzania, which is also reflected in a slightly lower MPI of 61% (TESRF, 2015. p. 89). Mufindi is characterized by its hilly topography, long rainfall and short dry seasons.

4. METHODOLOGY

4.1. Survey Design and Implementation

The field research took place by the end of 2015. At that time, electrified regions had had access to grid-electricity for 3 years. Data collection relied on a questionnaire with 132 detailed questions developed and applied by Peters et al. (2011; 2013) and adapted by the author to the local context. The questions were related to socio-economic background of the owners, business type, real capital endowment of the business, business development services, access to markets, employment, business´s growth constraints, production costs, communication and energy usage with a specific focus on lighting. The selection of the four grid-connected and two non-grid-connected villages was not done randomly and supported by local informants, such as village leaders and project representatives. Secondary information sources, such as official reports, other studies and census data, provided further information for the selection of sample villages (NBS, 2014; TTRI, 2009).

The aim was to identify 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. Sampled villages can be studied in Figure 1.

The selection of the micro enterprises was based on simple random sampling. In total, the sample consists of 38 grid-electrified and 33 non- grid-electrified micro enterprises. The inclusion of non-grid-electrified is critical, not only for reasons of comparability but also for reflecting their pre-grid-electrification status. In the last decade, prices of solar PV technologies have fallen constantly and solar systems have become more competitive and affordable (IEG, 2016).

Daily mean lighting and lumen hours are based on the information provided by the owners, on how many lighting hours of per operating

Figure 1: Sampled grid-electrified (blue circles) and non-grid-electrified (red circles) villages in 2015 (Author based on Protas, 2018a)

day the respective lighting devices are used. The calculation on daily lumen hours is based on assumptions of luminous flux. Table 1 indicates lower and higher levels of luminous flux of the most common lighting devices used by micro enterprises and households in grid-and non-grid-electrified areas: compact fluorescent lamp energy saver (30 Watt), energy saver (solar home systems [SHS]), Kerosene Wick Lamp, incandescent bulb (40 Watt), fluorescent tube (30 Watt) and solar lamp (stored in rechargeable batteries).

4.2. Theoretical Foundation of PSM

As previously mentioned, impact evaluation that relies on simple with and without or before and after treatment approaches is vulnerable to selection (beneficiaries selected themselves into the treatment) or placement (the exposure to the treatment did not happen randomly) biases because the isolation of other (un-) observable influencing parameters cannot be guaranteed in these simple approaches. However, when dealing with non-experimental data, the isolation of disturbing parameters is key to study the genuine impacts of an intervention (here: grid-electrification). To overcome these barriers, Rosenbaum and Rubin (1983) proposed PSM, which is based on the set-up of treatment and counterfactual groups that share most of their pre-treatment characteristics and get comparable in this way. Matching is done based on propensity scores or balancing scores *b(x)*, which describe the estimated and conditional probability of being treated (here: grid-electrified) given observed characteristics. Differences studied here in the mean outcomes on daily lighting, lumen and operation hours before sunrise and after sunset are attributed to grid-electricity.

The following assumptions have to be fulfilled to be able to conduct PSM: Firstly, the assumption on strong ignorability of treatment assignment, meaning that "potential outcome distributions are independent of treatment assignment - given observed covariates." Parameter not observed should not have an influence on the intervention:

$$(Y_1, Y_0) \perp D|X; \quad (1)$$

where D describe the individual given a set of covariates X, Y_1 describes the outcome of the treated individual in case of exposure to the treatment and Y_0 describes the outcome of the treated individual in case of non-exposure to the treatment.

Furthermore, PSM is based on the overlap condition. This assumption requires that, given the balancing score b(x), the conditional distribution of the pre-treatment characteristics is the same for treated and non-treated units. This means that for each covariate x, there is a positive probability of being treated or not:

$$0 < P(D=1|X) < 1. \quad (2)$$

Due to the constraint that the present study deals with observational data, it focusses on the estimation of "average treatment effects on the treated" ("ATT") which describe the "difference between expected outcomes values with and without treatment" for those individuals that were exposed to the treatment. This is given by the following equation:

$$ATT = E(Y_1|D=1) - E(Y_0|D=1); \quad (3)$$

where $D = 1$ describe the individual being treated. However, it is not possible to observe both outcomes of the treated individual at the same time. Instead, the researcher can observe the following:

$$\Delta = E(Y1|D=1) - E(Y0|D=0); \quad (4)$$

where Δ describes the difference between the expected outcomes of treated and non-treated individuals. This is where the reliance on a valid PSM-given the previously discussed assumptions are fulfilled- becomes critical because Δ can also be described as:

$$\Delta = ATT + SB; \quad (5)$$

where *SB* describes the aforementioned selection bias (Baum (2014) based on Rosenbaum and Rubin, 1983).

