Shedding light on the socio-economic dynamics of electrification: A multi-perspective study

Annika Groth

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Supervisors:

Prof. Dr. Bernd Möller

Europa-Universität Flensburg, Germany

Prof. Dr. Roland Menges

Clausthal University of Technology, Germany

List of articles

The thesis is based on the submitted or published scientific papers which are listed below.

Chapter	Article	Peer-reviewed
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5	Groth, Annika. Comparison of (pre-)electrification statuses based on a case study in Tanzania	
6	Groth, Annika. Socio-economic impacts of rural electrification in Tanzania *International Journal of Sustainable Energy Planning and Management Vol. 21 2019 76–92, http://dx.doi.org/10.5278/ijsepm.2019.21.6*	x
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Resumé

The overarching hypothesis of this work is reflected in the UN's SDG No. 7: the achievement of universal access to affordable, reliable, and modern energy services by 2030, which is considered to be of essential importance for the achievement of the other SDGs, which include the eradication of "poverty through advancements in health, education, water supply, and industrialization, [in order to] to combat climate change" (1). However, the role of access to energy services for inclusive economic growth and the eradication of poverty is not further described in SDG No. 7. The goal does not specify the type and direction of the relationship between access to energy services (electricity or energy consumption in the following) and socio-economic indicators. Furthermore, SDG Goal No. 7 does not reflect the channels through which the impacts of improved access to energy services may occur. Additionally, how universal access can be achieved is generally described as through infrastructure expansion, which includes renewable energy services and advanced and cleaner fossil fuel systems. However, knowledge of the direction and type of relationship between energy services and socio-economic indicators, as well as how to most effectively electrify a region (i.e. via off-grid, mini-grid, on-grid, and/or interconnected energy systems) to meet the SDGs by 2030, is crucial in planning and generating policies and also depends on local conditions. Here, the SDGs can be seen as general guidelines.

The thesis aims to shed light on the dynamics of energy access in the context of Sub-Saharan Africa (SSA) from two different perspectives: the macro and micro levels. Specifically, by relying on econometric methods, micro level analyses contribute to the reduction of the "extremely limited" research on energy sources that are used by households and small- and medium-size enterprises and associated with economic outcomes (2: p.5). Moreover, comparisons between interconnected mini-grid and off-grid systems, as done here, are rarely made in research (3: p.8). On the other hand, the macro level allows a determination of the macroeconomic long-term effects that arise from dynamic, economy-wide processes. Research on this level allows an identification of the impacts of energy conservation or energy efficiency measures (e.g. Kyoto mechanisms and policies closely aligned with the Paris Agreement's long-term goals) on the economic power of implementing nations, or vice versa, the effects of economic development on energy consumption. By better understanding these dynamics, policies can be adapted accordingly.

Countries from the Global South are frequently affected by shocks and imbalances, such as political upheaval or severe drought, which are reflected in their process of development. Therefore, international key indicators and indexes measuring development on the socio-economic level are characterized by structural breaks. This work assumes that these breaks can impact the type and direction of the relationship between access to energy services and economic activity, thereby giving direction to policy formulation and planning (4). This part of the present research contributes to the significant existing literature in terms of portraying the case of Kenya, but using longer time series data, including the period of the global financial crisis in 2007/2008 and enhanced econometric approaches to measure the relationship.

The case of Kenya is studied on a highly aggregated level. Macro data show that electrification has gained speed in the last decade, and according to official figures, the access rate grew by more than 50% between 2000 and 2016 (5, based on 6). At the same time, the Kenyan GDP increased by 4.6% on average per year (7). The analysis focuses on the relationship between electric power consumption (used as a proxy for electricity consumption due to data constraints) and GDP. It becomes evident that this relationship is not one-dimensional per se, i.e. running from GDP to electric power consumption or vice versa, and interruptions in the time series data sets, e.g. reflecting imbalances of economic activity or energy shocks, need to be considered in the analytical process. For the entire sample period, between 1970 and 2014, no causal relationship between the indicators can be detected. However, when a subsample period that reflects a structural break in the data is studied, a unidirectional relationship running from electric power consumption to GDP can be established. Whereas the first finding implies that electric power saving policies or electricity shortages should not have a negative impact on GDP, the second result suggests that economic output expansion could be negatively affected by restricted electricity consumption. A key message that can be derived from the analysis is that structural breaks should be considered in the analysis process in order to allow for well-founded policy and planning suggestions. On the other hand, more detailed and comprehensive data concerning electricity consumption and economic output expansion should be collected to better reflect the reality in these countries. Informal sector activities play a major role and many businesses rely on electricity sources (such as diesel generators) that, due to their unofficial usage, are not reflected in the very broadly defined key indicators. A key question that remains is whether the (inter-)relationships established at a higher aggregated level can also be established at a lower, less aggregated level, which could suggest a trickle-down effect.

Owing to rapid and substantial advances in terms of cost reduction and technological improvements in off-grid energy systems (prices of solar energy systems declined by 80% between 2008 and 2015 (8: p.83, based on 6) and higher penetration rates of solar power technologies in remote areas of SSA (9, 10), this work is in the line with existing research (11) and hypothesizes that countries from the Global South can leapfrog traditional modes of electrification to improve livelihoods and achieve socio-economic development objectives and goals (5, p.47). The constantly changing pre-grid electrification statuses of households and small and medium businesses in rural areas of the Global South need to be reflected in research on rural electrification because they can give valuable insights for planning. The present work contributes to this reflection.

Therefore, a core part of this work focuses on comparing the socio-economic situation of households and small enterprises in six villages in the Mufindi, Iringa Region of Tanzania. In 2012, the research area became electrified by an interconnected mini-grid system from the Mwenga Hydro Power Project, powered through a 4 MW hydro generation plant. The investigation takes as its point of departure a baseline study conducted in 2009 by the Tea Research Institute of Tanzania. The present research has collected additional survey data on the household and enterprise level in 2015. Two villages in the area are still to be connected and were not part of the 2009 Mwenga Hydro Project Baseline Study, which is why they offer a good opportunity to study the effects of recent electrification. The participating villages share similar characteristics in terms of climatic conditions, topography, infrastructure, access to markets, distance to larger cities, and economic characteristics such as income sources. However, the villages in the connected and non-connected areas have or have had different pre-electrification statuses.

The purpose of the baseline study (Chapter 5) is to compare the pre-grid electrification socio-economic status of the villages from 2009 and 2015, and to analyse how the situation in the electrified villages changed compared to 2009. The focus is primarily on units that already have access to solar power. Using qualitative data and descriptive statistics, the study reveals that these units tend to possess more electric appliances and belong to higher income classes. Furthermore, secondary literature and sources add more insights into the surrounding conditions. Compared to findings from the Mwenga Hydro Power baseline study from 2009, in 2015, solar system usage was more widespread in rural Tanzanian areas. Baseline data reveal that grid-electrified households combine the usage of solar home systems (SHS) and grid electricity. The study further detects that access to grid electricity is not necessarily only accessible for higher income classes and that poor households also rely on grid electricity. On the other hand, off-grid SHS systems are mainly owned by households from higher income classes. If this finding can be confirmed on a broader scale, it implies that off-grid systems can contribute to pre-grid electrification households and thereby prepare them for a future arrival of the grid; however, their possession may be limited to richer households. The results of this study comprise a valuable baseline or starting point for further initiatives of the present project as well as similar developments in developing countries, where good data for stakeholder analyses in the area are often absent and a basis for a deeper analysis is required.

Based on a quasi-experimental method – PSM – research on the micro level (Chapters 6 and 7) concludes that lighting and lumen hours are significantly higher in grid-electrified areas than in households that are not yet grid-connected. No significant impacts on lighting and the operating hours of micro businesses were revealed. Thus, off-grid technologies in not yet grid-connected areas already bridge part of the “lighting gap” compared to mini-grid connected areas. However, regarding household usage of electrical equipment and expenditures for energy sources, only minor differences can be detected. For example, expenses for dry-cell batteries are significantly lower in grid-connected households. This implies that households can at least save part of their energy expenditure by accessing grid electricity. The use of dry-cell batteries is widespread, especially in rural areas. Consequently, these findings also suggest that the adequate disposal of batteries should be ensured, particularly in off-grid areas, in order to reduce the potential risks to the environment and people (also observed by Bensch et al. (12)). Businesses owning electric devices were too few and the sample size too small to allow for a rigorous impact evaluation apart from lighting and operating hours. Overall, a limited possession of electric devices may be interpreted as an indicator for the time delay it takes until grid electrification measures can unfold their full potential.

The last part of this thesis aims to study the reliability and availability of grid electricity. Compared to off-grid technologies, lighting through grid electricity is still significantly higher, even if it is affected by (regular) power outages. The study further reveals that the interconnection of the mini-grid system and the main grid can be beneficial by enhancing both parameters.

Across all studies, findings suggest that off-grid home-scale systems, such as SHS or pico PV systems, can already meet the electricity demand of households (and small businesses) up to a certain threshold. These off-grid energy solutions can be driven by the market(s) and not necessarily depend on (public) funding. Therefore, electrification planners should carefully assess the costs and benefits of grid extension projects versus off-grid electrification measures (as also claimed by Peters et al. (13)) and should also consider their role as complementary, back-up, or bridging technologies (as also discussed by Grimm et al. (14)). On the other hand, the findings may also underline the fact that welfare gains happen through various channels and need complementary infrastructures, such as transportation, water and sanitation, sewerage, telecommunications, as well as access to financial and educational services and markets, which must be in place in order to enhance the demand and (productive) uses of households and micro enterprises. This confirms common knowledge in the field.

The thesis is organized as follows: Chapter 1 introduces the research field, questions and objectives. It also gives an overview of the country context of Kenya and Tanzania. Chapter 2 presents the theoretical foundations, while Chapter 3 describes the methodological foundation of the studies. The papers are presented in Chapters 4 to 8. Chapter 9 summarizes and discusses the findings and provides the outlook and recommendations for further research.

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Abbreviations

ATC	Average Treatment Effect On The Untreated
ATE	Average Treatment Effect
ATT	Average Treatment Effect On The Treated
CIA	Conditional Independence Assumption
CCS	Condition On Common Support
CGE	Computational General Equilibrium
DiD	Difference-In-Difference
EGN	Energy Growth Nexus
EKC	Environmental Kuznets Curve
ESMAP	Energy Sector Management Assistance Program
GDP	Gross Domestic Product
GNI	Gross National Income
GNP	Gross National Product
GTP	General Purpose Technology
HDI	Human Development Index
KNES	Kenyan National Electrification Strategy
LED	Light Emitting Diode
MDG	Millennium Development Goal
MPI	Multidimensional Index of Poverty
PAYG	Pay As You Go
PQLI	Physical Quality of Life Index
PSA	Propensity Score Analysis
PSM	Propensity Sore Matching
PSS	Propensity Score Stratification
PSW	Propensity Score Weighting
RCT	Randomized Controlled Trials
SAP	Structural Adjustment Programs
SDG	Sustainable Development Goal
SMEs	Small And Medium Enterprises
SSA	Sub-Saharan Africa

SHS	Solar Home System
TOT	Treatment On TheTreated
UNDP	United Nation Development Program
USD	US Dollars
VAR	Vector Autoregressive Model
VEC	Vector Error Correction Model

1. Introduction

This work must begin with the description of a situation I experienced during my field study at the end of 2015: meeting with a young man who was working hard in the field in front of his house. The sun was burning intensely and the sweat dripped from his forehead. The movements of his hoe were rhythmic, moving in time to the music that came from his house. He stopped, smiled at us and warmly invited us to have the interview inside his house, where it was much cooler and more comfortable. He reported using electricity from the mini-grid system to run his radio and that the music motivated him to work in the field. While looking around and talking to the young man, I realized that his household possessed – apart from the radio – two mobile phone chargers and used electricity for lighting a few bulbs inside the house. His young wife entered the house, carrying their little baby on her back. She had come back from collecting water at the spring, and began cleaning the cooking hut in front of the house. My research-oriented mind promptly started to process what I had observed in these few moments: the young family seemed to live on subsistence farming (the fieldwork done in front of the house), they cooked with firewood (a bundle of firewood lay in front of the cooking hut), and they possessed very few (electric) items but relied on electricity to run these devices. At least some income must have been generated to be able to afford regular (?) access to electricity (even though the business model of the mini-grid system relies on prepaid payment). However, the housing conditions were very simple, also in terms of installations for electricity – security concerns aside. For a moment, I felt ashamed that I had immediately tried to categorize these people, and focused instead on what they reported to me. They expressed being happy with the improved living conditions, but said that they were heavily impacted when a system-wide short-circuit happens because this could imply a loss of income to replace a broken item and thus other priorities have to be neglected. I realized their vulnerability as well as the implicit flexibility to adapt to any kind of situation, including climatic conditions, required of them on a daily basis. For example, during my research stay, I experienced periods of intense precipitation that lasted for several days. Villages were cut off because of floods. Heavy rainfall also led to continuous power failures. However, in general, I noticed their pride in their perceived improved living conditions.

Thus, when I think about the term “socio-economic development”, where should I start to measure progress in development? Where is the threshold that defines the transition from the state of developING to that of developED? Where are the boundaries in space and time? And what has been achieved so far? One of my major lessons learned throughout the research process is that perspective matters. According to official figures, the research area in Tanzania and its population belong to one of the poorest regions in the world. According to the poor old neighboring women, the interviewed family was seen as being “more progressively advanced” because of their access to electricity and usage of a few electrical appliances. Through the lenses of my northern lifestyle and experiences, the young family appeared to be poor because of their lack of access – or the challenges they faced in achieving a certain level of access – to what we (northern people) define as the basic necessities: a clean water supply and sanitation, health and transport facilities, good nutrition, (social) security, financial services, and education. Electricity is a crucial input factor for covering almost all of these needs. On the other hand, in the process of research, and as will be discussed in more detail below, I have realized again that local context matters; when the frequently and quickly changing local conditions and needs are considered in planning and policy, electrification can contribute to welfare to a much greater extent.

1.1 General Background

"Rather than asking what kind of development we should target – perhaps the question should be: What kind of development we can monitor?"

The quote from Jerven (15: p.106) reflects the challenges of policy makers and researchers who aim to formulate policies and targets based on inferences from comprehensive data sets. For example, the data-based reflection of macroeconomic dynamics forms the basis of argumentation in many international contracts and negotiations. Economic growth is still a target that countries should thrive to achieve for the SDG No. 8 (UN): "Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent GDP growth per annum in the least developed countries" (16). Thus, the notion of economic performance is still the most widely used by policy makers, business leaders, investors, and the media to measure economic success (17, 18: p.7). Yet there is considerable debate about whether the concept of (eternal) economic growth should still be striven for in order to achieve long-term "welfare and sustainability" (for example, the Post-Growth Conference in 2018 (19)), and this discussion will be addressed in greater detail in Chapter 9.

In the context of countries from the Global South, the collection, analysis, interpretation, and dissemination of data can be a difficult task due to insufficient (financial) resources (Jerven (15)). This is reflected in the quality of the inferred knowledge resulting from studying these data sets, and this will be illustrated here using a simple example of the two countries under focus in the present thesis: Kenya and Tanzania. As can be seen in Figure 1 below, on the surface, Kenya has made major achievements in terms of access to electricity. By 2016, the access rate reached 56% compared to 3.3% in 1990 (7). However, these improvements do not seem to be reflected in the data sets on poverty reduction, where levels have been at a higher level (42.5% in 2005) compared to 1990 (31% of the population) (7). The situation in Tanzania seems to be very different. The progress in terms of electrification has been slower, but the poverty rate declined sharply, from close to 90% in 2000 to below 50% in 2011 (7). According to the 2018 and 2019 Tracking SDG 7 Energy Progress Report (20, 21), Tanzania and Kenya have recently become "access winners" and belong to the main drivers of SSA countries counteracting access losses made through population growth.

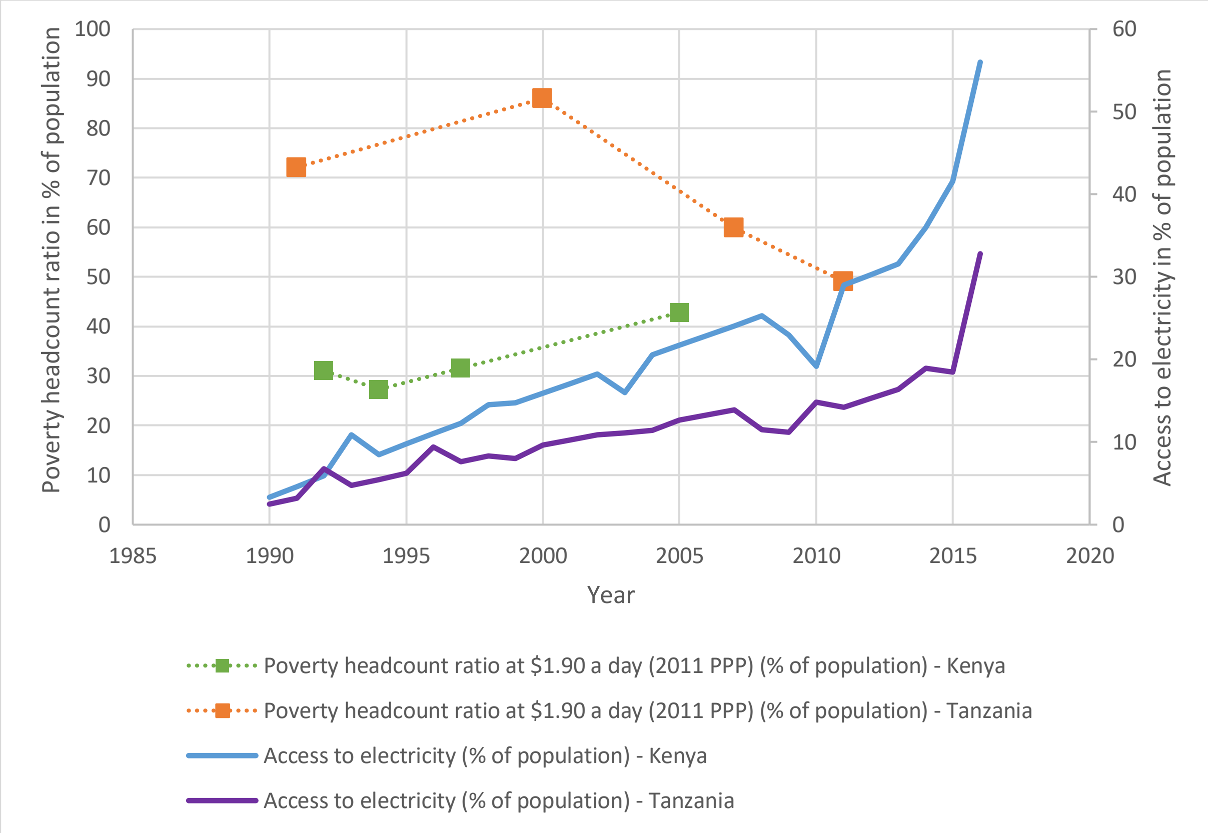

Figure 1. Access to electricity and evolution of the poverty rate in Kenya and Tanzania in percent from 1990 to 2016

Source: Author based on (7)

As can be seen in Figure 1 above, their access rates increased steeply, by with more than 6% on average per year, between 2010 and 2016 in the case of Kenya and more than 2% on average per year in Tanzania. With more than 70% of the Kenyan population having electricity in 2017 (7), there is still a gap to achieve the ambitious "Last Mile Connectivity Program" of the Kenyan government, which targets universal access by 2020 (22). On the other hand, the Tanzanian government is targeting 50% or 75% of its population to be electrified by 2020 or 2035 (23: p.8). Both countries still belong to the top 20 countries with electricity deficit access (20, 21).