Different matching methods consisting of greedy, genetic and optimal matching with different settings related to replacement and caliper are applied to study the ATTs. The following steps in accordance with (Leite, 2016) are conducted in R (R Development Core Team R, 2014) based on the packages MatchIt (Ho et al., 2011), Matching (Sekhon, 2011), OptMatch (Hansen and Klopfer, 2006), survey (Lumley, 2017) to estimate the "ATT": Identification of covariates, propensity score estimation, evaluation of common support, PSM, evaluation of covariate balance across the different matching procedures, and the estimation of treatment effects. Additionally, the analysis could be rounded off by a subsequent sensitivity analysis, which is not undertaken here.

5. RESULTS AND DISCUSSION

5.1. Descriptive Statistics

In Table 2, observed differences between micro enterprises in grid-electrified and non-grid-electrified villages are displayed. As can be seen, on absolute level, the business owners of the

Table 1: Luminous flux of lighting tools

Lighting device	Luminous flux	
	Lower luminous flux (in lumen)	Higher luminous flux (in lumen)
Compact fluorescent lamp energy saver (30 Watt)	1500	2100
Energy saver (solar home systems)	210	420
Kerosene wick lamp	8	82
Incandescent bulb (40 Watt)	400	680
Fluorescent tube (30 Watt)	750	3540
Solar lamp (stored in rechargeable batteries)	25	200

Source: Author based on (The lightbulb company, 2017; ESMAP, 2009; Bensch et al., 2017; Aman et al., 2013) counterfactual group have a higher level of education (in years) compared to business owners from the grid-electrified areas. However, this difference is statistically not significant, which can be interpreted in such a way that the business owners generally have similar educational backgrounds. The same also applies to the gender and age of the business owners, the number of employees, which is close to one in both areas, and the share of enterprises dealing with agriculture (around 50% in both areas). In these cases, the discrepancies between them are minor and statistically not significant. Interestingly, the share of businesses dealing with services is higher in non-grid-electrified areas (33% compared to 21%). On the other hand, the absolute share of businesses dealing with trade (61% compared to 42%) and manufacturing (11% compared to 0%), and the absolute real capital endowment of businesses at estimated resale values, are much higher in the grid-electrified villages. This might underline the fact that micro enterprises in grid-electrified regions tend to have more electric devices than in non-grid-electrified regions (Groth, 2016). Many manufacturing jobs are labour-but also technology-intensive, requiring electricity for their operation. Furthermore, the manufacturing sector is traditionally seen as a driver of industrialisation and economic development. However, again, it is important to note that none of the differences studied on absolute level are statistically significant. This might be an indicator for the comparability of micro enterprises from grid-connected and non-grid-connected villages with regard to their background characteristics, even though we are dealing with micro enterprises from different business fields. Following this indication, micro enterprises from the non-grid electrified areas might constitute a valid counterfactual.

With regard to the outcome variables that are in the focus of the study, on absolute level, average lighting and lumen hours and operation minutes per operating day differ between micro enterprises from the grid-electrified and non-grid-electrified villages (Table 3).

Interestingly, with 20.7 h/day, daily lighting hours in electrified areas are indicated to be higher on average than in non-grid-connected villages (16.5 h/day). Notwithstanding, micro enterprises from the non- grid-electrified areas indicated to operate longer on average per business day than micro enterprises from grid-electrified villages. However, only in relation to lumen hours-lower and higher levels assumed- the differences studied are statistically significant. This could be an indicator of the increase in lighting quality experienced by grid-electrified micro enterprises through their access to grid-electricity.

5.2. Identification of Covariates and Propensity Score Estimation

The selection of covariates or so-called pre-treatment characteristics is based on former research and theoretical considerations (Lenz et al., 2017; Chaplin et al., 2017). The incorporated variables are hypothesized to be true confounders, because they relate to the probability of having access to grid –electricity (the treatment) and the treatment effects - the outcomes that are examined here. However, covariates that are only associated with grid-electrification but not with the outcome should not be included in the model. On the other hand, as previously mentioned in the section on the theoretical foundations, covariates should be "non-responsive" to the treatment.

To consider the most common types of businesses in the area, the present study considers dummy variables on agriculture (indicating whether businesses are dealing with (sawing) mills or not), manufacturing, trade (indicating whether businesses are dealing with trade, such as retail shops, or not) and services (indicating whether businesses offer services or not). Additionally, the study includes a dummy variable that indicates whether the owner of the business is female or male. Real capital endowment, describing the estimated capital stock in resale values of an enterprise, is used as a proxy for the pre-grid-electrification business size and profitability of the business, even though the latter is not studied as an effect of treatment (here: grid-electrification). Even if it has already been noted that micro enterprises from grid-electrified villages tend to

Table 2: Descriptive statistics on surveyed micro enterprises from grid-and non-grid-connected areas in 2015

Background characteristics	Grid-connected	Non-grid connected	Test statistic
Education of business owner (in years)	8.3	11.2	t=−0.91
Average age of business owner	34	33	t=0.30
Share of male business owners	68%	76%	χ^2=0.17
Share of businesses dealing with agriculture	47%	52%	χ^2=0.01
Share of businesses dealing with manufacturing	11%	0%	χ^2=1.96
Share of businesses dealing with trade	61%	42%	χ^2=1.65
Share of businesses dealing with services	21%	33%	χ^2=0.80
Average real capital endowment of business (in Tshs.)	18,987,329	4,010,000	t=1.03
Average number of employees	1.3	1.1	t=0.98

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

Table 3: Average consumption of lighting and lumen hours per day of grid- and non-grid-connected micro enterprises in 2015

Outcome variables	Grid-connected	Non-grid connected	Test statistic
Average lighting hours per day	20.7	16.5	t=0.91
Average lumen hours per day (lower levels assumed)	25763	4258	t=7.02***
Average lumen hours per day (higher levels assumed)	42500	8006	t=5.30***
Average operation minutes per day (during darkness)	66	96	t=−1.58

***,**,*indicate 1%, 5% and 10% levels of significance own more electric devices (Groth, 2016), it cannot be ruled out that non-grid-electrified micro enterprises might already have some as well due to their reliance on solar PV systems and/or generators.

Table 4 shows the selected covariates and the logistic regression model for propensity score estimation. As can be seen, only the dummy variable on trade is statistically significant. However, this is not problematic, because, as also noted by Kumar and Rauniyar (2018. p. 10) in their study, the goal at this point is to estimate propensity scores and not to "model an underlying selection mechanism." The model fits the data respectable, as the different pseudo-R-squared suggest. The model specification is confirmed by the significant likelihood ratio test statistic.

5.3. Evaluation of Common Support

The distribution of the estimated linear propensity scores is shown in Figure 2. There is some common support between grid-electrified (=1) and non-grid-electrified (=0) micro enterprises, which can be interpreted as if there is enough overlap between scores from treated and untreated areas to estimate ATT with matching methods.

5.4. PSM Procedure

This paper relies on different matching procedures to match grid-electrified micro enterprises with non-grid-electrified micro enterprises. These methods encompass "One-to-one" and "One-to-many greedy matching" with replacement, which means that one grid-connected case can be matched to one or more not grid-connected case(s) and is put back to the group of observations for further matchings.

Further, the "Greedy matching" procedures consider a caliper of 0.25 standard deviations, which allows for a more precise check on the appropriateness of the overlapping areas between both sets of logit propensity scores. Additionally, within this caliper, the methods look for the nearest propensity scores of not grid-connected households to be matched to propensity scores of grid-connected households. This is also why the methods are known as a "nearest neighbour within caliper matching procedures." The study also takes into account matching based on "Genetic matching" with replacement and no caliper, as well as "Optimal matching." According to Leite (2016) a drawback of "Greedy matching" is that it does not focus on matching quality.