What do these figures tell us about the relationship between socio-economic development and electrification? In the case of Kenya, it could be assumed that progress in electrification is negatively related to poverty reduction, whereas in the case of Tanzania, there seems to be a positive relationship between progress in access to electricity and progress in poverty reduction.

The indicators displayed in Figure 1 are based on highly aggregated data. Income and expenditure data are usually derived from national household surveys (7, based on 24, 25). The implementation of these surveys may differ in terms of budget disposal, methodology, timeliness, space, frequency, and quality. As critically assessed by Jerven (26), the quality of internationally standardized and aggregated (time-series) data on GDP and income from SSA countries (including Kenya and Tanzania) still suffers from methodological constraints, including errors of omission, poor availability, precision, and accuracy, which may restrict its use for evaluating the development status of countries. Moreover, informal sector activities may not be sufficiently reflected in official statistics. The disparities and distribution patterns of data on different levels, such as on the local, topographical, cultural, social, or even individual plateau, can hardly be reflected on highly aggregated levels due to the nature of averaging “individual circumstances”, which implies a loss of “some valuable information” (27: p.2).

As will become apparent in the course of this work, representing genuine living conditions and understanding underlying mechanisms and forces remain challenging tasks. However, it also becomes clear that new approaches, concepts, and methods (will) contribute to overcoming some of these constraints.

A question that arises at this stage is to what extent development objectives can be met by off-grid energy systems, which are often limited in terms of scale and capacity. At the same time, access to grid electrification does not necessarily imply that the needs of the electricity consumers are effectively met. This is especially the case when dealing with inefficiencies in the electricity sectors of SSA countries, which are often faced by under-maintenance and inoperable generation capacities (5, p.51). Therefore, it would also be interesting to know if the interconnection of off-grid (here: mini-grid) systems to the main grid can be beneficial for electrified households by enhancing the reliability and availability of access to grid electricity.

This thesis aims to shed light on the causal dynamics between electric power consumption and economic development in the SSA context. For this purpose, macro and micro perspectives are adopted, recent theoretic approaches in this field discussed, and data sets are evaluated with newer empirical methods. Specifically, the following questions will be addressed:

- Is there a causal relationship between electric power consumption and economic output? If so, what is the type and direction of this relationship, and is it impacted by structural breaks? What kind of implications can be derived from that?
- To what extent do access to and use of different modes of electrification and their parallel existence affect the socio-economic conditions of households and micro enterprises in the SSA context? Can causality be established?
- More specifically, to what extent does access to and use of electricity from an interconnected mini-grid project affect the socio-economic conditions of households and micro enterprises in rural SSA areas compared to not yet grid-connected but potentially pre-electrified, off-grid home-scale system users?

The study on Kenya from the macro perspective strives to achieve the following:

- Analyze and determine the type of relationship between electric power consumption and GDP in Kenya between 1970 and 2014
- Investigate the role of structural breaks
- Discuss implications based on the results

The analyses based on the case study from the Mwenga Hydro Power Project in Southern Tanzania aims to:

- Determine the (pre-grid) electrification status of rural households and micro enterprises
- Assess the effects of (grid) electrification on the lighting of rural households and micro enterprises
- Assess the uptake of electric appliances and their usage
- Assess the effects of electrification on the energy expenditures of rural households
- Assess the effects of electrification on the operating hours of rural micro businesses
- Identify the barriers to micro business development
- Assess and compare the reliability of (interconnected (mini-)) grid electricity

The following methods are used to carry out the analyses. To evaluate the causal relationship between GDP and electric power consumption per capita, the study makes use of the augmented Toda-Yamamoto non-Granger causality approach and Johansen co-integration tests (Chapter 4).

From Chapter 5 onward, the studies are based on data collected at the end of 2015 as part of a field research stay in Tanzania. The studies in Chapter 5 and Chapter 8 make use of descriptive and qualitative data analysis, whereas the impacts of electricity on households and micro enterprises are studied with the support of a non-experimental research design –PSM (Chapters 6 and 7).

The next section gives an overview of the current socio-economic conditions in the two countries under study, Kenya and Tanzania.

1.2 Conditions in Tanzania and Kenya

The two neighboring countries of Kenya and Tanzania differ significantly from each other in many aspects, including their colonial experiences, their capitalism-socialism dichotomy discourse after gaining independence in the 1960s, their primary language, and “varied internal regime-level institutions and priorities” (28: p.60).

Nevertheless, the two countries have a lot in common. First of all, they share similarities in terms of their geographic location and access to the Indian Ocean, which can be advantageous for their economies because it allows them to be involved in international shipping and trading. While African maritime sectors are still less integrated into world trade, projects under the Belt and Road Initiative of the Chinese government support the growth of the port infrastructure in Africa (29).

Indeed, Kenya is referred to as the “trade hub” of the East African region (30: p.10). Both countries border Lake Victoria (the world’s second largest freshwater lake (31) and share similar climatic conditions, which are mainly tropical with regional variations. There is high solar potential in both countries: the average solar radiation level per day varies between 4 and 7 kWh/m² (32: p.447, based on 33, 34: p.2966), which qualifies them in particular for the exploitation of solar-based technologies.

With approximately 54 million people, Tanzania is at the forefront of East African countries (35), while Kenya´s population amounts to 47.6 million people (31) (see Table 1 below). On average in the past decade, Tanzania’s population grew by 3.1% per year, whereas the Kenyan population grew by 2.7% on average per year (7). Both populations are very young. The median age in Tanzania is 17.7 years (35), and the Kenyan median age is slightly higher at 19.7 years in 2017 (31). The high proportion of young people is also reflected in the total age dependency ratio[1], which is 76% of the working-age population in Kenya and 92% of the working-age population in Tanzania (7).

	Kenya	Tanzania
Total population	47,600,000	54,000,000
Average population growth rate per year [in %]	2.7	3.1
Population density [people per sq. km of land area)]	87.3	64.7
Urban population [in % of total]	26.6	33.1
Median age of the population [in years]	19.7	17.7
Age dependency ration [in %]	76	92

Table 1. Population data in Kenya and Tanzania

Source: Author based on (7, 31, 35)

However, these figures need to be interpreted with caution, due to the fact that the child labour rate is reported to be substantially high in both countries. In Tanzania, almost 25% of all children between 5 and 13 years of age are engaged in child labour activities (36). In Kenya, this figure amounts to approximately 26% of all children (37). Additionally, life expectancy rates are, compared to Western standards, relatively low, with approximately 66 years in Tanzania, and 67 years in Kenya in 2017 (7).

[1] The World Bank (7) defines age dependency as the ratio of dependents, i.e. people younger than 15 or older than 64, to the working-age population (those aged 15-64). Data are shown as the proportion of dependents per 100 working-age population.

Income inequality in SSA countries is extremely high. In 2016, approximately 55% of the national income of SSA countries was attributed to the top 10% earners. The World Inequality Report from 2018 (38) classifies this region as comprising “inequality frontiers” with an “extreme and persistent level of inequality” (p.42f). According to the most recent measures surrounding income distribution, the Kenyan GINI coefficient amounts to 40.8 (in 2015), compared to 37.8 (in 2011) in Tanzania (see Table 2 below). These figures are slightly lower than the East African mean GINI coefficient of 41.8, and in the case of Tanzania are even lower than the world average GINI coefficient of 38.3 (8: p.135, 7). However, inequality in term of socio-economic opportunities is also regionally perceptible: arid areas versus less arid areas, and urban areas versus rural areas, in terms of access to education, (infrastructure) services, and jobs (30: p.10).

Kenya is the leading economy among East African countries. Recently, it passed a threshold set by the World Bank and is now classified as a lower middle-income country. As indicated in Table 2 below, the corruption index is high in Kenya, whereby the country is ranked 144 out of 180 countries compared to Tanzania, which is at position 99 (39). On the other hand, the transition toward a market economy or the liberalization of the Tanzanian economy is still continuing, and key sectors are still mainly under the control of the public sector.

According to the latest global report on competitiveness, at position 93 out of 140, Kenya is classified as the most competitive economy in East Africa, and has been highlighted for its potential for innovation (40: p.35). However, institutional conditions, domestic competition, and infrastructures have to be further developed and strengthened in order to provide a more fertile framework for innovation (40: p.10). Tanzania occupies a lower rank, at position 116, and although its macroeconomic conditions have been evaluated as being stronger than in Kenya, the country particularly indicates weaknesses in the fields of ICT adoption and innovation capability (40: p.551).

	Kenya	Tanzania
GINI coefficient	40.8	37.8
Corruption index position	144	99
Global Competitiveness Index 4.0 2018 rank	93	116
Agriculture, value added [% of GDP]	31.5	30.1
Services, value added [% of GDP]	45.4	37.5
Industry (incl. construction), value added [% of GDP]	17.5	26.4
Manufacturing, value added [% of GDP	8.4	5.5

Table 2. Economic indicators of Kenya and Tanzania

Source: Author, based on (7, 8, 30, 31, 35, 39, 40)

As can be seen in Table 2, the agricultural sector is the backbone of the economy in both countries. The majority of the workforce is employed in this sector, with around 65% in Tanzania (35) and 75% in Kenya (31) of the total workforce. However, in 2017, the agricultural sector contributed only about a third of the value added to the GDP in both countries (7). The service sector is the most important contributor in terms of value adding to GDP, at 45.4% of GDP in Kenya and 37.5% of GDP in Tanzania (7). The tourism sector activities are key in both countries, and in Kenya, the tourism sector alone accounted for 20% of GDP in 2017. The Tanzanian gold production and export industry has experienced a boom over the past few years (35), which is reflected in the contribution of the industry sector to the GDP, at 26.4% of GDP in 2017 (7). In Kenya, on the other hand, the contribution of the industry sector to the GDP amounted to 17.5% in the same year (7). With less than 10%, manufacturing contributes proportionally less to the GDP in both countries (7).

Informal sector activities from micro and small (household) enterprises are not represented at all in official statistics, and available data on their activities is scarce. According to a recent study from the World Bank in 2016 (41), almost 95% of enterprises and businesses in Kenya are attributed to the informal sector, and around 70% of the employment beyond farming is found here. Additionally, it should be noted that the productivity from the informal sector is substantially lower compared to the productivity of the formal sector. Notwithstanding these factors, a major share of Kenyan enterprises (ca. 52%) is indicated as relying on electricity to run their businesses (41: p.3, p.32). A similar picture arises in Tanzania (42). Therefore, the role of informal sector activities in the nexus between electrification and socio-economic development (as will be further discussed in Chapter 4) should not be underestimated.

Both economies are more globally integrated than two decades ago, however, which is in line with the current trend on the African continent (8: p.35) and is reflected in more diversified trade partnerships. In 2017, the trade value of Kenyan total exports amounted to more than $ 5.7 billion USD, whereas the trade value of Kenyan total imports was much higher, at $16.7 billion USD (42). In 2000, the trade volumes of Kenya were substantially lower, at approximately $ 1.6 billion USD for exports and almost $ 2.9 billion USD for imports (42). As can be seen in Figure 2, the European Union is still among the most important trading partners of the Kenyan economy. This applies in particular to the Kenyan export sector. Imports from emerging countries (BRICS countries), and in particular from China, have gained importance since 2000. In 2017, China covered almost a quarter of all imports to Kenya, whereas in 2000 China’s share amounted to only 3% of all imports (see Figure 2).

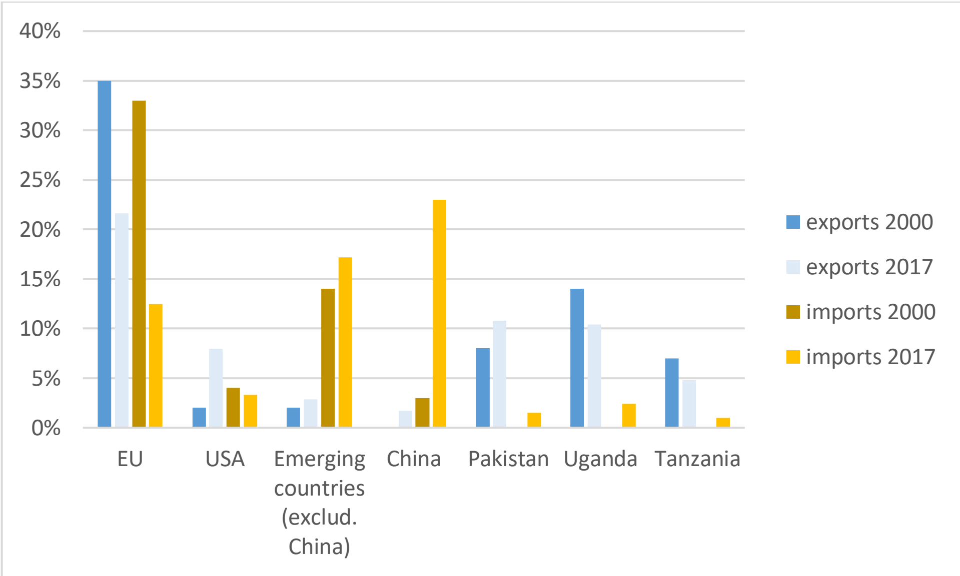

Figure 2. Shares of exports and imports of goods to and from Kenya in 2000 and 2017 by country.

Source: Author's elaboration based on (42)

The increasing importance of emerging countries, and of China in particular, as trading partners can also be noted in Tanzania (see Figure 3). Between 2000 and 2017, the trade volume of Tanzanian total imports increased from $ 1.6 billion USD to $ 7.8 billion USD (42), and during the same period, the Tanzanian total export volume increased from $ 0.6 billion USD to $ 4 billion USD (42).

As can be seen in Figure 3, within the last two decades the importance of the EU as a leading trading partner has declined sharply, while emerging countries (excluding China) have gained considerable importance as export partners (from less than 20% of total exports in 2000, to 40% of total exports in 2017). For example, India's demand for Tanzanian raw materials (particularly for the abovementioned gold) is high (43). With an increase of Chinese imports to Tanzania from less than 5% of total imports in 2000 to almost 20% of total imports in 2017, China's reputation as an important trading partner of East African countries is highlighted once more.

East African countries mainly export unprocessed goods, however, whereas the majority of imports comprise final goods, which reveal their structural and economic weaknesses and overall vulnerability to price fluctuation and currency depreciation (8: p.146, p.155). For example, Chinese product imports relate mainly to machinery and mechanical appliances as well as electrical machinery and equipment (HS 1988/92, 84-85_MachElec), and capital goods in both countries (44, 45). This reflects the current significant Chinese investment in infrastructure projects on the African continent (8: p.72), and there are plans for further expansion. In 2015, the Chinese government pledged further investment of $ 60 billion USD on the African continent (46).

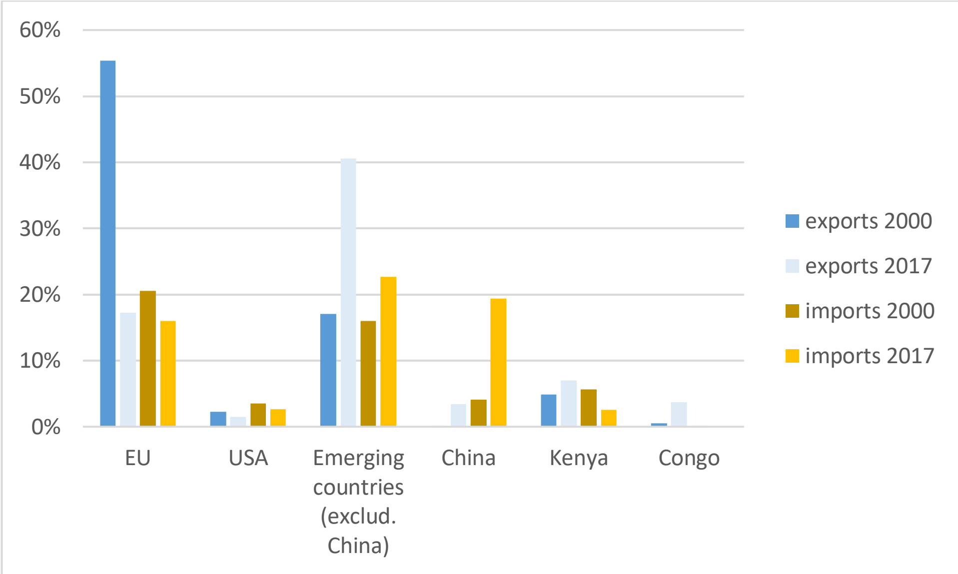

Figure 3. Shares of exports and imports of goods from and to Tanzania in 2000 and 2017 by country.

Source: Own elaboration based on (42)

China's crucial role in electrifying African countries is not only in terms of direct investment. Chinese heavy investment in its own renewable energy sector is one of the factors responsible for the cost decline of solar power-based technologies in recent years, rendering them more affordable for poorer countries. It is predicted that the substantial expansion of energy infrastructure based on renewable energies in China (up to 1.1 TW of solar PV until 2050 (47)) will lead to further cost reduction pressures on an international level, from which other countries can also benefit. Bloomberg NEF estimates that the costs of a standard PV plant will be reduced by 71% by 2050 (47). The import of products related to renewable energy from China, such as solar PV panels, is already on a steep rise on the African continent (10: p.65), thereby also impacting the speed of electrification in the two countries being studied.

However, as of 2018, grid extension is still the most preferred electrification mode in Kenya. This is also reflected in Chapter 4 while studying the relationship between economic output and electric power consumption. It is expected that the needs of three-quarters of the consumers lacking access to electricity (about 3 million) will be met by grid extension, whereas the rest will be addressed by off-grid systems (30: p.13). Being active in this field since the 1980s, Kenya has one of the most mature and booming off-grid sectors in the world, particularly in terms of solar off-grid technologies. A comparable picture arises in Tanzania. Grid extension is still preferred over off-grid electrification (23); however, a quarter of Tanzanian mainland households still rely on solar power for their main source of electricity. In rural areas, this figure even amounts to approximately 65% of households with access to electricity (48: p.47).