Yet, the use of the "Greedy matching" method is advantageous as less stringent assumptions must be fulfilled. Conversely, "Genetic matching" and "Optimal matching" allow for a higher matching quality.

5.5. Evaluation of Covariate Balance of the Different Matching Techniques

The evaluation of covariate balance is crucial for the check on matching quality of the matching procedures applied. As previously discussed in section 4.2, PSM is based on the assumption of strong ignorability of assignment to grid-electrification, which implies that given the observed characteristics, micro enterprises from grid-electrified and non-grid-electrified areas should have the same probability to get electrified. To ensure the fulfilment of the assumption, we check if covariate distribution between treated and untreated cases is balanced.

Covariate balance of the different matching procedures is displayed in Table 5. As can be seen, in case of the greedy matching methods, the balance is the strongest with maximum absolute standardized mean differences below 0.25 for all covariates, which is an indicator for sufficient performance (Leite, 2016. p. 10) based on Stuart and Rubin (2007. p. 168) and Rubin (2001).

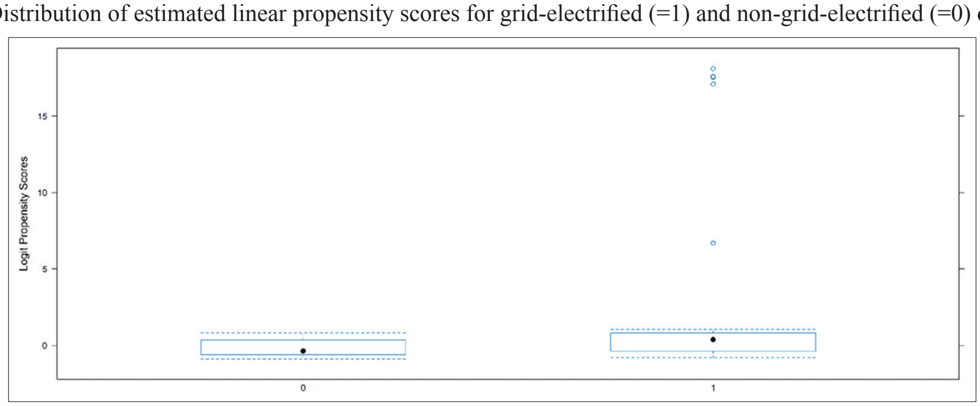
In contrast to the greedy matching procedures, genetic and optimal matching yield poor covariate balance which is higher than 0.25 in both cases, and which is why results based on their matching must be interpreted with caution.

Table 4: Logistic regression model for propensity score estimation

Covariates	Coefficient	Standard error
Gender of business owner (male)	−4.286e−01	6.375e−01
Agriculture	−7.495e−02	6.321e−01
Manufacturing	1.773e+01	1.932e+03
Trade	9.413e−01*	5.868e−01
Services	−2.406e−01	6.195e−01
Real capital endowment	1.333e−08	2.802e−08
Mc Fadden Pseudo R^2	0.12	
Cox and Snell Pseudo R	0.15	
Nagelkerke Pseudo R	0.2	
Likelihood ratio test statistic (Chi-square)	11.316*	

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

Figure 2: Distribution of estimated linear propensity scores for grid-electrified (=1) and non-grid-electrified (=0) observations



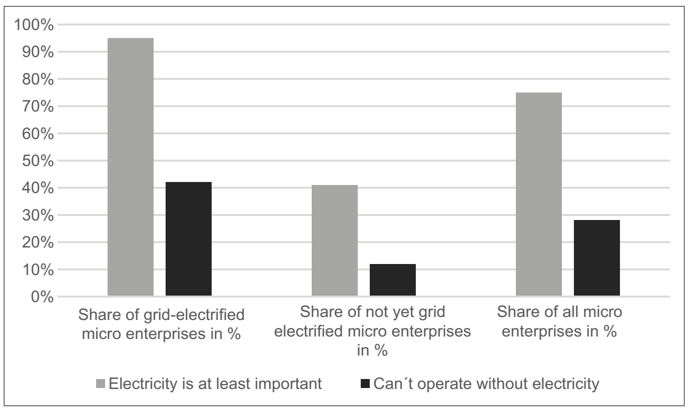
5.6. Estimation of Treatment Effects

Estimated ATT across the different matching methods are shown in Table 6. The impact of grid-electricity on lumen hours - which is an indicator for enhanced quality of lighting - is confirmed on a highly significant level across all methods and lumen levels.

Only the one-to-one greedy matching method estimated significant impacts of grid-electrification on lighting. As already has been established on descriptive level in section 5.1, no effect of grid-electricity on extended operation hours can be examined. The findings are consistent with findings from other studies (Riva et al., 2018, p210 f) based on Adkins et al. (2010) and Peters et al. (2011). Based on their analyses in the African context, having access to electricity-irrespective of grid-connection statuses-does not necessarily lead to extended operation hours of businesses.

In the next section, the dynamics and interactions between different parameters dealing with electricity and market demand and supply will be investigated on a qualitative level.

Figure 3: Share of micro enterprises in % indicating the importance of electricity for operational purposes



5.7. Socio-economic Dynamics

Approximately 97% of micro enterprises in grid-connected and non-grid-connected areas reported to sell their products locally and 99% of them indicated that consumption of them takes place in the vicinity. Since 2012, the year the mini-grid system became operational, more micro enterprises have been founded in grid-electrified areas than in non-grid-electrified areas (more than 80% of micro enterprises in the grid-electrified villages compared to 50% in non-grid-connected areas).

As indicated in Figure 3, having access to electricity is of essential importance for 42% of the businesses in grid-electrified areas. These businesses indicated not to be able to operate without having access to it. In non-grid-connected areas, only 12% of the businesses reported not to be able to run their business without access to electricity. Overall, 75% of all the interviewed micro enterprises reported that electricity is at least important for their daily operations. At least on a qualitative level, this also underlines the importance of pre grid-electrification for the operational business.

Following Riva et al. (2018), Figure 4 displays the positive ("+") and negative ("−") dynamics between different factors related with electricity use and market demand. In the focus of the present paper is the section on "market production and revenues" (Riva et al., 2018. p. 209 ff.), which concentrates on local market structures and studies the interactions between "electricity demand and market production" through different channels.

Regarding an enhanced productivity and local production through higher extended operational hours (e.g., evening working time), the present study does not identify a significant difference between grid-connected and non-grid-connected businesses (section 5 in Tables 3 and 6 before). Following this criterion, having access to

Table 5: Covariate balance across matching methods

Matching methods	Maximum absolute standardized mean difference	Covariates with absolute standardized mean difference above 0.25 (%)
One-to-one greedy matching with replacement and caliper (=0.25)	0.24	0
One-to-many greedy matching with replacement and caliper (=0.25)	0.22	0
One-to-many genetic matching with replacement (no caliper)	0.33	17
Optimal matching (full matched data)	0.35	38

Table 6: Treatment effects across matching methods

Matching methods	Average treatment effect "ATT" lighting hours	Average treatment effect "ATT" lumen hours	Average treatment effect "ATT" operation minutes (during darkness)
One-to-one greedy matching with replacement and caliper (=0.25)	9.045**	21400.3*** (lower levels) 35932*** (higher levels)	−21.91
One-to-many greedy matching with replacement and caliper (=0.25)	1.6592	19750*** (lower levels) 32693*** (higher levels)	−26.893
One-to-many genetic matching with replacement (no caliper)	5.25	20827*** (lower levels) 33320*** (higher levels)	−23.895
Optimal matching (full matched data)	5.462	21177*** (lower levels) 34204*** (higher levels)	−20.58

***,**,*indicate 1%, 5% and 10% levels of significance grid electricity is not significantly influencing market supply of grid-connected micro enterprises in a more positive or negative manner than non-grid-connected businesses (Figure 4). However, in contrast to the statistical findings, on an anecdotal level, more than 70% of grid-electrified businesses reported that electric light is important for the expansion of their operation hours, and approximately 90% of them indicated to have higher sales through the regular use of electric light. This might again reflect the importance and influence of pre-grid-electrification (e.g., via SHS) on operation business hours and lighting needs, which might have been met already.