In a recent report on global off-grid solar market trends, Kenya and Tanzania are classified as "upgraded" off-grid solar markets. These markets are defined as "highly penetrated maturing markets, where suppliers may consider upgrading existing customers to higher quality technologies and service levels and should seek innovative distribution partnerships to penetrate the "harder-to-reach customers" (10: p.69). This observation reflects what will be discussed in more detail in Chapters 5 to 8: The role of off-grid systems in (pre-grid) electrifying the countries should not be underestimated. A more comprehensive description of the two electricity sectors can be found in Chapters 4 to 8. The next section presents the theoretical foundation on which the analyses conducted in Chapters 4, 6, and 7 are based.

2. Theoretical foundation

2.1 The macro perspective: converging and diverging trends

It is scientifically proven that planetary boundaries will not allow all of Earth's inhabitants to consume and emit in the same manner to which citizens from the Global North are accustomed – and which they have done for a very long time – in order to meet the SDGs and global environmental goals by 2030 (49). This has recently been reconfirmed by the latest IPCC assessment report, underlining the need for mitigation and adaptation actions on the international level to limit global mean temperatures to below 2 or even 1.5 degrees above pre-industrial levels in 2100 (50). These actions require economic systems to shift away from fossil fuels and damaging land use practices (51). At this stage, it again becomes clear that access to and use of energy resources and the dynamics of economic systems appear to be somehow related. The theoretical foundations of this relationship will be discussed in more detail in Section 2.4.

For a significant period of history, the development of the world economy was very homogeneous and slow, closely linked to the development of the world's population (52, based on 53). This changed with the shift of some countries toward industrialized economies in the 18th century, which implied substantial productivity gains for them, and "the Malthusian trap of the stagnation in worldwide per capita income that existed from the year 1000" has since been overcome (52: p.6, based on 53). From that point onward, the global economy came to be increasingly subdivided into economies with uneven levels of development across people, place, and time (52: p.6).

Nowadays, the wealth gap between the Global North and countries from the Global South is immense. In addition to threats posed by climate change, the persistent unequal distribution of economic resources and opportunities challenges societies both internally and across borders (54), not least because it affects their economic performance (55: p.11, based on 56, 57). As noted by Rodrik (58: p.3f, based on 59, 60), it seems that "convergence has been the exception rather than the norm since the great divergence spawned by the Industrial Revolution" and " the world is divided into a rich core and a poor periphery". A way to get an idea of this disparate distribution is to examine the global distribution of income, which enables an "outcome-oriented" perspective on the "material dimension of well-being" (61: p.6). According to indicators of income inequality (based here on pre-tax national incomes, thus before redistribution measures) from the World Inequality Database (62), 1% of the global population accounted for more than 20% of global income in 2016, while 50% of the world population earned approximately 10% of global income in the same year.

To illustrate this imbalance, Figure 4 displays the distribution of income growth captured by average individuals in different income groups between 1980 and 2016 (63: p.9). The distribution, also called the "elephant curve", clearly depicts the unequal distribution of income growth capture. The top 1% captured 27% of total income growth, while the bottom 50% only gained 12% of the total income growth in the last three decades. The spread in shares of income growth shown in Figure 4 indicates the marginalization of more than a billion of people, a trend that also encompasses people from northern countries (see the shrinking of the income growth share of the middle class in the US and Western Europe in Figure 4).

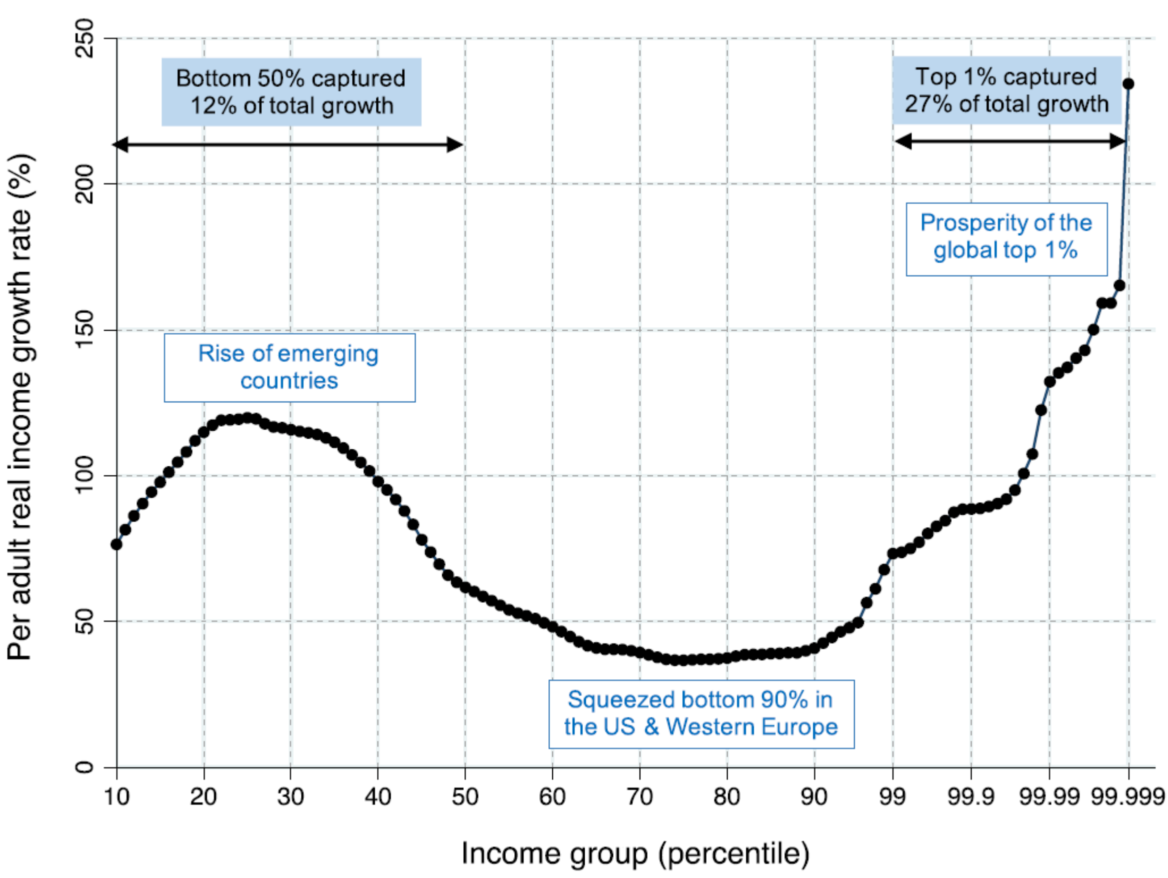

Figure 4. Total income growth by percentile across all world regions, 1980-2016.

Source: (63: p.9)

Yet, as remarked by Rodrik (58: p.3f), there are some exceptions in terms of convergence. Accordingly, the illustration in Figure 4 also shows the catching up of some emerging economies at the global level, where millions of poor people, particularly from China or India ("Chindia"), have benefitted from income growth in the last three decades (38: p.106, based on 64): In China, the national average income has grown by 800% since 1978. The bottom 50% and middle 40% of income earners experienced sharp increases in income (400% and 700%, respectively). However, the income of the top 10% earners grew by 1200% during the same period. In 2015, 42% of national income was earned by this income class, whereas the share of the bottom 50% amounted to only 15% of Chinese income. The share of the middle 40% income class stayed relatively stable, around approximately 44% of national income during this period (38, based on 64: p.108).

The divergent developments in Chinese national income distribution are attributed not merely to the urban-rural disparity, which is forecast to remain substantial, but mainly to regional discrepancies. On the other hand, the authors (38) also note that the distribution of shares in national income has not changed significantly since 2006. According to their research (38, based on 65, 66), this may reflect data constraints as well as the introduction of comprehensive policies of the Chinese government aiming to reduce inequality and the attenuation of structural changes. Anti-corruption and redistribution measures appear to be having an impact and have helped to at least stabilize the income distribution since then (49: p.19).

China’s economic achievements in recent decades have been remarkable. On a global level, the economic gains of China (as well as India) have contributed significantly to income growth among the poorest half of the world population. Since 2000, the between-country average income inequality diminished significantly (38: p.55). Stiglitz (55: p.15) describes the Chinese GDP growth model within the last 30 to 40 years as a “miracle,” with exceptionally high rates and an expansive reduction in poverty that has not been seen before in the history of the well being of mankind. The developments in China contributed to a large extent to the achievement of certain MDGs; in particular, the reduction of the global poverty rate, which halved between 1990 and 2015.

In contrast to China, SSA countries contributed to a lesser extent to the fulfilment of the MDGs. As already mentioned in Section 1.2, development gains in SSA were much lower compared to China and were also partly offset by population growth. Income inequality remains extremely high. In 2016, approximately 55% of income was earned by the top 10% (38: p.42), and poverty levels are still at comparatively high levels (see section 1.2).

A way to illustrate the heterogeneous economic developments in countries from the Global South is to examine GDP per capita as a proportion of that of the United States between 1960 and 2017 (Figure 5; author, based on (67: p.3, 7). Here, too, the economic progress of China compared to countries from SSA, including Tanzania and Kenya, becomes visible, particularly in the last decade. However, we can also note that China´s GDP per capita is still significantly lower than that of the USA in 2017.

At the same time, the steep rise of Chinese GDP per capita has been remarkable over the last two decades. If we interpret this development as a “catching-up effect”, meaning the economic convergence of those emerging economies like China toward the more advanced economies (despite the abovementioned rise of the within-country income inequality), it would be interesting to know which factors contributed to the Chinese economic performance.

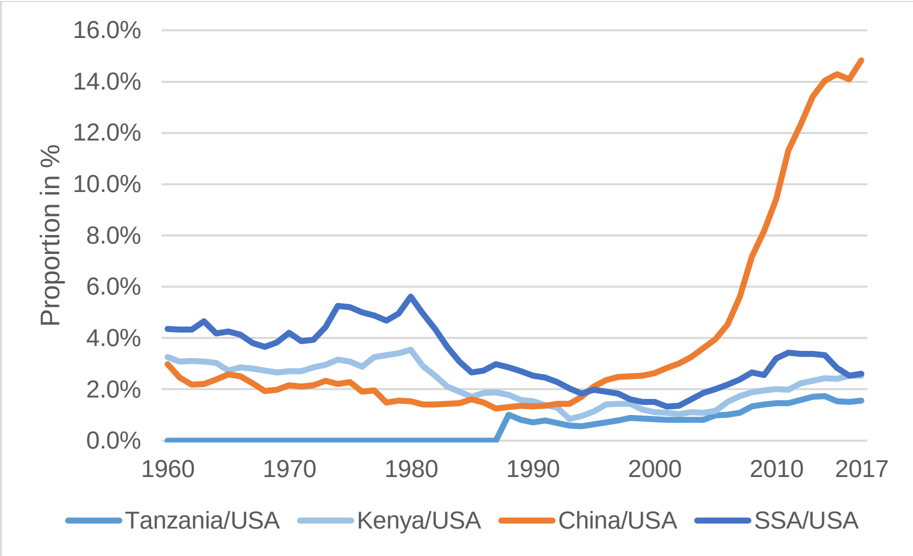

Figure 5. GDP per capita as a proportion of that of the United States

Source: Author's elaboration, based on (67, 7)[2]

In China, an "old growth strategy" (68: p.6), a "strategy cantered on high savings and investment, strong export orientation and a focus on manufacturing and construction industries" (68: p.4) but based on an "extraordinary expansion in coal consumption", and the public sector´s role in the provision of educational services (achievements in "learning") and infrastructures (55: p.31) are reported to be responsible for its strong economic growth in the last three decades. This reflects the shift away from a traditional, agriculture-based economy towards a more industrialized economy, underlining the important role of energy consumption in Chinese economic development. A critical success factor of the Chinese economy was and still is its ability of technical borrowing and industrial upgrading, describing the absorptive capacity of the country to leapfrog technologically by exploiting imported technologies or by imitating them (69, p.338)[3].

According to Randers et al. (49: p.43), "newer historic experiences" of China could serve as an economic model for poor countries. Countries from the Global South could follow the "new development model" to push "transformational actions with systems-wide effects on SDGs". In particular, the authors emphasize the crucial roles of the implementation of "some democratic qualities through bureaucratic reforms

[2] Due to data constraints, data on Tanzania is limited to the period between 1988 and 2017.
[3] This might stand in contrast to the endogenous-growth theory (Romer (1990) (70), which, among other things, assumes that technological change may be an outcome of costly frontier investments of private companies, and the benefits of it may be mainly constrained to them because the technological advances are protected by patent (69: p.366).

according to long-term plans" and the inclusion of local knowledge and resources in the centrally-planned processes of Chinese economic development (49: p.32, based on 71). For example, the strong competition between mostly collectively owned but locally managed public authorities, townships, villages and enterprises (Tangible and Village Enterprises (TVEs)) is listed as one of the decisive success factors (55: p.10) until the privatisation wave started in the late 1990s.

The extent to which human rights were and continue to be violated remains questionable, as well as how this may have contributed to the success of the economic model. It also is difficult to predict whether China will manage to overcome the economic gap with the Global North in the future (55: p.15). At present, it is still debated whether China can escape the "middle-income trap" (72), which describes the situation of countries that have reached the level of a middle-income country (MIC) in a short time period but are not able to graduate to the level and productivity of highly-developed economies.

Related to the two SSA economies under study here, we are not able to determine a convergence behaviour toward the US economy over time (see Figure 5). On the contrary, as can be seen in Figure 5, the proportional share of SSA countries, particularly of Kenya, is currently less than it was in the period after gaining independence in the 1960s until 1980, which describes the period of decolonisation. This could be interpreted as an indication that there is (still) no uniform solution for "catching up". Indeed, experiences and analyses of economic development paths and the heterogeneous responses to programs have shown that there is (still) "no universal recipe" or uniform approach to promote and sustain development (67: p.7).

In the next section, I will discuss the most prominent approaches to and concepts of economic development elaborated since the 1970s, and describe them in the context of Kenya and Tanzania.

2.2 From trickle-down to behavioural economics

In the 1970s, it became "evident for the first time" that trickle-down effects do not take place and that economic growth does not necessarily go hand-in-hand with poverty reduction (69: p.132). The awareness was influenced by global economic circumstances, including the first oil crisis from 1973. This was particularly obvious in East Asia and Latin America, where, despite the oil crisis, high growth rates were recorded at that time, while poverty reduction was much less pronounced or insufficient (69: p.132). Thus, it became popular to call for state intervention (69: p.134) to meet basic needs, enhance social welfare, and install a multidimensional approach to address human development (69: p.132f, based on 73).

One of the most influential theories that gained popularity in this time period is dependency theory, whose ideas draw heavily on the work of Frank (73, 74: p.117). According to the theory, there is an economic imbalance between the interdependent core and (semi-) periphery regions. The core regions (e.g. northern countries or the west) benefit substantially from trade with the periphery regions (e.g. countries from the Global South), while the regions at the margin suffer from unequal economic exchanges and exploitation, which manifest in their poverty, inequality, and dependency. Thus, the development of the core regions goes hand-in-hand with the underdevelopment of the peripheral regions (74, p.119). To spur their economic development, the theory suggests that peripheral areas should disconnect from the core areas (or global markets), and form their own independent internal systems. An important basis for dependency theory is provided by the Prebisch–Singer hypothesis (75, 76), which assumes that primary commodity prices relative to manufactures (terms of trade) develop to the disadvantage of producers of primary goods in the long run.

Following these notions, many developing countries shifted to import-substitution industrialization (ISI) and export-oriented industrialisation (EOI) strategies, aiming to enhance and protect domestic production. Tanzania belonged to one of the African countries in which centralized planning initiatives played a major role[4]. In the course of the 1970s, the Tanzanian state was heavily engaged in production and investment, and the large (insurance) companies and banks were owned by the state (77: p.370). This time period was also characterized by exceptionally high levels of international financial assistance to Tanzania, however, which peaked in 1980. Edwards (77: p.373) attributes the high levels of financial aid to the international aid community, which "fell in love" with President Julius Nyerere's vision of African Socialism (*Ujamaa*), presented in the Arusha Declaration in 1967. In Kenya, planning measures were comparatively soft throughout the course of the 1970s (77: p.370). With the aim to spur industrial growth, the Kenyan government implemented comprehensive import substitution strategies. These measures had devastating and distorting impacts on (the competitive position of) the economies, which intensified in the wake of the collapse and the outbreak of the second oil crisis in the late 1970s (78: p.3).

At a global level, the age of monetarists and followers of top-down, neo-liberal discourses from the 1950s and 1960s re-emerged in the course of the 1980s. Following serious macroeconomic imbalances fuelled by the oil crisis in 1978 and the debt crises in the early 1980s, the latter decade was characterized by the implementation of Structural Adjustment Programs (SAPs). SAPs were largely driven by the Bretton Woods Institutions, which imposed tight policy prescriptions on their lending. Their aim to restructure economies from the Global South involved the trade liberalisation for goods and services, deregulation of the banking sector, foreign direct investment, competitive exchange rates, and the privatisation of public enterprises. The measures implied a heavy reliance on market forces and a comprehensive cutback of state interventions (69, p.135), which in turn minimized the role of the state in ensuring price stability. The policies are also known under the term "Washington Consensus" (79).

Bourguignon (67: p.6), notes that the policy shift in the 1980s was not "completely unjustified" in the context of many African economies due to the negative consequences of unsystematic state interventions driven by "elites or populist governments", which caused large fiscal deficits and excessive public debts in the previous decade. In this context, Edwards (77: p.359f) critically discusses the role of the international aid community in Tanzania during that time period. According to him, the aid support of less favourable policies may have contributed to the weakening of the Tanzanian economy, while

[4] Edwards (77) cites Ragnar Nurske, Paul Rosenstein- Rodan, and Albert Hirschman as key thinkers of the planning approach.

corruption and economic dependency increased at the same time. The author remarks that the circumstances in Tanzania may represent a classic example of misguided and misallocated financial aid (as discussed by Easterly (80) and Moyo (81)). A comparable picture arose in Kenya. The 1980s were characterized by a "stop-and-go relationship" with donors and lenders, describing the difficulties of Kenya in meeting the Structural Adjustment Loan conditions that they imposed (82: p.20).

Thus, despite (or perhaps because of) the paradigm change that took place in that decade, the 1980s are also known as the "lost decade" (83), particularly for African countries. Many development gains from previous decades were lost within this "period of economic stagnation and job losses" (69, p.23). Moreover, it took countries in SSA more than a decade to return to their pre-crises economic growth paths (67: p.6). According to Stiglitz (55: p.24), stagnation caused by SAPs took even longer: only after a quarter of a century were SSA countries able to reach pre-crisis levels of per capita incomes, and many of them were less industrialized than before.

The Kenyan GDP per capita (in current USD) decreased by about 50% between 1980 and 1993 (7). Similarly, the Tanzanian nominal GDP shrank by 45% between 1976 and 1991, while the Tanzanian real income per capita reduced by 15% in this time period. The breakdown of the Tanzanian economy during that time is also described as "one of the most spectacular economic disintegrations ever" (77: p.358). It took about one decade for the Tanzanian GDP level of 1976 to be reached again in the year 2000 (77). In the course of the 1990s, the Kenyan and Tanzanian economies started to liberalize and to open their markets towards the global markets. This was also reflected in their higher integration into global markets, which has been discussed in Section 1.2. A more detailed description of the status quo of their current economic situation can also be found in section 1.2.