Yet, as also discussed by Azimoh et al. (2015, p362) for the South African context, the claims of business owners on higher sales or improved business performance due to electricity access and enhanced operation hours must be interpreted with caution and studied more in detail because they might overestimate the impacts.

The heterogeneous nature of interviewed businesses from grid-electrified and non-grid-electrified areas (Table 2 in section 5.1 before) makes it difficult to analyse savings on energy related costs. Some of the businesses rely heavily on energy to become productive and operational (such as mills), whereas others (e.g., retail shops) depend less on energy inputs. Therefore, the nexus between savings on energy related costs and production efficiency and net revenues is not discussed here.

More research is needed to study the impact of an enhanced electricity demand on productivity and revenues and/or income of different types of micro enterprises. This is also consistent with the observation made that approximately 58% of grid-electrified micro enterprises indicated to use electricity also for operational purposes, whereas in non-grid-electrified areas, already approximately a third of the micro enterprises reported to rely on electricity for operational purposes. This could also underline the fact, that micro enterprises do not differ statistically in terms of their real capital endowment (as previously discussed in section 5.1), which also include electric appliances. However, the aforementioned data constraints do not allow to distinguish between the different operational purposes, which is why they are not studied more in detail here.

On average and in absolute terms, employment rate of micro enterprises is slightly higher in grid-electrified areas compared to non-grid-electrified areas (Table 2 in section 5.1 on descriptive statistics). Yet, the difference is statistically not significant. Thus, until now, there is no indication for positive or negative impacts (e.g., by shifting from mechanical to electrical work) of grid-electrification on employment in micro enterprises, and most of the businesses seem to only employ the enterprise owner himself. This could also be an indication for the fact that very few companies perceived the search for qualified employees as problematic (Figure 5).

Regarding the local market demand, most of grid-electrified businesses indicated that their access to grid electricity favoured the growth of their customer base. Some specifically mentioned improved product quality and innovation (for example, the use of modern milling machines improves product quality, or the use of electric appliances allows to improve the design of furniture manufactured). Others reported that electricity allows them to use more efficient electric appliances. Thereby, their production costs can be reduced, which allows them to become more competitive. The access to electricity enhanced customers´ demand for electric devices, which motivated some businesses to expand their business lines.

Conversely, none of the businesses reported to rely on electric communication devices or tools for marketing purposes to expand their customer base. The use of mobile devices might impact production efficiency and net revenues, e.g., when used for accessing information and/or connecting with customers and business partners. Notwithstanding, more than 70% of the grid-connected micro enterprises indicated to use mobile phones on a daily basis for business activities, whereas in non-grid-connected villages, this figure is slightly above 50% of the interviewed businesses. This corresponds with the observation made, that enterprises from the grid-connected villages tend to possess more electric devices than those from the non-grid-electrified areas (Groth, 2016).

Figure 4: Positive and negative dynamics between electricity demand and market production (Author based on Riva et al., 2018)

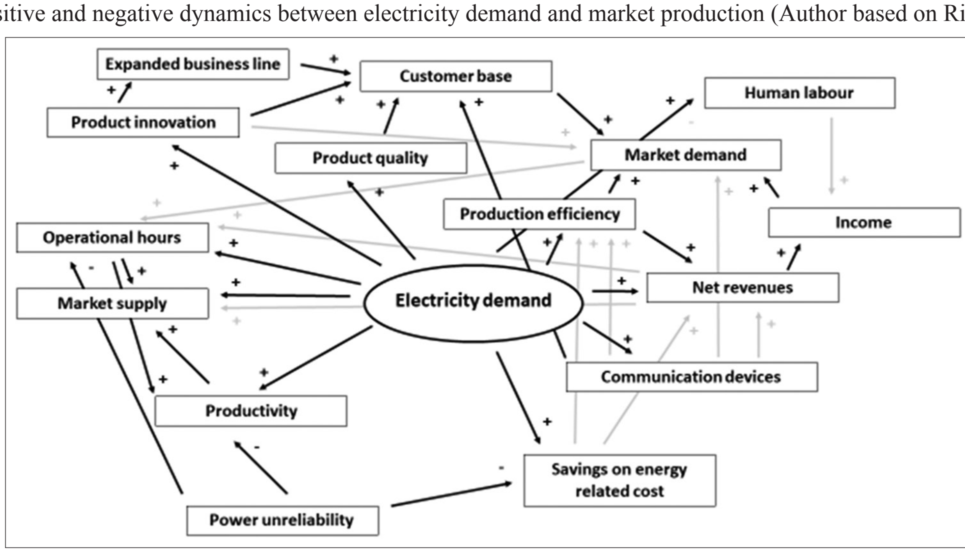
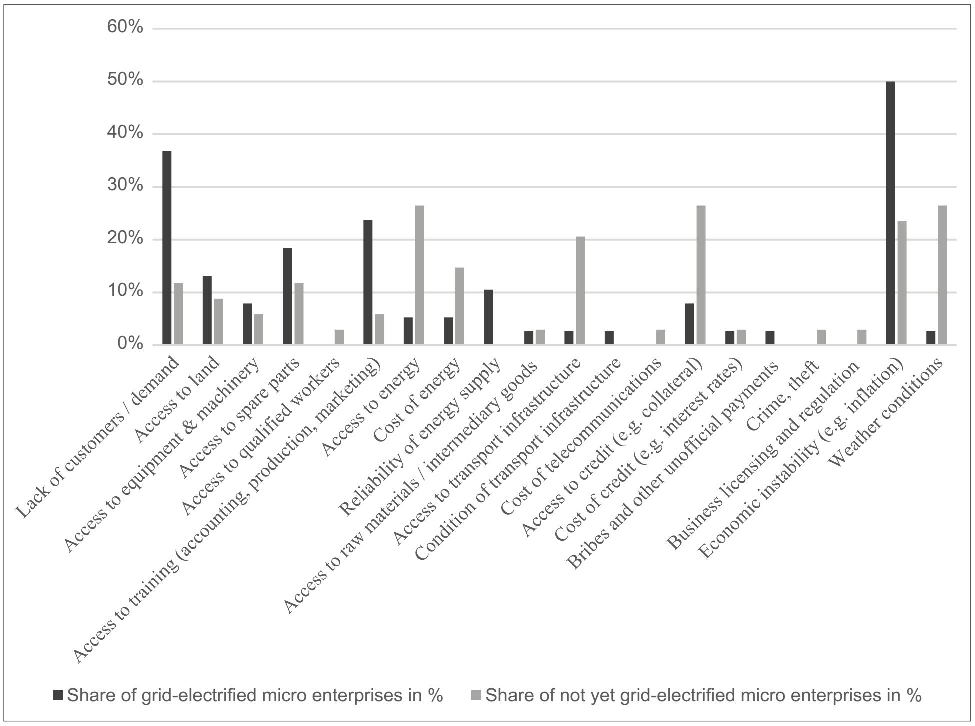


Figure 5: Perceived major business constraints of grid-and non-grid-connected micro enterprises in %



Few grid-connected businesses (11% of them) compared to non-grid-connected micro enterprises (approximately 24%) reported that their customer base has stagnated or reduced since 2012, the year of the mini-grid system becoming operational. Micro enterprises faced with these challenges indicated that they are mainly caused by increased competition, which might be an indicator for the crowding out effect of new businesses created on existing businesses, as also has been observed by Peters et al. (2011), in the case of micro enterprises in rural Benin. At this stage of research, it becomes evident how important it is to consider the development of the purchasing power of the customer base to investigate whether purchase power increased or whether purchases are simply shifted to different (new) and potentially electrified businesses. Additionally, the drivers of the creation of new businesses should be studied more in detail. Interestingly, the lack of customers has been indicated as one of the major constraints for business development by grid-electrified micro enterprises (Figure 5).

Figure 5 displays the most severe problems for business operation and growth of grid-electrified and non-grid-electrified micro enterprises. Economic instabilities are perceived as a major business constraint in both areas. On the other hand, most of the grid-connected micro enterprises reported to be negatively impacted by the lack of customers and demand, as well as by the lack of access to training or capacity building.

Regarding the reliability of grid-electricity supply, approximately 82% of grid-electrified micro enterprises indicated that their business activities are affected regularly by unforeseen blackouts, which cause damage to equipment and forces them to engage in other activities, to shift, or even stop their operational activities. However, only about 11% of the grid-electrified micro enterprises (Figure 5) reported to perceive reliability of energy supply a major constraint.