At the beginning of the 1990s, criticism of western development policy became sharper in the wake of the post-development discussion. In the opinion of post-developers, the real motivation of the west in supporting development in "underdeveloped" countries from the Global South consisted of defying the dangers of expanding socialism, justifying market expansion, and imposing on them a backward version of their own unsustainable way of life (84). Among the most influential thinkers of the post-development movement were Sachs (85) and Esteva (86).

In the course of the 1990s and at the beginning of the 21st century, further notions on economic development appeared. Many of them acknowledged the shortcomings of the Washington Consensus, especially in the wake of the Asian crisis in the late 1990s. Central to these were the return of state interventions into economic processes and a greater emphasis on the role of legal frameworks, governance, and institutions (55: p.3). The abovementioned economic model of China represents a contrasting practical example to the notions based on the Washington Consensus, because it emphasises the role of the state by also "using markets" (55: p.23).

Among the most prominent Post-Washington Consensus (and also post-neoclassical) scholars and approaches (69: p.137) are those on endogenous growth (e.g. Romer (70)) and multiple equilibria (e.g.

Bardhan (87)), open economy industrialisation (e.g. Justin Lin (88)), new institutional economics (e.g. North (89) and Acemoglu et al. (90, 91)), and new political economy (92), but also those on behavioural economics (93–95). Many recent approaches and concepts surrounding economic development have been elaborated in response to market failures, such as the financial markets during the global financial crisis of 2007/2008. Overall, these approaches encompass top-down (e.g. Sachs (96) and Easterly (97)) and bottom-up concepts (e.g. Banerjee and Duflo (98)).

The heterogeneity of approaches surrounding how to address and stimulate economic development is also critically reflected in research on rural electrification programs. In the course of economic liberalisation and comprehensive structural adjustment measures during the 1980s, governmental budgets and spending declined in several countries of SSA. Cook (99) identifies this as one of the reasons why only insufficient investments were made in infrastructure projects. The shift towards a greater inclusion of the private sector via the enhancement of private investments in electricity utilities during the 1990s has also not proven to be successful (100: p.306). Many utilities are heavily indebted and struggle with achieving financial and technical soundness, which is reflected in a poorly maintained infrastructure that suffers from limited capacity and reliability. Consequently, the ability to invest is limited. These circumstances also describe quite well the situation of the Tanzanian utility Tanesco in recent years (101). For decades, electricity sectors in both countries were characterized by large utilities and regularized by bundled authorities with a focus on on-grid electrification. Inert institutional and regulatory capacity is reported to still be one of the barriers to energy system transitions and extensions in developing countries (e.g. Winther et al. (102: p.62f) for the case of Kenya).

As a result, electricity access gains remained low in both countries until recently (see Section 1.2). Thus, a model (e.g. centralized power generation and grid extension) that has proven to work successfully in the context of northern countries (and even in China), may not be appropriate to stimulate economic growth in the context of countries from the Global South (103: p.235, based on 104).

It should be further noted that addressing climate change and compatibility with global climate goals (e.g. the Paris Agreement of 2015) does not allow countries from the Global South to replicate the transition patterns of developed countries. This includes the manifestation of achievements. Once again, it questions the replicability of the economic transformation of China, which relied heavily on fossil fuel-powered energy consumption. Thus, homogenisation in the sense of the adoption of current and past (western) (energy) consumption patterns and lifestyles is not a sustainable, durable solution (see 50).

Since the late 1990s, holistic approaches to poverty reduction and rural electrification have started to gain attention. This has implied a shift from the focus on grid extension and low tariffs toward multidimensional approaches that include decentralized, off-grid technologies but also the support of activities beyond electrification (105). Among these are awareness campaigns such as training on the usage of electricity or financial mechanisms that simplify payment and the acquisition of appliances (105, based on 106). Public-private partnerships in rural electrification projects and new business models overcoming barriers of low connection rates (e.g. PAYG) have since gained importance.

Nowadays, there is a broad consensus on the important role of (endogenously given) improved technologies, learning, and innovation for the enhancement of economic performance (55: p.9, 7, based on 107, 108, 70). In the process of “learning through innovation”, however, the technical, societal, and institutional contexts should be considered in order to promote economic development (103: p. 229).

The African Union (8: p.74) identifies a potential for economic development in “Industry 4.0”, triggered by technological developments and digitalisation that could allow African entrepreneurs to enter “new modes of production” and gain better access to global markets. However, the opening up of these opportunities requires comprehensive investments in “technological infrastructure that enhances innovational systems” (8: p. 74). Conversely, as in the industrialized world, digitization can also mean that many jobs will be automated in the future, which can pose a threat to existing jobs in the second economic sector (8: p.75).

In relation to energy system transitions, this implies that advances in technologies could counterbalance some of the challenges faced in the energy sectors. Yet, the transition and/or the expansion of current (sometimes inert) energy system infrastructure requires high investment and time, among other factors, because it must be able to deal with the abovementioned slow institutional capacity development. Energy system transition should therefore take local conditions into consideration (103). On the other hand, new research suggests that electricity access gains are not necessarily only dependent on targeted policy measures (such as grid extension), but rather have arisen from endogenous sources (such as private markets and private companies, partly also with donor support). Despite institutional and regulatory barriers, two of the most vibrant off-grid energy markets in the world recently emerged in Kenya and Tanzania (10). This is at least partly reflected in the increased role of off-grid energy systems and their impacts on the pre-grid-electrification statuses of households and micro enterprises, as studied in Chapters 6 and 7. This development also stresses the importance of technologies and innovations that evolve more independently from institutional frameworks. The next section discusses the conceptual development from macro to micro measurements of human wellbeing.

2.3 From macro to micro measurements – conceptual approaches to development

“GDP measures everything ‘…except that which makes life worthwhile.[5]’”

Nowadays, it is widely agreed that economic growth does not necessarily go hand-in-hand with increased prosperity and/or human wellbeing and welfare (55: p.13). Whereas “income growth” may be perceived as a “key instrument to achieve higher wellbeing” by enhancing the “wellbeing of selected segments of the population” [6] *not* at the expense of others (69, based on 110), it may be inadequate to

[5] (18: p.7, based on Robert F. Kennedy’s speech at the University of Kansas, March 18, 1968)
[6] In their study from 2013, Dollar et al. (109) have shown that three-quarters of the income growth of the bottom 20% is attributable to general economic growth (69: p 70 based on Dollar et al. (2013) 109).

capture the whole complexity of human well-being. For example, there are several non-tradable (public) goods and services that are of significant importance to wellbeing and economic welfare and are difficult to measure in monetary terms (e.g. peace, safety, and liberty) (111, 112). Measurements on economic output expansion, which are mainly derived from "estimates and survey data maintained in a country's System of National Accounts (SNA)" (18: p.4) therefore lack essential information. Yet the System of National Accounts is still a global standard for measuring economic activity.

A recent report from the OECD revealed that the recent economic growth of African countries was correlated to well-being indicators to a lesser extent compared to the rest of the world (8: p.41). What do these findings imply for the application of traditional concepts aiming to describe and compare welfare between nations? And what do the OECD results say about the relationship between economic output expansion and the development of human wellbeing?

It seems that socio-economic processes do not take place uniformly across boundaries in space and time. In the Stiglitz-Sen-Fitoussi Commission report from 2009 (113), Stiglitz et al. note that traditional measures of economic performance are insufficient to reflect structural changes, the rapidly changing quality of products and services, the distribution of income, consumption and wealth, and non-market activities. Conventional measures fail to describe societies' (or individuals') progress and their social, economic, political, and environmental challenges. The reliance on solely conventional economic concepts, measuring market production – economic performance – in monetary terms as an indicator for well-being and sustainable economic evolution is out-dated: "GDP is an inadequate metric to gauge well-being over time particularly in its economic, environmental, and social dimensions, some aspects of which are often referred to as sustainability" (113: p.8). Thus, conventional development indicators are commonly perceived as being too flawed to provide instructive guidance for decision makers. Instead, there should be measures whose metrics take into account the heterogeneity of countries (e.g. the abovementioned geographic conditions) and address political (including government and services), social and environmental sustainability (55: p.13). The issue of equitable and democratic development should also be considered in the reflection of societal transformation (55: p.5).

A rough overview of the development of important conceptual steps in describing human wellbeing and welfare is given in Figure 6. Traditional welfare concepts include aggregated measures such as those on the GDP, GNP or GNI (per capita).

The idea of transformative concepts that go "beyond GDP" goes back even further than the Stiglitz-Sen-Fitoussi Commission report from 2009 (113). The 1970s and the emerging notions of "basic needs" and quality of life indexes are cited as starting points for the development of more complex concepts on human well-being (114, 115). In contrast to merely focusing on income or economic output, these early concepts on basic needs went beyond and suggested the inclusion of measures on "access to food, water, shelter, clothing, sanitation, education and health care" (115: p.34) when studying the progress of societies. In his essay from 1978, Morris (114: p.34, based on 116: p.226) noted that the "trickle down" effects of (slow) income growth on the wellbeing of the poorest did not materialize, particularly in developing countries. Moreover, he observed that indicators of wellbeing and income growth seemed to be less correlated. Aiming to address the constraints of traditional welfare concepts, he introduced his idea on the “Physical Quality of Life Index (PQLI)”, which ranks countries based on their composite measures on literacy, infant mortality, and life expectancy.

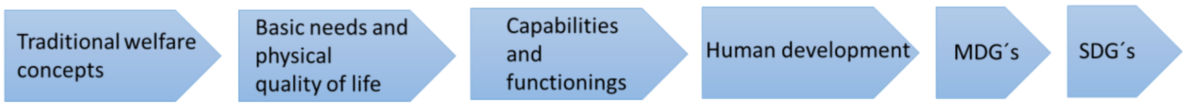

Figure 6. From GDP to SDG

Source: Author’s elaboration

Official measurements on human development achieved conceptual depth with the inclusion of a more humanistic perspective and the “enlargement of choices” that “go well beyond traditional liberalism” by emphasising the need for actions to “strengthen human capabilities” (117: p.2, 118: p.10). The capabilities approach (“capabilities and functionings” in Figure 6) by Sen (119) represents a key contribution to the conceptualisation of human development by placing an emphasis on the expansion of freedoms, which is derived from the improvement of human beings’ (individual and subjective) capabilities and their objective conditions (120, 69: p.69).

In 1990, the UNDP introduced the most prominent and still widely used welfare index to rank countries: The Human Development Index (HDI) (121). Covering the fields of health, education and standard of living, the index composites country-level indicators on life expectancy at birth, educational attainment, and PPP-adjusted per capita income to a single average index, whereby it attaches equally distributed weights to all indicators. The equal distribution of weights is regarded as one of the major weaknesses of the HDI from 1990 (122: p.15, 123). In 2010, the HDI definition was updated by including more indicators and shifting from an “arithmetic (additive) mean to a geometric (multiplicative) mean” (69, p.65). It thereby increased in significance because it “limits substitution possibilities across dimensions of basic needs” (69, p.65). Moreover, it is now adjusted to contain information regarding inequality. However, the abovementioned weakness concerning weighting is still present in the modified HDI (69, p.65).

Since 1990, several approaches have emerged capturing the multidimensionality of “human development” and aiming to replace conventional measures of wellbeing. Among the newer concepts are the Multidimensional Index of Poverty (MPI) (124), the Better Life Index from the OECD (125) but also the sets of global multiple goals, targets and indicators of the United Nations’ MDGs (126) and SDGs (127). The MDGs were perceived as “reductionist” and still follow a top-down approach by having a “narrow focus on meeting basic needs” and “a relevance limited to least developed countries” without considering local conditions and “structural and root causes of poverty” (128: p.8-9).

On the other hand, the SDGs are transformative and broader in terms of including many sectors and going beyond poverty reduction, aiming to “break out of the North-South political divide” (128: p.10). As discussed in Section 2.1, northern countries also suffer from a rise in socio-economic inequalities, such as income inequalities, and are also affected by ecosystem limits. Therefore, the “consensus global norm concerning both the ends and means of development” (128: p.5), the global agenda on the SDGs, not only refers to countries from the Global South but also encompasses the development of northern countries.

There is an on-going discussion regarding the prioritisation of SDGs and the overlaps between them. In their 2018 report, Randers et al. (49: p.36) note that in order to achieve the SDGs by 2030, decision-makers need to rethink their strategies and priorities. They conclude that following conventional growth-focused strategies only encompasses “weak incentives” to achieve all the SDGs. On the contrary, they determine that some progress will be made in terms of the eradication of poverty and hunger, but these targets will not be achieved until 2050 and come at the cost of other SDGs and planetary boundaries. Consequently, human wellbeing would be undermined in the long run. They therefore call for a systematic implementation of measures addressing SDGs that consider potential trade-off effects.

In general, it is still under debate whether the focus should be on comprehensive multidimensional indexes (such as the HDI or MPI), a set of indicators (such as the MDGs or SDGs), or a “dashboard” of isolated indicators (55, 113, 115) to monitor progress. Aggregated multidimensional (or “mashup” (129)) indexes have the advantage of simplifying the measurements to compiled indicators that allow a concise picture of wellbeing at a glance. However, their “mashup” character may not be useful for setting priorities in the development and implementation of policies (122). Additionally, composite indexes may lack essential information necessary to cover all the relevant dimensions of poverty (122).

On the other hand, a collection of multiple indicators may help to overcome these weaknesses, e.g. by providing more specific information on various dimensions of poverty that can be monitored independently from each other. However, these may be less concise than a single index and challenges regarding the heterogeneity of indicators and the selection of the indicator dimension level persist. Moreover, it should be noted that quantitative indicators are by nature “reductionist” because the quantification of a complex social reality only allows part of the “full social objective” to be depicted (128: p.7, based on 130, 131, 132). Furthermore, the process of quantification and measurement is constrained by data availability and the capacities and (financial) recourses required to collect and elaborate data (128), which is particularly a major barrier in developing countries (see Jerven (15, 26)). Newer data mining techniques (e.g. based on satellite imagery and Big Data analytics) are gaining importance in measuring different aspects of development (133).

To better reflect and understand the dynamics at the root, there is a call for a stronger emphasis on microeconomic behaviours and conditions to serve as a basis for the development of effective instruments for poverty reduction from the bottom-up (98). This call reflects the status quo of conceptual development described in Section 2.2, which includes behavioural economics.

More specifically, Duflo et al. (98) ask for randomized controlled trials (RCTs) to obtain a better understanding of the societal context, local conditions and needs. RCTs enable innovative development interventions to be experimentally tested, and can thereby give valuable insights into the effectiveness of interventions (134). They are particularly recommended for implementation if unobservable factors that change over time could have an influence on the impact of the intervention (134: p.47f.). However, RCTs are very difficult to conduct, or are simply not applicable on the macro level due to the requirement of random assignment and random sampling. This is why research methods addressing the macro level are rarely conducted in an experimental research setting (55: p.2). Furthermore, while the internal validity of the conclusions may be quite robust, the procedure may lack external validity by having “limited real world relevance” (134: p.45). Thereby, interventions that turned out to be successful in the area of investigation may not lead to comparable results in other development contexts (103, based on 135).

For the rollout of infrastructure projects such as rural electrification, experimental research methods, which randomly assign units to treatment or not, may be difficult to implement for political and ethical reasons. Non-experimental research methods or quasi-experimental methods help to overcome these constraints by simultaneously addressing the problems of endogeneity and are therefore more frequently applied in impact evaluation research on (rural) electrification.

Being based on a quasi-experimental method, namely PSM, the studies in Chapters 6 and 7 contribute to this research field. However, recently, despite the aforementioned concerns, experimental research designs have also become more popular in this research field (discussed in more detail in Chapters 6 and 7). The next section deals with the energy development nexus on the macro scale.

2.4 The energy development nexus on the macro scale

As previously discussed, despite the weaknesses of conventional concepts measuring economic performance and welfare, the implications of research findings based on these notions are still of the highest relevance as they continue to form the basis for policy measures, negotiations, planning, and so on. This is certainly also due to the fact that the database on newer concepts is still relatively thin and needs to be expanded, also with regard to countries from the Global South.

The motivation behind many electrification projects is to promote economic growth through increased energy production and consumption, which should in turn contribute to reducing poverty. The importance of energy is also reflected in SDG No. 7, which is interlinked with the development of many other SDGs (49: p.31). Vera identifies that 125 out of the 169 targets of the entire agenda on SDGs are associated with the goal to "ensure access to affordable, reliable, sustainable, and modern energy for all" (136: p.XII, based on 137).

On the other hand, measures to tackle climate change (such as decarbonisation) may impact economic activities and energy security. Thus, there is a need to understand and describe the mechanisms between energy consumption and economic output (expansion) in order to address questions of poverty reduction and energy efficiency and security in a sustainable manner.

Findings on causality are supposed to be key for the formulation of policies. For example, it is important to know what kinds of effects (if any) the actions addressing energy conservation or energy efficiency measures, such as Kyoto mechanisms and policies closely aligned with the Paris Agreement's long-term goals, may have on the economic power of implementing nations, or vice versa, how an economic recession may impact energy consumption. In particular, the latter plays a role in the context of the study carried out in Chapter 4, which takes into account the period of the global economic crisis of 2007/2008.

There is broad consensus that economic activity and energy usage are related (138), but there is doubt concerning the causality of the relationship. The nexus between energy and economic output, EGN, has been studied extensively in the last four decades (139: p.3)[7]. Likewise, the nexus between economic output and electricity consumption, a subsection of energy consumption, has been studied intensively with no uniform conclusions regarding the causality of this relationship (141, 142).

Typically, researchers studying EGN distinguish between four hypotheses to test the causal linkages between energy and economic variables: neutrality, feedback, growth, and conservation (141, 143, 144). In the case of support for the neutrality hypothesis, researchers have not determined a statistically significant causal relationship between the variables under detection. This finding implies that changes related to energy variables (e.g. caused by environmental policies) should have no impact, or only have a minor impact, on economic variables. For example, economic growth would not be hampered or promoted by changes in electricity consumption if it were only of minor (statistically not significant) importance for the development of economic output (145, based on 146).

In contrast, in the case of support for the feedback hypothesis, changes in energy variables impact the economic variables and vice versa. The factors are considered to be complementary and as behaving bi-directionally to each other. Due to the multiple interaction possibilities between the variables, (139: p.4) see difficulties in deriving 'specific' policy recommendations by only knowing about the significant existence of this type of relationship.