Non-grid electrified companies have not indicated this as a restriction, although they could also be affected by the fact that off-grid systems do not function optimally either. For example, Azimoh et al. (2014) in the context of Sub-Saharan Africa have found that access to energy can be impaired by inappropriate use and maintenance of off-grid systems. Furthermore, as previously mentioned in section 3, some of the grid-electrified businesses combine grid-electricity with off-grid technologies, which might counterbalance the effects of grid interruptions. This would complement findings from Terrapon-Pfaff et al. (2014) who see the cost competitiveness and sustainability of off-grid systems under pressure when the grid arrives. According to them, technical, financial and regulatory, administrative and legislative constraints-that often prevail in developing countries-complicate interconnections of decentralised and centralised energy systems. Qualitative data analysis suggests that assessments of cost-competitiveness of off-grid energy systems in case of arrival of grid-electricity should also reflect the negative impacts of grid-unreliability for business operations. Interestingly, the mini-grid system itself, within the framework of this study defined as the generator and distributor of grid-electricity through its interconnection to the main grid, is already counterbalancing failure effects of the main grid (Groth, 2018). Yet, more data is needed to quantify the impacts of interruptions on business operations.

Only 11% of grid-connected micro enterprises or 0.03% of non-grid-electrified micro enterprises reported to have received business related training. More than a fifth of business owners from the grid-access areas reported to have difficulties in getting access to business related training (Figure 5). To conversely compare, many of the non-grid-connected companies reported to suffer from lack of access to energy, transport infrastructure and credit facilities. These challenges reflect the need for complementary infrastructures, such as access to financial services and transport which might contribute to lower transaction costs and enhanced market demand.

Furthermore, capacity building activities can be crucial for product innovation and efficiency. In this regard, all enterprise owners - irrespective of their grid connection status - expressed their interest in receiving training on business management and technical skills.

6. CONCLUSION

Since 2008, the year of when one of the most cited studies was published by the World Bank (IEG, 2008), the evidence on impacts of rural electrification on socio-economic indicators-such as income, education and health-has not changed much and remains thin and controversial, especially in the Sub-Saharan African context (Peters and Sievert, 2016; Odarno et al., 2017; Lenz et al., 2017). However, since then, off-grid systems, such as SHS, became more affordable, the binary definition of having access to electricity or not is too narrow (Bhatia and Angelou, 2015) and the pre-grid-electrified status of households, micro enterprises and institutions needs to be reflected in research. The present study analyses the impact of grid-electricity on lighting, lumen and operation hours of micro enterprises connected to a with the central grid interconnected mini-grid system in Mufindi, located in the Southern Highlands of Tanzania. Based on PSM, the results indicate that lighting and lumen hours are positively and partly significantly impacted by grid-electricity. This can be interpreted as an increase in lighting quality through grid-connected systems. However, no significant effects have been detected in terms of extended operation hours through access to grid-electricity and off-grid powered electricity can meet already a higher share of the current lighting demand of micro enterprises. Qualitative analysis suggests that at least part of micro enterprises electricity demand can already be sufficiently met by off-grid technologies. The lack of access to markets and capacity building measures, but also economic imbalances are regarded as major constraints, which confirms the observations made by other researchers in the African context (Lenz et al., 2017; Dinkelman, 2011; Chaplin et al., 2017).

The findings of the study suggest that rural electrification planners should consider pre-grid electrification statuses of micro businesses and the complexity of their short-and long-term electricity demand, which depends on complementary infrastructure and activities. Results could be backed up by a subsequent sensitivity analysis and potential biases through unobservables and endogeneity might be addressed by relying on the instrumental variables approach. Future research might include more indicators, such as connection costs and firm performance, and study how to most effectively stimulate electricity demand and development of micro enterprises. It could further consider the heterogeneity of firms and the effects of blackouts and interruptions on the operational activities and performance of the businesses. In this context, the interconnection of the mini-grid system to the central grid or of off-grid systems to the grid system might play an important role, because it might counterbalance the impacts of blackouts in the grid system.

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