There is a unidirectional Granger causality running from energy to GDP in the case of support for the growth hypothesis: the development of the economy depends on energy. This direction of the relationship is in line with the perspective of ecological economists who consider energy as a critical input factor for economic output expansion (147: p.30). In this context, it is important to note that this

[7] The pioneering study on Granger causality between income and energy of Kraft and Kraft (140) is usually mentioned as a starting point in literature.

hypothesis may stand in stark contradiction to the empirical evidence of the decoupling effect (139: p.8), which describes the decoupling of economic growth from energy consumption in decarbonising economies. Bacon et al. (2) argue that some studies supporting the growth hypothesis are misleading in terms of interpreting energy conservation as being negatively associated with GDP expansion. Therefore, they call for the application of econometric methods that allow a differentiation of the reasons for energy conservation, such as “a shift along the production function” that has been promoted through technical progress, e.g. in terms of improved energy efficiency, or a shock in energy prices. Both cases may lead to lower energy consumption but may also have differing effects on economic output (2: p.30).

Conversely, the hypothesis on conservation describes a unidirectional causal relationship from GDP to energy. This describes the case where the economy is less dependent on energy, but energy usage is determined by the development of the economy and may be considered as an intermediate good (139). This is in line with the notion of mainstream economists who do not consider energy as a determining primary factor in economic production in any time period (139), as opposed to the factors of capital, labor and land (147: p.28, based on 148).

However, as mentioned before, findings concerning causality between energy consumption and economic output are not uniform across studies. Smyth and Narayan (2014) (149) in particular observe mixed evidence in studies testing Granger causality, which is also the focus of the study in Chapter 4, due to differences in model specifications, econometric approaches and institutional framework conditions in different countries. At least the application of an augmented production function model, which considers economic output as a function of capital, labour, and energy consumption, is currently a common standard in research on EGN (149: p.354).

Due to the large number of publications in the field that have largely heterogeneous results, some researchers argue that there is little to no added value to the sciences in further studies that study the relationship between energy and economic variables (149, 150).

However, upcoming studies introducing methodological novelties (described in more detail in Section 3.1) or dealing with more disaggregated data sets and new concepts are still considered valid contributions to research and important guidelines for policy measures (139). Research at the threshold between the energy sector and economic activity is still of the utmost relevance when taking into account recent developments, such as the electrification of the transport sector or the accelerated spread of innovative (energy supply-related) technologies (151). This also underlines the increasing role of electricity compared to other energy sources.

More recent research not only studies the nexus between energy variables and economic variables, but also considers environmental aspects and controls for regime shifts in forms of structural breaks in time series data (139: p.22, 149: p.354).

In line with the targets set by the Kyoto Protocol and the Paris Agreement, variables reflecting EGN include those dealing with renewable energy sources or environmental pollution (e.g. as an input or by-product of production) (2), whereas measurements of economic power also include newer concepts of GDP (152: p.151). The inclusion of environmental parameters (such as carbon dioxide and sulphur dioxide emissions) shows the proximity of research on EGN to research on EKC (Environmental Kuznets Curve), which describes research on the nexus between economic output expansion and environmental degradation (139: p.9).

Newer generation studies include more (refined) variables in their models, such as (international) trade, financial development (e.g. measured by foreign direct investment), pricing structures, population growth, urbanisation, and different energy types and fuels (e.g. electricity (as a tradable good)), but also less common indicators such as militarisation and tourism development (153, 149: p.354). As will be discussed in more detail below, frameworks that include more than two variables determining production and demand of GDP and energy (e.g. energy prices as control variables) are considered to be suitable for addressing potential biases (2).

Figure 7 displays the research framework of the study in Chapter 4. It deals with a bivariate research framework by analysing the relationship between per capita GDP and electric power consumption in Kenya. The arrows between the variables in Figure 7 symbolize the type of relationships in the sense of the hypotheses on growth, conservation, and feedback described above. It should be noted that electric power consumption represents a fraction of total energy consumption. Thus, the effects of energy consumption outside the power sector on Kenyan economic performance are not taken into account here. However, recent trends indicate that the importance of electricity in total energy consumption is expected to increase in the future (139: p.26).

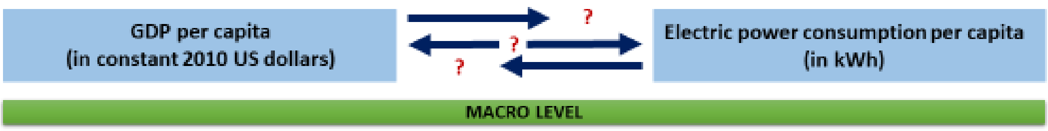

Figure 7. Bivariate research framework

Source: Author

The study in Chapter 4 delivers important insights into the research field, not only by relying on an enhanced econometric approach and considering an extended time period compared to other studies (discussed in more detail in Sections 3.1 and 4) but also because it represents a perspective that contrasts with the micro perspective. Thereby, the reader gains a comprehensive overview and understanding of the mechanisms that work on both levels.

One of the conclusions of the study in Chapter 4 is that more and disaggregated data is needed to get a profound idea about the conditions, drivers, and barriers at the bottom of economic development and its interplay with electricity. This is a particularly challenging task, because indicators should reflect activities, which, in the context of countries from the Global South, often take place in the hidden and informal sector. For example, in his study of Turkey from 2008, Karanfil (154) observed that differentiating between official GDP measures and proxies of unrecorded economic activities in research on EGN may lead to mixed results concerning the relationships, which questions the reliability of findings that are based on official data records. Furthermore, it should be considered that the aggregate of electric power consumption also includes consumption for (non-)productive uses (e.g. on the household level) that may not necessarily contribute to output expansion but improve the living quality and thereby contribute to poverty reduction. This underlines the importance of research conducted on the micro level, which will be discussed in more detail in the next section.

2.5 The electricity development nexus on the micro scale in the framework of the theory of change – from access to electricity to enhanced welfare

In research on the evidence of the impacts of (rural) electrification, researchers frequently refer to the theory of change to analyse and make explicit the (un-)intended causal effects (and spill-over effects) of electricity consumption on selected indicators for a defined population. 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. Both direct and indirect impacts of interventions describe the final stage of a causal chain and are, in contrast to outcomes, long term and can be negative or positive (134). Along the whole "result chain", assumptions play a crucial role and need to be specified at each step or linkage. The concept of theory of change allows multi-directional relationships to be taken into account, such as feedback loops and is therefore not restricted to a one-dimensional perspective (as also addressed in Chapter 7). Commonly studied impact indicators of electricity use are the income, education, energy expenditures/savings, health, and time savings of households, enterprises, and (public) institutions.

To get an idea of a framework in the sense of theory of change, Figure 8 shows a result chain (Author, based on 155: p.21). The analyses undertaken in the present work differ in terms of their levels, namely the macro and micro levels. As described above, on the macro level, this work examines the type and direction of the relationship between GDP and electric power consumption (see Section 2.4 and Chapter 4), while on the micro level, it assesses the impacts of electricity consumption on households and micro enterprises (see Chapters 5 to 8). As shown in Figure 8, electric power consumption theoretically has final impacts on human and private sector development through diverse channels; on welfare outcomes. Electricity is seen here as an intervention for the intervention´s "beneficiaries" – households, institutions, and enterprises.

The channels through which this intervention is supposed to become effective are manifold but, according to the way they are displayed and studied here, are assumed to be one-dimensional. The blue arrows indicate the relationships and links that are in the focus of the present study. The treatment outcomes studied in Chapter 6 and 7 encompass the (intermediary) outcome of lighting, namely study time of children after darkness, usage time of the most frequently owned appliances, energy expenditures, and operational time of microenterprises. In Chapter 8, the effects of electricity outages are studied in the context of lighting. It should be noted that the socio-economic effects of (grid) electrification may become effective at a much later time, which is why households may have higher inter-temporal discount rates than electrification planners. For example, parents may discount the effects of electrification on their children´s evening study time and their future income on a higher level than planners (156: p.5). This may lead to a substantial gap between electricity demand estimations and real electricity demand, a challenge that will be discussed in more detail in Chapter 9.

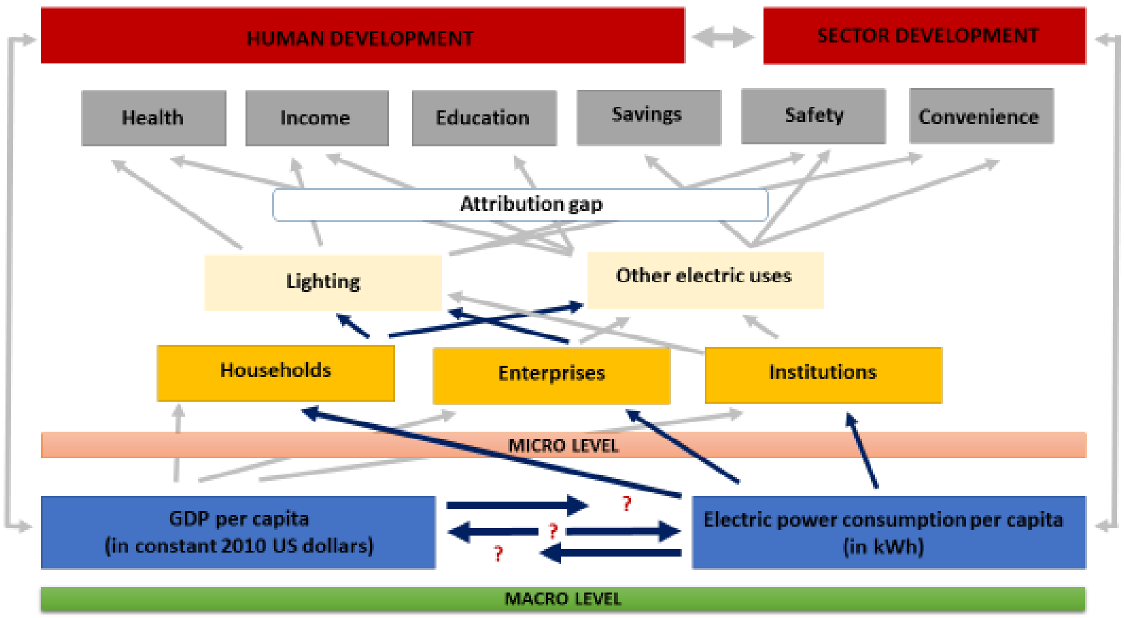

Figure 8. Result chain framework

Source: Author, based on (155: p.21)

3. Methodological foundation

3.1 Establishing causality and co-integration in the nexus between energy and economic variables

While there has been extensive research on co-integration and the causality linkages between economic variables and energy variables (141, 142, 144), there is still no consensus concerning the type and direction of the relationship. As recently critically surveyed by (157: p.356), the energy economics literature relies on myriad econometric methods to study the nexus, yet still with mixed results concerning causality and/or long-term relationships.

Methods to analyse co-integration and causal relationships in the field of EGN encompass bi- and multivariate research frameworks, deal with short- and/or long-term panel and/or time series data, and involve single- and/ or multi-country studies. Due to constraints on data availability, many researchers rely on studying the multi-country case by pooling (annual) time series data in the framework of panel models. For example, relying on a panel co-integration method (158), pooled annual time series data for energy consumption and economic growth for 40 SSA countries for the years between 1980 and 2007 were used to study the relationship on the regional level.

Table 3 displays an overview of the most popular methods applied in research on this field, these include the approaches used in this study in Chapter 4 (displayed here in bold).

Granger causality - **Vector autoregressive model (VAR)** - Vector error correction (VEC) - Autoregressive distributed lag bounds test (ARDL) - Bootstrapped - Pairwise - **Toda–Yamamoto** - Dolado - Lutkepohl
Sim causality
Hsiao causality
Co-integration - **Johansen–Juselius co-integration** - Engle–Granger
Dynamic panel estimation
Dynamic simultaneous equation panel data models
Panel causality
Panel data with structural breaks
Bootstrap panel unit root tests
OLS regression
Dynamic panel causality
Panel co-integration - Pedroni panel co-integration
Vector error correction model
Error correction model
Parametric and nonparametric test
Forecast error variance decomposition

Dynamic modelling	
Computable general equilibrium (CGE) modelling	

Table 3. Overview of the methodologies applied in research on EGN

Source: Author, based on (157: p.357-358)

According to Tsani & Menegaki(157), the application of CGE models has recently been on the rise to better reflect the complexities of the dynamics interacting at the threshold between energy consumption and economic output expansion. Thereby, a longer time period can be analysed and a disaggregation on the sectorial level as well as a representation of different interacting actors becomes possible (157, p.362).

Smyth and Narayan (149: p.356) propose that future research should study the regime-dependency of co-integration, long-run estimations, and Granger causality between energy and economic variables to identify whether the detected findings are tied to certain economic cycles. Furthermore, they propose that future studies should analyse whether the findings on these relationships change with time, and thus are time-varying. Smyth and Narayan (149) also suggest deepening the research knowledge in modelling the forecasting potential of energy variables, structural breaks, and non-linear data in existing research frameworks.

In their survey on meta-analyses examining the EGN literature, Hajko et al. (139: p.18) detected that research on the linkage between energy and economic variables is “subject to major methodological deficiencies, publication, and misspecification biases” (p.18). This has also been observed by Bacon et al. (2: p.27, p.31f), who identify an omission of (explanatory) variables and the misspecification of the models, which may lead to a misidentification of (non-causal patterns (see 159) as one of the greatest weaknesses of research done on the links between energy (or electricity) consumption and GDP.

Moreover, Bacon et al. (2: p.30f) attribute heterogeneity in results concerning causal relationships between energy and economic output to “simultaneity”. This describes the case where studies do not consider the possibility of reverse relationships but focus their model only on the “growth” approach. They further identify the non-stationarity of data, measurement errors, and heterogeneity as major sources of biases. The issue of heterogeneity arises when researchers rely on a panel research framework. Researchers have to ensure that the heterogeneity among the countries of the panel is taken into account to be able to derive meaningful implications on the country level.

Despite the call for more multivariate models to better reflect the complexities at the EGN (see 160 for example), those models may not be immune to error susceptibility. On the contrary, multivariate models may be vulnerable to “over-parameterization and loss of degrees of freedom”, leading to biases in estimations (149: p.356). Therefore, despite the abovementioned weakness of potentially omitting variables, the focus on a bi-variate model framework studying a single country can be advantageous, especially when dealing with a small sample size. It simplifies the process in order to derive insightful policy implications for the individual country under study.

The analysis on Kenya in Chapter 4 tests (non-)Granger causality via a VAR, modelling the economic functions, and the augmented Toda-Yamamoto procedure, which also takes into account structural breaks and statistical checks on the stationarity of time series data. To give further merit to the results, the study in Chapter 4 also conducts the Johansen–Juselius test on co-integration. Whereas model specification is comparatively simple, the study contributes to the literature by also considering shifts in the time series data, which includes the period of the global financial crisis. The consideration and modelling of structural breaks within the present research frameworks on EGN play and will play a key role in future studies (149: p.356).

Menegaki and Tsani (152: p.165-166, 161), identify different levels of research in the EGN literature. As displayed in Figure 9, on the first level they distinguish between studies dealing with aggregated and/or disaggregated energy consumption data. The study presented in Chapter 4 analyses the relationship between economic development and electric power consumption (see Figure 9), and therefore deals with a disaggregated level of energy consumption.

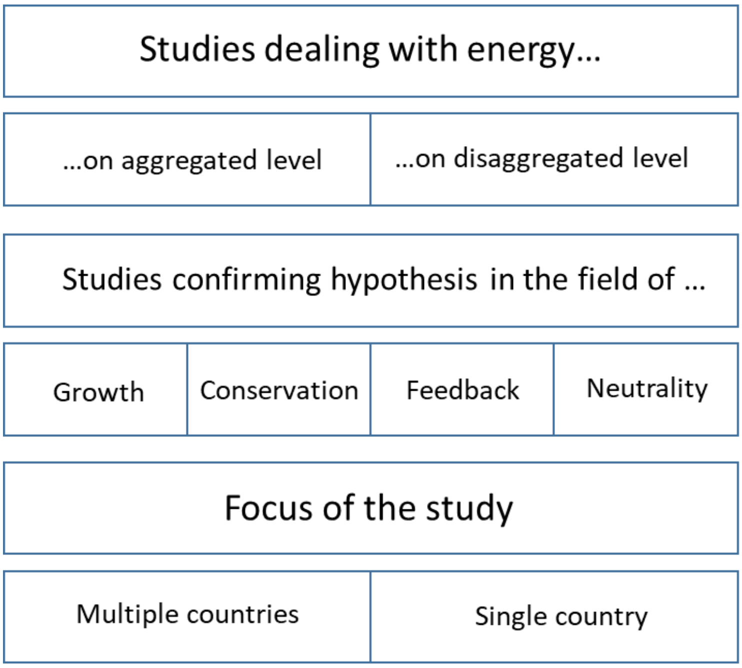

Figure 9. Different levels of research in the EGN literature

Source: Author, based on Menegaki and Tsani (152: p.166)

However, at this stage, it should be noted that disaggregation only refers to the fact that the indicator presenting electric power consumption forms a subpart of energy consumption and still consists of data on a highly aggregated level, which may hide or not contain essential information on electricity consumption (as reflected and discussed in Chapter 4 and section 2.2). As previously mentioned, it further does not include the effects of energy consumption outside the power sector.

Secondly, Menegaki and Tsani (152, 161) differ between studies that distinguish in terms of their findings the aforementioned four hypotheses, for which many EGN papers test. Following these criteria, the study in Chapter 4 belongs to the supporters of the neutrality and growth hypotheses. Moreover, being based on the case of Kenya, the study presented in Chapter 4 belongs to the group of single-country studies. Menegaki and Tsani (152: p.148, p.150) advise considering single-country studies as "equally important" compared to multi-country studies when dealing with low-income countries because of the implications of the studies' results for national policy making, which may not be universally applicable across countries.

The case study of Kenya becomes particularly important when one takes into account the fact that cases from developing countries are studied with much less frequency (see 141, 149). Therefore, being a single-country study, the findings and implications can be transferred to countries with similar geographical, "energy and economic traits" (p.362), such as the Sub-Saharan East African country Tanzania (152: p.362). The next section concerns the theoretical foundations of the micro perspective of this thesis.

3.2 Evaluation problem

The attribution gap displayed in Figure 10 describes one of the most challenging problems for impact evaluation researchers: the situation in which researchers are not able to clearly 'attribute' the impact to 'only' (or even at all) to the previously given input in order to isolate the genuine, causal effect of an intervention from other influencing factors. The major purpose of a rigorous impact evaluation is to "attribute the effectiveness" of an intervention, which can be achieved by comparing the actual scenario to a counterfactual situation (134, p.4).

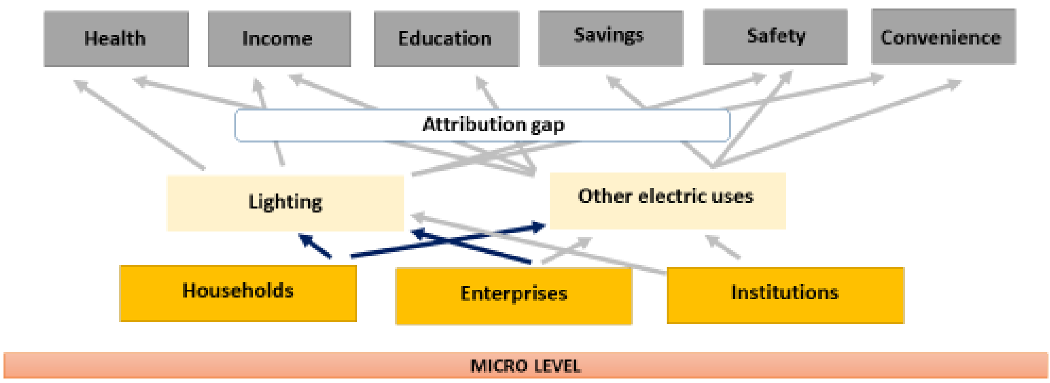

Figure 10. Research result chain framework – micro level

Source: Author, based on (155: p.21)

Figure 11 illustrates the idea of a quantitative impact evaluation (134). It describes one of the greatest challenges that researchers face when dealing with an ex-post impact evaluation of an intervention at the time t+1: The identification of the outcome measure Y^{0}_{t+1} of the counterfactual scenario, which describes the situation in the absence of a treatment or an intervention, is – in contrast to the post-intervention outcome measure Y^{1}_{t+1} – unobserved. Conversely, the observed outcome Y^{1}_{t+1} may be distorted by the impacts of unobservable factors (confounders).

For example, observable or unobservable (personal) characteristics and contexts may lead to placement and selection biases. There is placement bias when the intervention was not randomly addressed to the participants but, for example, intentionally placed following a political plan. Selection bias happens when participants select themselves to be recipients of the treatment. Further, there could be spillover effects running (in-)directly from the treated to the counterfactual units. However, the actual outcome or causal effect that is solely attributable to the intervention (illustrated by the "impact" in Figure 11) is described by the difference between Y^{1}_{t+1} and Y^{0}_{t+1}. To be able to estimate the causal effect(s), the impact evaluators need to establish a profound statistical framework that allows them to identify valid counterfactuals by overcoming the aforementioned bias(es).

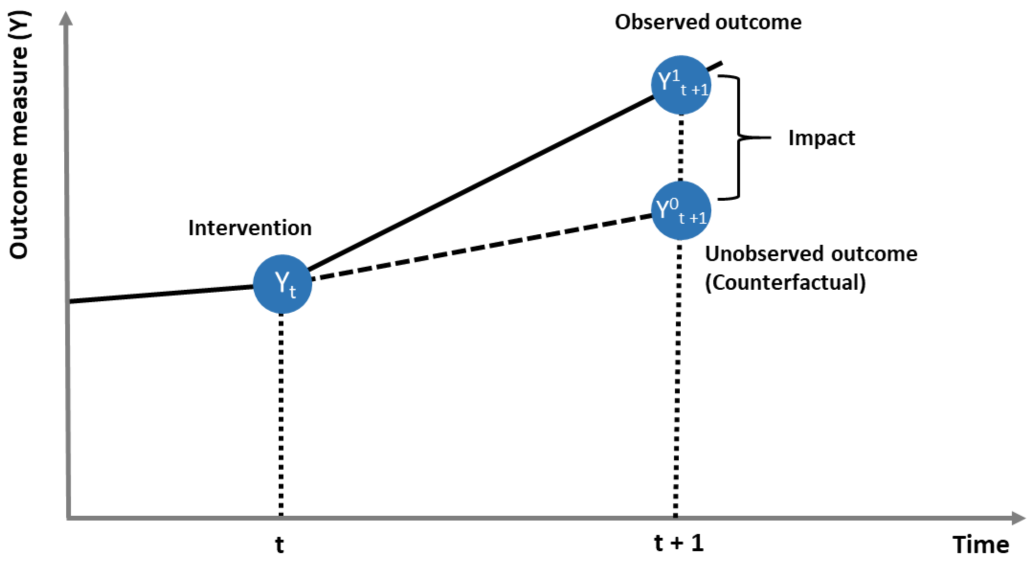

Figure 11. Idea of a quantitative impact evaluation

Source: Author, based on (134: p.32)

Researchers must ensure that counterfactual units are as identical as possible to the treated units. This is certainly not possible with the same observational unit; an intervention cannot be studied in two different situations at the same time or before and after an intervention where all parameters are fixed and no changes have occurred.

Equally, simply comparing units with and without exposure to the intervention is highly complicated due to differing initial characteristics and contexts of the units that may not be observed. Simple with- and without or before and after comparisons (so-called reflexive comparisons) are not adequate to capture outcomes that can only be attributed to the treatment, even if there may be a correlation between the intervention and the outcome observable (134). Rosenbaum et al. (162: p.41) define this as a "missing data problem". It is also specified as the fundamental problem of causal inference (163). For that reason, effects cannot be studied on the individual level and the evaluation problem is commonly addressed at the population level (164).

Methods of impact evaluation addressing the challenge of identifying appropriate counterfactuals include experimental designs, quasi-experimental methods, and regression-based approaches, but also qualitative methodologies such as participatory impact assessments (134).

Theoretically, the most suitable research design to tackle bias and influencing factors is randomly chosen research units, however, practical research cannot always achieve this. As mentioned in Section 2.3, in research on (rural) electrification, an experimental research framework, such as simple RCT, is difficult to implement due to ethical reasons, e.g. when a household is randomly assigned to gain access to electricity whereas another is not. This may also be one reason why experimental research on the impacts of (rural) electrification is still limited (105). However, cluster RCTs can help overcome this weakness by assigning the intervention on a higher level, e.g. the village or regional levels. Yet, political problems can arise at this level of assignment. Moreover, this approach cannot be applied ex-post intervention (or only in cases of encouragement designs) (134). Nevertheless, recently, there has been an increase in research work done on the experimental level (165).

Non-experimental methods that address the identification of counterfactuals encompass quasi-experimental research methods and regression-based approaches. Quasi-experimental research methods to establish counterfactual or comparison groups include, propensity score analysis (PSA), difference-in-differences (DiD), synthetic controls and regression discontinuity designs. PSA is in the focus on this paper (Chapters 4 and 5) and is discussed in more detail in the next section.

3.3 Theoretical foundation – propensity score analysis

An experimental research framework is rarely applicable in the present research setting. Ex-post electrification data from the Mufindi study (Chapters 5 to 8) does not allow treatment and control groups to be established for the purpose of treatment effect analysis. Therefore, two studies in this thesis (Chapters 6 and 7) rely on propensity score analysis (PSA). PSA encompasses propensity score matching (PSM), propensity score stratification (PSS) and weighting (PSW), but is here limited to PSM. PSM is based on the "potential outcome approach” or Roy-Rubin-Model (166: p.33, based on 167 and 168) and can be seen as a “provider of imputations for the potential outcomes” (169: p.100).

The PSM method allows the construction of one or more statistical counterfactual(s) or comparison group(s) based on the calculated probability of participating ("balancing score" or "propensity score") in the intervention (here (mini-)grid-based electrification). For that purpose, researchers need to identify the units (e.g. individuals, households, enterprises, communities, region, etc.) that share pertinent observable (pre-treatment) characteristics that are not affected by the intervention. These observable characteristics or observed covariates are assumed to reflect the probability of being exposed to the intervention, and thus affect the treatment selection, and to have an effect on the outcome.

In the case of many covariates, it is not possible to match all of them because of the "curse of dimensionality". In order to address this limitation, Rosenbaum et al. (162: p.43) suggest calculating the balancing scores as vectors of these determinants. The propensity score is the "conditional probability" on which units have the same probability to be either part of the treatment or the control group. Two crucial conditions that have to be fulfilled to establish a valid PSM are the conditional independence assumption (CIA) and condition on common support (CCS).

3.3.1. Conditional independence assumption (CIA)

Factors that are not observed should not have an influence on the intervention. Consequently, they should not have an impact on the outcomes, which is the so-called conditional independence or un-confoundedness (166: p.35, based on 170 and 162). The assignment to the intervention should be strongly ignorable (162: p.43).

Ideally, there should be no systematic differences between comparing the participating and non-participating units before the intervention. It is therefore of essential importance to collect data on a highly informative level[8], which in the best case should not change over time and come from the same sources (171), such as the same questionnaire being applied (166). Given the observed covariates, it implies (162, based on 172: p.2):

$$(Y_{i1}\ ;\ Y_{i0}) \perp z_i \mid x_i. \tag{1}$$

3.3.2. Condition on common support (CCS)

Given the balancing score b(x), Rosenbaum et al. (162) assume that the conditional distribution of the pre-treatment characteristics x is the same for treated and non-treated units:

$$x \perp z \mid b(x). \tag{2}$$

This condition forms the basis for the matching procedure and ensures a meaningful comparison between the treated and non-treated units. The condition on common support implies that there should be as much coincidence as possible in the distribution of the propensity scores of participating and non-participating units. Units with the same observed covariates X have a positive probability of being both participants and non-participants. Thereby, the researcher can identify matching (non-)participants. If

[8] Highly informative data describes here the pre-treatment characteristics of households and enterprises that need to be collected to be able to construct comparison groups (e.g. household conditions).

this condition were not to be fulfilled, the outcome of the unobserved units would not "even logically exist" and the treatment effect could not be estimated.

3.3.3 Average treatment effect

The calculated mean difference between the outcomes of these two matched groups is interpreted as the (population) average intervention or treatment effect. In line with Rosenbaum et al. (162: p.43), the estimation of the effect is defined as an "unbiased estimate of the average treatment effect" (ATE), and the expected difference in the group responses to treatment or non-treatment as:

$$E(r_1) \mid z_i = 1 - E(r_0) \mid z_i = 0; \qquad (3)$$

where E describes the expected values in the population and r_1 or r_0 describe the responses r of the units being treated z_i = 1 or not having received a treatment (also called control units) z_i = 0. Units have been selected randomly. This can also be written as:

$$E(Y_{i1}) \mid z_i = 1 - E(Y_{i0}) \mid z_i = 0; \qquad (4)$$

where Y_i describes the expected outcomes.

However, as this study deals with the 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):

$$E(Y_{i1}) \mid z_i = 1 - E(Y_{i0}) \mid z_i = 1; \qquad (5)$$

treatment effect for treated unit i = outcome_i (observed) - outcome_i (unobserved) or treatment effect for non-treated unit i = outcome_i (unobserved) - outcome_i (observed), where only the expected observed and potential outcomes Y of the units being treated z_i = 1 are considered.

On the other hand, there are also the treatment effects of the units not being exposed to the intervention, the "average treatment effect on the untreated" (ATC), which is:

$$E(Y_{i1}) \mid z_i = 0 - E(Y_{i0}) \mid z_i = 0; \qquad (6)$$

where only the expected observed and potential outcomes of Y of the units not being treated z_i = 0 are studied.

In a totally randomized setting and in experimental research, ATE, ATT and ATC are equal and therefore interchangeable. However, in the present research setting, the types of treatment effects could differ substantially due to the aforementioned presence of selection bias, which includes hidden and non-observed biases. This is also why a subsequent sensitivity analysis rounding off the analysis is of crucial importance (169: p.11, based on 173 and 162).

Furthermore, an estimation of the ATE in the population may not be the focus of many researchers because they could also include (non-)participants that are not eligible or not targets of the treatment or program to be studied (e.g. if a program addresses only low-income households, the random inclusion of high-income households in the estimation of impacts may not reflect the intention of the intervention (166: p.34, 164: p.443f). Therefore, the ATT are the most frequently studied treatment effects in development research (169) and are also the focus of the present thesis. The next section describes the steps involved in PSM.

3.4 Implementation – propensity score matching

The implementation of PSM involves several steps (see Figure 12 below) and followed the procedure given by Leite et al. (169). The analysis starts with the identification of covariates for the estimation of the propensity scores. The model specification has to fulfil the aforementioned criteria of CIA. The next step involves the estimation of the propensity scores, which are based on the specified covariates. Then, the units are matched to their propensity scores. In the case of binary treatment, which refers to the cases studied in chapters 6 and 7, participating and non-participating units are matched based on their single propensity score. By matching processes, a comparison of the effects of the intervention on participating and non-participating groups becomes possible.

Figure 12. Implementation steps in PSM

Source: Author, based on (166)

The propensity score analysis in Chapter 6 puts its focus on the “genetic matching” procedure, while in chapter 7 the study applies different matching methods. 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 into the group of observations for further matchings. Additionally, the “greedy matching” methods applied here consider a caliper of 0.25 standard deviations. Within this caliper, the methods look for the nearest propensity scores of un-treated units to be matched to the propensity scores of treated units. This is why the methods are also known as a “nearest neighbor within caliper matching procedures”. The study in Chapter 7 also conducts “genetic matching” based on covariates and propensity scores “with replacement and no caliper” and “optimal matching”. According to Leite et al. (169), “greedy matching” does not strive for optimal matching, thus matching quality is not the focus of this specific method. However, the use of the “greedy matching” method is advantageous as less stringent assumptions have to be fulfilled. On the other hand, “genetic matching” and “optimal matching” ensure a higher matching quality (169). The next step involves checking the fulfilment of CCS. If enough common support is identified, checks on matching quality or on covariate balance and estimation of treatment effects follow. Finally, the results are examined with regard to their robustness by relying on a subsequent sensitivity analysis.

4. The relationship between electricity consumption and affecting factors under the perspective of non-Granger causality in Kenya

The relationship between electricity consumption and affecting factors under the perspective of non-Granger causality in Kenya

Annika Groth
Interdisciplinary Institute for Environmental-, Social- and Human Studies
Department Energy and Environmental Management
Europa Universität Flensburg, Munketoft 3b, 24937 Flensburg, Germany
E–mail address: annika.groth@uni-flensburg.de

ABSTRACT

Kenya is one of the fastest growing economies of the African continent. In 2014, nearly 36 % of the total population had access to electricity. Although electric power access is still far away from universal in the country, analysis of time series data shows that electrification in Kenya is taking place at a faster rate than ever before. Time series data can often be interrupted by events, which need to be reflected in the process of analysis. This is rarely done in research on Sub-Saharan Africa. This paper analyses the causal relationship between GDP and electric power consumption per capita using time series data from 1971 to 2014. To test that relationship, the study makes use of the augmented Toda Yamamoto non Granger causality and Johansen cointegration tests. The study also controls for structural breaks and allows for non-stationarity in the time series data. No causal relationship between GDP and electric power consumption per capita for the whole period in Kenya is detected. The cointegration analysis that controls for a break confirms the results for the whole sample of Kenya. These results indicate that, electric power saving policies or electricity shortages should not have a negative impact on GDP. However, a uni-directional relationship running from electric power consumption to GDP is established when a subsample, encompassing the period between 1971 and the identified break year of 2000, is studied. Based on this finding, electricity shortages or saving policies might have negative impacts on economic output expansion. Controlling for structural breaks is critical to achieving robust results. Knowledge of the causality between electricity consumption and economic output growth while considering the presence of structural breaks facilitates the work of planners, regulators and investors with respect to electrification planning. More disaggregated data is needed to better reflect real electricity consumption and the ongoing economic transition in Kenya.

Keywords

(Non-) Granger causality, Toda Yamamoto procedure, Cointegration analysis, Structural breaks, Sub-Saharan Africa, Electric power consumption, GDP

Nomenclature

t	period expressed in years
y_t, x_t	variables modeled in the VAR in year t
a, c	constants
p	number of lags
ε	error term
$\alpha, \beta, \gamma, \delta$	lagged coefficients
m	maximum order of integration
n	number of structural breaks
$t_{k,t}$	simple linear time trend
Δ	first -difference operator
$ElecPower_t$	electric power consumption in period t
GDP_t	Gross Domestic Product in period t
t^*	break point period
c	linear trend
$i_{2,t}$	dummy variable
$d_{2,t}$	dummy variable
k	maximum lag length

1. Introduction

On a global level, electrification rose from below 75 % in 1990 to approximately 85 % in 2014 and is projected to increase to 91 % in 2030 ([1] based on IEA's New Policies Scenario). However, in 2014, more than 1.061 billion people worldwide - half of them located in Africa (excluding Northern Africa) - still lacked access to electricity [1]. In some African regions, electricity access gains have been outpaced by population growth, which is why only slight achievements have been made since then.

Kenya is one of the least electrified in Sub-Saharan Africa. After recovering from the global financial and domestic crisis in 2008, only more than a third of the total population in Kenya - approximately 36 % - had access to electricity in 2014 [2] [5]. With a total of 2299 MW of installed power capacity, power capacity is still very low in Kenya. The major share of electric power in the country (80%) is generated by hydro and geothermal sources, which generate more electricity than fossil fuels (19 % in 2015) [3]. The electricity sector faces numerous challenges, such as the effects of droughts and low water levels, frequent power rationing, and blackouts. However, Kenya is recognized as a country where electrification rate is most steeply rising [4].

This sharp increase in the rate of electrification fits with the recent economic achievements made. In 2014, Kenya crossed a threshold and is now classified by the World Bank as a middle lower-income country. The country is perceived as "the economic, financial and transport hub of East Africa" [5]. Counting for more than half of the generated GDP in 2016 [5], the service sector has recently gained importance as a contributor to GDP. Until now, the final electricity consumption from commercial and public sector has been limited, with approximately 15 % of the total electricity consumption in 2014 [6]. Most electricity is consumed by the industry sector, even though the latter accounts for less than a fifth of the GDP [5].

This raises the question of how economic transition and changes in electricity consumption might impact each other. If a causal relationship between these variables can be detected, it would be interesting to know what kind of implications can be derived from the confirmed direction of causality. From the perspective of energy, environmental and economic policy, it is essential to know about the direction of the causal relationship between GDP and electric power consumption in order to adapt policies accordingly. This is especially important in developing countries, where the reduction of poverty and universal access to electricity are major policy goals. Tackling climate change and the transition to a low carbon future requires adapting or implementing systems that allow global emission targets to be achieved. Thus, it is of crucial importance for decision makers to know how specific policies that have an influence on electric power consumption might impact on economic output, or vice versa.

The causal relationship between energy and economic variables has been extensively studied, not only in developed countries but also in developing ones. A starting point of reference is the study by [7], who detected a one-directional causality running from economic output to energy or electricity consumption. This study prompted numerous papers in this field, which have been summarized by several authors, including [8], [9], [10] and – recently - by [11].

However, to date no consensus has been reached regarding the direction of this relationship. On the one hand, the divergent conclusions reached by these studies can be attributed to the different econometric methodologies applied, including different model specifications and assumptions, as well as from omitted variables, misspecifications, different sample sizes, and the impact of the latter on sampling variability and context-specific dependencies, such as diverging stages and structures of economic development [12], [13], [14], [15].

On the other hand, developing countries in particular are frequently affected by adverse shocks, for example through institutional changes, political tensions, macroeconomic instabilities or sudden energy supply shocks. Time series data might reflect these events. Researchers agree that structural breaks in the data set influence the validity of test results and that not controlling for them might lead to misleading results and biased inferences. Yet, research on causality between economic and energy variables controlling for structural breaks is more commonly undertaken for industrialized countries [16], [17], [18], and less for countries from the global south [19], [12], [20].

The present study contributes to the literature by assessing the relationship between electric power usage and the GDP in Kenya between 1971 and 2014, with and without controls for a structural break. An augmented Toda Yamamoto procedure for times series data [21], [22], based on [23], is used to test on non-causality between the two variables. Ordinary unit root tests, such as the augmented Dickey-Fuller test (based on [24], [25]), the Phillips-Perron test (based on [26]), or the Kwiatkowski–Phillips–Schmidt–Shin test (based on [27]) are combined with the Zivot-Andrews (based on [28]) and the Perron unit root tests (based on [29]), which allow one structural break to be included in the data set, to control for the presence of unit roots and structural breaks and the stationarity of the variables. For a valid cross-check of the results from the augmented Toda Yamamoto procedure, a cointegration analysis based on Johansen et al. [30] is additionally implemented.

The remainder of this paper is structured as follows: The next section (Section 2) contains a literature review. Section 3 introduces the methodology and describes the data and model. Section 4 reveals and discusses the results and findings of the empirical analyses. Section 5 concludes and gives an outlook.

2. Literature review

The following hypotheses, describing the type of relationship between energy or electricity consumption and economic output, are commonly identified in energy-growth literature: *Growth or conservation*, describing the unidirectional relationship; *feedback*, describing a bidirectional relationship; and *neutrality*, where no relationship between the variables is detected at all. The Granger causality approach [31] is one of the most popular methods for studying the nexus between energy consumption and the GDP [22]. However, as will be discussed more in detail below in section 3, this approach suffers from some weaknesses. As a result, more recent research in the field has tended to focus on the Toda Yamamoto procedure.

For instance, Kumar et al. [32] relied on an autoregressive distributed lag (ARDL) approach and the Toda Yamamoto method to investigate the long-term relationship between output per worker, capital per worker, and output per capita energy in Kenya and South Africa from 1978 to 2009 and 1971–2009, respectively. In terms of causality, they detected a unidirectional causality running from energy per capita and capital per worker to output per worker, which supports the growth-led hypothesis. They also established combined effects of capital stock per worker or output per worker and energy per capita on output per worker or capital stock per worker. However, no events interrupting time series data have been considered here.

Wolde- Rufael [33] investigated the long-run and causal relationship between economic growth and electricity consumption in 17 African countries using data from 1971 to 2001: The modified Granger causality procedure did not reveal a causal relationship between GDP per capita and electricity consumptions in Kenya. Additionally, the study did not establish a long-run relationship - a cointegration - between the two variables for the case of Kenya. The study stresses that, in many Sub-Saharan African countries, access to electricity is limited and the indicator measuring it may not reflect the activities of many small and medium enterprises which rely on other energy sources. Hence, results based on this indicator must be interpreted with caution, as will be discussed in section 5 below. The effects of the presence of structural breaks was not considered in [33].

Relying on a bootstrap-corrected Granger causality test and second generation of panel unit root and cointegration tests while accounting for multiple structural breaks and cross-sectional dependence in eleven Sub-Saharan countries, Hamit-Haggar [34] established a long-run and a unidirectional causal relationship running from clean energy consumption to economic output expansion for the case of Kenya for the period from 1971 to 2007. Based on the findings, Hamit-Haggar [34] argues for the promotion of clean energy sources to strengthen sustainable economic development.

Akinlo [35] investigated the cointegration and Granger causality between energy consumption and economic output expansion in eleven Sub-Saharan countries from 1980 to 2003, using the autoregressive distributed lag (ARDL) bounds test and Granger causality approach, and without considering structural breaks. For the case of Kenya, the study identified support for the neutrality hypothesis between the two variables, and a significant and positive long-run effect of energy consumption on economic growth.

In his 2010 study, Esso [20] used a procedure on threshold cointegration and the Toda Yamamoto approach while controlling for structural breaks to analyse the causal relationship between energy consumption and GDP between 1970 and 2007 in seven African countries. Esso [20] did not detect a causal relationship between energy usage and economic output for Kenya.

Dealing with a tri-variate framework, Mensah [36] studied the long-run and causal relationship between energy consumption, economic output and carbon emissions while controlling for structural breaks in six African countries from 1971 to 2009. Using the Gregory and Hansen cointegration and Toda Yamamoto approach, the study established a threshold cointegration in Kenya when real GDP is treated as an endogenous variable. Mensah [36] did detect a positive and significant impact of real GDP on energy consumption while controlling for a break. On the other hand, the study established heterogeneous results concerning the impact of energy consumption on real GDP when a regime shift in 1983 is considered. Furthermore, the study identified a uni-directional causality running from energy consumption to economic growth and underlined the importance of energy policies that should strengthen the energy sector and thereby drive the economic output expansion.

In [20] and [36], time series data at hand is limited from 1971 to 2007 and 2009, and might not reflect the situation in Kenya after 2007/2008 in an appropriate manner. The present paper can be seen as an extension of [20] and [36], as this study also includes the period after the global financial crisis of 2007/2008 up to 2014, thereby increasing sample size and addressing the potentially adverse impacts of the domestic and global financial crisis. The year 2008 was critical for the Kenyan economy. Even though the economy is mainly agro-based with a large informal sector, it was also affected by the global financial crisis. More importantly, it was heavily impacted by its own domestic crisis, stemming from the civil unrest following the presidential and parliamentary elections in December 2007 [37].

In a recent paper, Esso and Keho [38] studied the threshold cointegration and causal relationship between energy consumption, carbon emissions and GDP in 12 selected Sub-Saharan countries from 1971 to 2010. While overcoming weaknesses of other papers in the field by making use of the bounds test of Pesaran et al. [39], they did not control for structural breaks. For the case of Kenya, Esso and Keho [38] established that economic growth causes higher energy consumption, but no short-run causality between the variables could be detected.

From a methodological point of view, this paper drew on the findings of [40], who studied the Granger causality between energy consumption and economic growth in eight European countries using the Toda Yamamoto Procedure and a cointegration analysis. Here as well, the analysis did not produce uniform results with respect to the relationship between the two variables in the different countries under study, even though it also controlled for structural breaks. Contrary to studies focussing on developing countries, for this study long-term data was available, potentially leading to more robust results. The study stresses that policy development- especially that which aims to effect an environmentally sustainable economic output increase - should use research that analyses the causal relationship between economic growth and energy consumption while also controlling for structural breaks. The approach described in the following has earlier been presented at the conference held in Dubrovnik, October 2017 [41].

3. Methodology

3.1. Data

Annual data for the country on electricity consumption per capita (in kWh) and GDP per capita (in constant 2010 US dollars) was obtained from the World Bank's World Development Indicators [2]. The data covers the period from 1971 until 2014. Electric power consumption per capita measures electricity usage divided by the mid-year population, while economic performance is measured by gross domestic product also divided by mid-year population.

3.2. Model

The empirical analysis studies the relationship between electric power consumption and GDP per capita in Kenya. One variable or indicator might be predicted with more accuracy by also considering the lagged values of other variables that influence the variable in question. To study the direction of the relationship between the variables, this study applies a Granger non-causality test with annual time series data from 1971 to 2014. Because simple Granger causality tests might suffer from bias (es) [22], [42], [43], the paper applies the Toda Yamamoto procedure, which is a revision or augmented version of the Granger causality procedure and implements Granger non-causality tests, to analyse the relationship between the variables. This method increases the vector auto-regressions- model (VAR hereafter) by additional lags of the variables, which are not limited by the presence of unit roots. In this way, pre-test biases can be avoided and standard inference restored [22].
To carry out the tests, data series are converted to natural logarithms. The study was conducted using the statistical software EViews 10 Student Version Lite and R [44], using several packages (strucchange [45], [46], [47], AER [48], urca [49], tseries [50], AOD [51], vars [52], [49]).

As has been discussed before, the relationship between GDP and electric power consumption has been studied extensively with mixed results, and there is still no clear idea about the direction or neutrality of the relationship in research. Additionally, most of the studies in the context of granger causality and the relationship between electric power consumption and GDP do not control for structural breaks.

This paper studies the data first without considering discontinuities, and then studies it again while taking into account one structural break using the Toda Yamamoto method. We also allow for a structural break while testing for unit roots. This enables us to focus on how introducing structural breaks into the analysis might produce divergent or contradictory results. This is especially critical given that one of the greatest weaknesses of unit root tests such as the augmented Dickey-Fuller test is that it might detect a unit root or fail to reject a false unit root null hypothesis (Type II Error) that is actually not present, when the data is affected by structural breaks [29], [53].

Simple Granger causality tests based on Granger [31] estimate equations (1) and (2) (here in a bivariate setting, the so-called simple VAR model) [22]:

$$y_t = a_{1,0} + \sum_{i=1}^{p} \propto_{1,i} y_{t-i} + \sum_{i=1}^{p} \propto_{1,p+i} x_{t-i} + \varepsilon_{1t} \quad (1)$$

and

$$x_t = c_{2,0} + \sum_{i=1}^{p} \gamma_{2,i} y_{t-i} + \sum_{i=1}^{p} \gamma_{2,p+i} x_{t-i} + \varepsilon_{2t}. \quad (2)$$

p denotes the number of lags modelling the dynamic structure, where further lags are not statistically significant and ε describes the error terms, the so-called white noises, which might be correlated across equations.
If p parameters, specified as $\sum_{i=1}^{p} \propto_{1,p+i}$ or $\sum_{i=1}^{p} \gamma_{2,i} y_{t-i}$, are not jointly significant, which would be in line with the null hypothesis, lagged values of y_t or x_t are not "Granger-causing" the values of y_t or x_t respectively [22].

Although following the Toda Yamamoto procedure allows us to focus less on the integration and cointegration properties of the time series data at hand ([23], p. 227), this paper investigates the order of integration by relying on common methods (also following the procedure from

([54], p.3) such as the augmented Dickey-Fuller test, the Phillips-Perron test, or the Kwiatkowski–Phillips–Schmidt–Shin test, to establish a robust foundation for conducting the causality tests. These tests, subsequently referred to as the ADF test, PP test and KPSS test, allow us to determine the (non-) stationarity of variables, provided they have an unit root and follow a random walk (with a drift). For the ADF test, the Bayesian Information Criterion (BIC) -criteria is used to select optimal lag length. For the PP and the KPSS tests, which are also convenient in terms of cross-validation of the findings of the other unit root tests, the Newey-West estimator from the default Bartlett kernel is applied to determine the bandwidth (the optimal length of lags).

In the ordinary Granger causality procedure, conducting these tests is a critical step because the procedure relies on the assumption that time series data is stationary. Stationarity implies that the mean and (co-) variance of the time series data will stay the same over time, such that the data does not depend on time. Time series data which is identified as stationary is said to be integrated of order 0 and, thus I (0). If the variable is identified as non-stationary, transformation to stationarity can be applied. If the variable can be transformed to stationarity through one- time differencing, it is said to be integrated of order 1, and thus I (1). If d-differencing steps are needed to transform the data, the time series data is said to be integrated of order d, and, thus I (d).

As mentioned by [55], economic and energetic time series data are highly likely to be non-stationary due to their exposition to "constant changes of legal, technical regulations and rules," which is why when following the ordinary Granger causality procedure it is highly important to consider these changes in the analysis. These changes might also influence the existence of structural breaks in the time series data sets.

This paper follows the augmented VAR model as proposed by [54], who built on the TY procedure and expanded the model to consider structural breaks relying on [22]. The bivariate model for electric power consumption (from here on specified as ElecPower) and GDP (both expressed in logs and levels) in Kenya is specified (formulation based on [54], [22], [56], [57], [30] and [21]) as (3) and (4):

$$ElecPower_t = \sum_{k=0}^{n}(\varphi_k \, \Delta t_{k,t} + \omega_k t_{k,t}) + \sum_{i=1}^{p} \propto_{1i} \, ElecPower_{t-i} + \sum_{j=p+1}^{p+m} \propto_{2j} \, ElecPower_{t-j} + \sum_{i=1}^{p} ß_{1i} \, GDP_{t-i} + \sum_{j=p+1}^{p+m} ß_{2j} \, GDP_{t-j} + \varepsilon_{1t} \quad (3)$$

and

$$GDP_t = \sum_{k=0}^{n}(\varphi_k \, \Delta t_{k,t} + \omega_k t_{k,t}) + \sum_{i=1}^{p} \gamma_{1i} \, GDP_{t-i} + \sum_{j=p+1}^{p+m} \gamma_{2j} \, GDP_{t-j} + \sum_{i=1}^{p} \delta_{1i} \, ElecPower_{t-i} + \sum_{j=p+1}^{p+m} \delta_{2j} \, ElecPower_{t-j} + \varepsilon_{2t} \quad (4)$$

$\alpha, \beta, \gamma, \delta$ are the lagged coefficients to be estimated for ElecPower and GDP, respectively; m describes the maximum order of integration of the processes for each individual series, p equals the lag length, additional lags (equal to the maximal order of integration m) are added to address potential autocorrelation in the residuals. Following the TY approach, we use modified Wald statistics, which asymptotically have a chi-square distribution (χ^2), to infer from the non-causality test. By applying this method, linear restrictions are put on parameters of the VAR with the lag length of p. The VAR in levels is augmented by the maximal order of integration (m); hence, a VAR of length ($p + m$) is estimated. The terms on ε denote the residuals of the models. It is assumed that these are white noise disturbances with a zero mean and a constant variance, and that they are not affected by auto-correlation.

As previously mentioned, the relationship between the variables is estimated by with and without considering the structural breaks. In the former case, n describes the number of structural breaks and $t_{0,t}$ is a simple linear time trend, where the first difference of it, $\Delta t_{0,t}$, is a constant. Up to and including the first structural break year, thus for $k > 0$, , $\Delta t_{k,t}$ is equal to zero. Thereafter, it is equal to unity, which means that $t_{k,t}$ is a linear time trend, increasing by one unit per year after the structural break.

The null hypothesis H_0 of Granger non-causality of *ElecPower* on *GDP* is tested, where $\beta_{1i} = 0$ for $i = 1, \ldots, p$. The Granger non-causality of *GDP* on *ElecPower* is estimated in a similar manner, where the null hypothesis assumes that $\delta_{1i} = 0$ for $i = 1, \ldots, p$. Similarly, as specified by ([54], p. 4f.), the coefficients $\delta_{2,j}$ and $\beta_{2,j}$ *for* $j = p+1, \ldots, p+m$, are not considered at this step. The model is paired down with a maximum lag length of 10 lags (following the rule of thumb of Schwert [58]). The optimal lag length p is mainly determined according to the Schwartz Information Criteria (SIC) and specifies how many lags should be considered when estimating the not yet augmented VAR. It was determined using the minimum of the four lag selection criteria when using the VARselect function in R (AIC (Akaike Information Criterion), HQ (Hannan–Quinn Information Criterion), SIC (Schwartz Information Criteria) and FPE (Final Prediction Error Criterion). Lag length selection is critical because autocorrelation can be eliminated by a proper selection of lag length. A serial test, the Portmanteau Test [59], is applied to investigate process stability and autocorrelation in the residuals. Afterwards, the inverse of the root of each equation in the specified VAR model is studied to check the stability visually by plotting the cumulative sum of recursive residuals.

A test on cointegration based on [30] and [21] is conducted by performing the analysis with and without considering a structural break. The cointegration procedure findings might also provide a convenient cross-validation of the Toda and Yamamoto approach results [40] since according to [60] cointegration between variables also shows Granger causality between them.

For the purpose of the analysis when controlling for one structural break (based on [54], [30], [31], [21]), we rely on the augmented VAR model specified previously in this paper, but include two additional dummy variables in the model and consider them in the regression as follows:

$$\begin{aligned} &i_{2,t} = 1 \text{ if } t = t^*+1 \text{ and } i_{2,t} = 0 \text{ if else} \\ &d_{2,t} = 1 \text{ if } t \geq t^* \text{ and } d_{2,t} = 0 \text{ if } t \leq t^*. \end{aligned} \tag{5}$$

The break point period is described by t^* for $t = 1,..;T$. The VAR model for the analysis on cointegration controlling for one structural break includes a linear trend c, $d_{2,t-k}$, where k describes the maximum lag length, the interaction between the linear trend c and the $d_{2,t-k}$ and also $i_{2,t-l}$ for $l = \{0,1,..,k-1\}$, respectively, describing the exogenous variables of the system.
Unit root tests allow for one endogenously - and one exogenously - determined structural break (following [54], [22], based on [28] and [29]). The research relies on [56], based on [8], [61], [30], and [21] to assess the detected break and the results from the unit root tests also when applying the Toda Yamamoto procedure and carrying out the cointegration analysis. The augmented VAR is then specified as described above, but considering the determined structural break in the model. For the purpose of implementation in R, the analysis also relies on [62] based on [63] and [56].

3.3 Limitations and recommendations

A major drawback of the study is its small sample size, due to the fact that time series data for developing countries has not been recorded as it has for developed countries. Because of this limitation, the tests conducted here might suffer from a lack of robustness. To further improve findings, bootstrapping critical values of the unit root tests and specific to the data used here is recommended. Additionally, the analysis relies on a bivariate model. This type of model is often criticized for not including more than two variables. Omitted variables might lead to specification bias and the inclusion of more variables might lead to more precise, consistent and robust results. Moreover, different model specifications could be studied and discussed more in detail. The data studied here is only available on a highly aggregated level, which does not allow for a very detailed interpretation. For example, the dynamics of the different electric power consumers are not reflected properly in the data set. Therefore, extending the analysis could be extended to include more disaggregated or local data in order to support appropriate policy development. Further research could also fruitfully include more variables, longer time series, multiple structural breaks and address cross-sectional dependence, as has been done by [34].

4. Empirical results and discussion

Figure 1 depicts the logarithmic time series of electric power consumption and GDP per capita in Kenya from 1971 to 2014. Electric power consumption steadily increased between 1971 and the end of the 1980s, when a first break can be observed, and again until the 2000s, when a sharper break occurred. At least graphically, the oil crisis during the 1970s seems not to have had a dramatic impact on Kenyan electric power consumption. Conversely, the drought in 2000 appears to have caused a sharp setback in electric power consumption. Since then, electricity consumption increased with a much steeper growth rate, which also corresponds to a steeper GDP per capita growth rate. The latter was only interrupted by a slight break, potentially associated with the global financial and domestic political crisis of 2007/2008 [37].

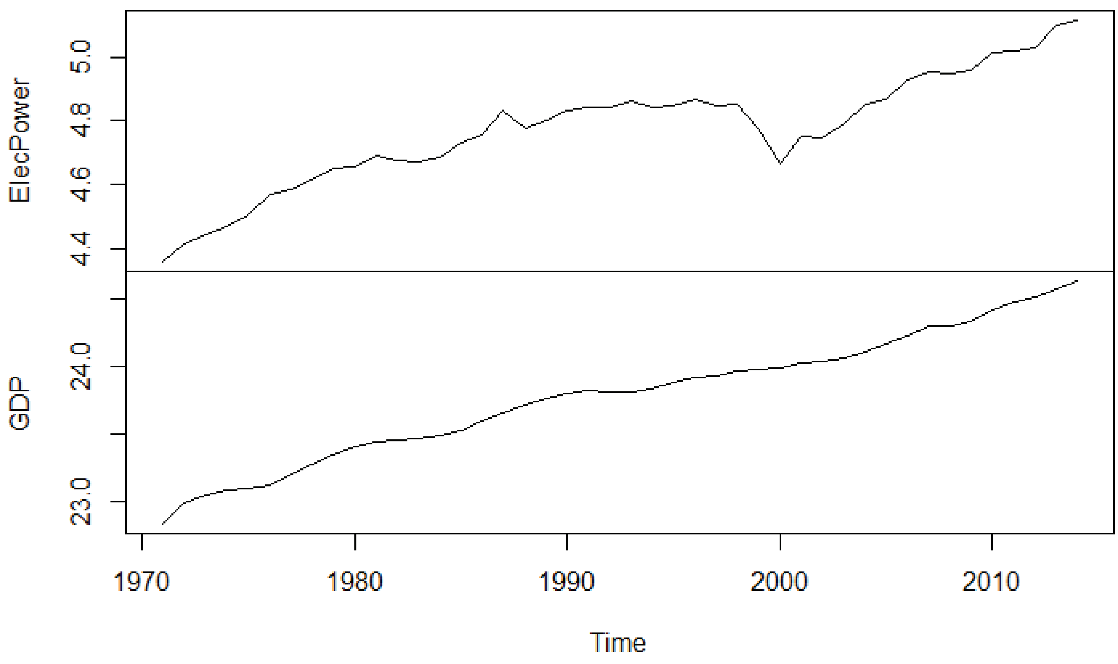

Figure 1. Logged electric power consumption and GDP per capita in Kenya from 1971 to 2014 (provided by the author based on [2])

In general, the graphical analysis displays less severe breaks in the evolution of the per capita GDP. Discontinuities in the time series data can be detected during the 1970s (the era of the oil crisis), the 1980s (where there was military coup attempt in 1982) as well as during the turn of the 20th century (when the GDP growth might have been hampered by the heavy drought crisis).

4.1. Unit root tests

Table A1 in the Appendix shows the different tests results from the check the presence of unit roots without considering structural breaks. As can be seen, ElecPower and GDP are both integrated of order 1, I (I), concerning the results of the ADF, PP and KPSS tests and with respect to different model specifications considering a "trend", "drift" or "none". Thus, the maximum order of integration is assumed to be one.

The results from unit root tests on the subsample are more diverse (see Table A2 in the Appendix). However, sample size is much lower in comparison with the original data set, which is why the results have to be interpreted with caution. Notwithstanding, with respect to the results of the ADF, PP and KPSS tests and different model specifications, the variables are also assumed to be integrated of order one, I (I).

The results of the ZA unit root test that accounts for one endogenous break point are shown in Table A3 in the Appendix. When conducting the ZAunit root test by testing the null hypothesis of a unit root with no structural break against the alternative hypothesis with a stationary process with a break for the whole sample period, a unit root is still detected when dealing with level, non-transformed variables, irrespective of the model specification of a process with a break in the intercept or in the intercept and trend. Therefore, when controlling for only one break in the series, the results of the previous unit root tests are confirmed and the variables are still integrated of order one, I (I).

Structural breaks identified by the ZA unit root test correspond mainly to the period loosely corresponding to 2000 and 2001. These breaks can also be studied in Figure 1, above. They might reflect the consequences of the drought crisis in 2000, which affected both, the electricity and agricultural sectors, with the latter being one of the backbones in Kenya. However, it has to be noted that the ZA unit root test does not identify a structural break in the years immediately before and after 2008, the year of the global financial crisis and internal political imbalances, which impacted the Kenyan economy heavily at that time [37], [64]. This underlines the importance of further extending the research, and calls for research that takes into account multiple structural breaks.

4.2. Lag order selection

According to different criteria, lag order selected for the augmented VAR is one for logged ElecPower per capita and two for logged GDP per capita for the whole sample period. The Portmanteau Test on serial correlation (within the VAR model, where lags included are equal to two) is insignificant (Chi-square= 50.117, p-value= 0.696). For a higher p-value, it is less likely to have auto-correlated residuals, which is why a VAR model including lags equal to two is specified. Model stability is further confirmed by the inverse of the roots of each equation in the VAR model. A visual inspection confirms that the model seem to be stable (see Figure A1 in the Appendix).

4.3. Causality tests

The results of the causality tests are presented in Table 1, below. No causal relationship between electricity consumption and GDP per capita for the whole period from 1971 to 2014 can be established. The null hypotheses that the variables are not Granger causing each other cannot be rejected, which has also been studied by [35] for the period between 1980 and 2003, and by [20] and [38] for the periods between 1971 to 2007 and 2010, respectively. When studying the subsample from 1971 to 2000, the year of the identified structural break, the finding changes. The null hypothesis of non-Granger causality is rejected at the 5 % significance level and a unidirectional Granger causality running from electricity consumption to GDP is identified, which is in line with findings from [34] and [36] but not with [33], who did not control for structural breaks. Even though our result has to be interpreted with caution due to smaller sample size, it might reflect the importance of considering structural breaks in the analysis.

Table 1. Results of the causality tests

		Wald- statistic	
Sample period		Log ElecPower	Log GDP
1971-2014	Log ElecPower	NA	3.6
	Log GDP	1.1	NA
1971-2000	Log ElecPower	NA	8.5**
	Log GDP	0.21	NA

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

4.4. Cointegration tests

The first step of the cointegration analysis checks the non-stationarity of the levels of the variables analysed here. The results of the unit root tests in Table A1 in the Appendix already confirmed the non-stationarity of the levels of the variables for the different model specifications. According to the analysis, the series are integrated of order one, I (I).

The null hypothesis of the Perron unit root test (see Table A4 in the Appendix) controlling for one break in the year 2000 cannot be rejected at the 10%, 5%, and 1% significance levels for both variables. It is therefore assumed that the series contain a unit root and the assumption that the data is integrated of order one, I (I), is kept.

The results of the cointegration tests are presented in Table 2, below. A cointegration between electric power consumption and GDP per capita when (not) controlling for the structural break is not established. The trace statistics indicate that there is no cointegration at the 10 %, 5 %, and 1 % significance levels. This is in accordance with the findings of the causality tests discussed above in section 4.3. When a cointegration between two variables is detected, then they must have uni- or bidirectional relationship as there is a linear combination between them in the long run [60].

Table 2. Results of the cointegration tests

No. of breaks considered	Model	No. of hypothesized cointegrated equations	Trace statistic
None	Linear deterministic trend	None At most one	21.09764 2.874647
One	Linear deterministic trend	None At most one	17.45174 1.569854

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

5. Conclusion and outlook

This study investigates the causal relationship between electric power consumption and GDP per capita in Kenya between 1971 and 2014. To assess this relationship an augmented Toda Yamamoto procedure, which also accounts for one structural break in the times series data, is applied. Moreover, a cointegration analysis is conducted to have a validation check on the results. Confirming the findings of other studies [20], [33], [35], [38] no causal relationship between electricity usage and GDP is established for the period from 1971 to 2014. Based on the results, electric power saving policies or electricity supply shortages should have no negative impact on GDP per capita. The cointegration analysis controlling for a break confirms the results from the (non-) causality test for the whole sample. However, when controlling for a structural change in the year 2000, the findings change, and a uni-directional relationship running from running from electricity consumption to GDP is identified for the period between 1971 and 2000, which is in line with findings from [34] and [36]. Based on this result, ensuring and enhancing access to reliable and stable electric power can boost the GDP of Kenya. Developing countries are frequently affected by a wide range of occurrences such as regime changes or droughts, which cause breaks in the time series data. Controlling for structural breaks thus has an impact on results and should be considered when studying the causal relationship between energy and economic variables in developing countries.

Further research could be done at a more disaggregated level, which would support a more detailed policy development. To obtain better insights into the nexus between economic output and electricity usage, other indicators reflecting the real electric power consumption per capita could be considered. This becomes especially clear when considering the on-going restructuring of developing economies, the energy intensities of different sectors contributing to GDP, and the limited access to electricity from the grid, which has also been discussed by [33]. In Kenya, many businesses rely on electricity generated by generators. However, data collection has only recently begun [65], such that research in this field is still limited. Additionally, more variables, such as environmental variables, and structural breaks could be considered in order to address the problem of omitted variables, and to assess the impact of multiple structural breaks on the time series data.

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Declarations of interest

None.

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Appendix

Table A1. Unit root tests of logged variables
without structural breaks

Sample period 1971-2014			
Test	Series	Model	Test statistic
ADF	ElecPower, level	none	2.4961
ADF	ElecPower, level	trend	-1.9897
ADF	ElecPower, level	drift	-1.0841
ADF	ElecPower, 1st diff	none	-3.2953***
ADF	ElecPower, 1st diff	trend	-3.9505**
ADF	ElecPower, 1st diff	drift	-4.0301***
PP	ElecPower, level	constant	-1.4189
PP	ElecPower, level	trend	-2.3374
PP	ElecPower, 1st diff	constant	-6.334***
PP	ElecPower, 1st diff	trend	-6.2636***
KPSS	ElecPower, level	constant	0.7522***
KPSS	ElecPower, level	constant, linear trend	0.1177**
KPSS	ElecPower, 1st diff	constant	0.1603
KPSS	ElecPower, 1st diff	constant, linear trend	0.1371*
ADF	GDP, level	none	4.252
ADF	GDP, level	trend	-1.5826
ADF	GDP, level	drift	0.41
ADF	GDP, 1st diff	none	-1.8114*
ADF	GDP, 1st diff	trend	-3.9812**
ADF	GDP, 1st diff	drift	-4.0598***
PP	GDP, level	constant	-1.1732
PP	GDP, level	trend	-3.1489
PP	GDP, 1st diff	constant	-5.8016***
PP	GDP, 1st diff	trend	-5.5863***
KPSS	GDP, level	constant	1.1877***
KPSS	GDP, level	constant, linear trend	0.1646**
KPSS	GDP, 1st diff	constant	0.2193
KPSS	GDP, 1st diff	constant, linear trend	0.1654**

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

Table A2. Unit root tests of logged variables

Subsample period 1971-2000			
Test	Series	Model	Test statistic
ADF	ElecPower, level	none	0.3642
ADF	ElecPower, level	trend	1.5587
ADF	ElecPower, level	drift	-2.0422
ADF	ElecPower, 1st diff	none	-1.144
ADF	ElecPower, 1st diff	trend	-2.0031
ADF	ElecPower, 1st diff	drift	-0.5713
PP	ElecPower, level	constant	-2.7746*
PP	ElecPower, level	trend	1.475
PP	ElecPower, 1st diff	constant	-2.7373)*
PP	ElecPower, 1st diff	trend	-4.2128**
KPSS	ElecPower, level	constant	0.9223***
KPSS	ElecPower, level	constant, linear trend	0.2413***
KPSS	ElecPower, 1st diff	constant	0.6856**
KPSS	ElecPower, 1st diff	constant, linear trend	0.1204*
ADF	GDP, level	none	3.0133
ADF	GDP, level	trend	-0.8677
ADF	GDP, level	drift	-1.276
ADF	GDP, 1st diff	none	-1.7107*
ADF	GDP, 1st diff	trend	-3.5174 **
ADF	GDP, 1st diff	drift	-2.8978*
PP	GDP, level	constant	-2.9939**
PP	GDP, level	trend	-2.5583
PP	GDP, 1st diff	constant	-4.9493***
PP	GDP, 1st diff	trend	-4.9827***
KPSS	GDP, level	constant	1.0833***
KPSS	GDP, level	constant, linear trend	0.239***
KPSS	GDP, 1st diff	constant	0.4638*
KPSS	GDP, 1st diff	constant, linear trend	0.0464

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

Table A3. Zivot Andrews unit root test of logged variables
with one structural break

Series	Model	Test statistic	Break Point
GDP, level	break in the intercept	-2.9899	1995
GDP, 1st diff	break in the intercept	-5.0949**	2002
GDP, level	break in the intercept & trend	-2.6531	1976
GDP, 1st diff	break in the intercept & trend	-5.5011**	1989
ElecPower, level	break in the intercept	-3.4346	1996
ElecPower, 1st diff	break in the intercept	-6.206***	2001
ElecPower, level	break in the intercept & trend	-4.2915	1998
ElecPower, 1st diff	break in the intercept & trend	-6.1296***	2001

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

Table A4. Results of Perron unit root test

Model	Residuals from first-stage regression	Test statistic
B	Modified ADF[1] Logged Elec Power	-2,313194
B	Modified ADF[2] Logged GDP	1,721868

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

[1] Based on [29], [61]
[2] Based on [29], [61]

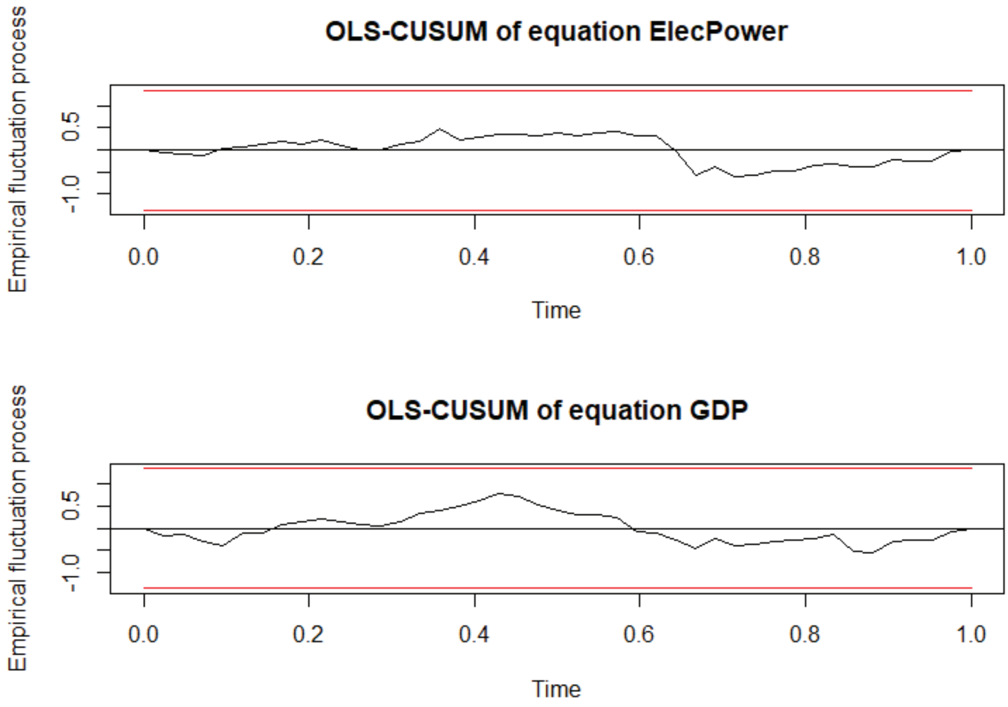

Figure A1. Model stability analysis for lags = 2

5. Comparison of (pre-) electrification statuses based on a case study in Tanzania

Comparison of (pre-) electrification statuses based on a case study in Tanzania

Annika Groth
Department of Energy and Environmental Management in Developing Countries
Europa Universität Flensburg, Flensburg, Germany
e–mail: annika.groth@uni-flensburg.de

ABSTRACT

Mini grids in areas without access to central grids may significantly contribute to increased energy access around the developing world. Here, universal energy access is an important driver for development and will result in a number of socio-economic benefits in newly electrified areas. The present paper compares the socio-economic situation of households and small enterprises in six villages in Mufindi, Iringa Region of Tanzania. In 2012, this area became electrified by an interconnected mini-grid system from the Mwenga Hydro Power Project, powered through a 4 MW hydro generation plant. The research departs in a baseline study conducted by the Tea Research Institute of Tanzania in 2009. The present research has collected additional survey data on household and enterprise level in 2015. Two villages in the area are still to be connected and have not been part of the 2009 Mwenga Hydro Project Baseline Study, which is why they offer good opportunities to study effects of recent electrification. The participating villages share similar characteristics in terms of climatic conditions, topography, infrastructure, access to markets, distance to bigger cities and economic characteristics such as income sources. However, the villages in the connected and non-connected area have or had different pre-electrification statuses. The purpose of this study is to compare the pre-electrification socio-economic status of the villages from 2009 and 2015 and to analyze how the situation in the electrified villages changed compared to 2009. The focus is especially on units that already have access to solar power. Using qualitative data and descriptive statistics, the study reveals that these units tend to possess more electric appliances and to belong to higher income classes. Furthermore, secondary literature and sources add more insights concerning the surrounding conditions. The results of this study comprise a valuable baseline or starting point for further initiatives of the present project as well as similar developments in developing countries, where good data for stakeholder analyses in the area are often absent, and a basis for a deeper analysis is required. Current research includes the identification of control and counterfactual groups for a more profound comparison.

KEYWORDS

Rural electrification, socio-economic development, interconnected mini-grid systems, Tanzania, Mwenga Hydro Power Project

INTRODUCTION

Background

The United Republic of Tanzania has been one the fastest growing economies in the Eastern African Region with an average annual real GDP growth rate of 7% in the last decade [1]. Population size amounts to 50.8 million people in 2014 with an average annual growth rate of 3% in the last years [2].
National GDP per capita in Tanzania at current market prices grew from US $ 18.610.460.327 in 2006 to US $ 44.895.392.077 in 2015 [3]. The workforce of the economy is heavily dependent on agriculture, which employs approximately 67% of total employment but only adds 30.5% of value to the GDP [3]. Value added by services accounts for 43.6% of the GDP in 2015 and 26.6% of the total work force, whereas the industry only accounts for 25.9% of the GDP in 2015 and 6.4% of total employment in 2014 [3].

There has been some progress since the country liberalized trade in the mid to late 90´s and implemented comprehensive market-oriented reforms and macroeconomic policies (e.g. through the government's 1996 Economic Recovery Program). Foreign Direct Investments, net inflows increased fivefold from 403 Mio. US $ in 2006 to 1.9 Billion US $ in 2015 (BoP, current US $) [3]. Live expectancy at birth has grown from 50 years in 1990 to approximately 65 in 2014. The share of the population living with less than US $1.90 per day reduced substantially since 2000. The poverty headcount ratio at US $1.90 a day (PPP 2011, international prices) nearly halved between 2000 (84.74% of the population) and 2011 (46.6% of the population) [3].

However, poverty measures indicate that poverty levels are still extremely high. The MPI, the Multidimensional Poverty Index, which measures poverty beyond income, the percentage of population that is defined as multi-dimensionally poor in terms of education, health and standard of living, is very high with 66,4% in 2010 [2]. It further indicates that 31.3% of the population live in extreme poverty [3]. This is also reflected in the Human Development Index (HDI) of Tanzania, which measures the average achievements in three basic dimensions of human development. With an index of 0.521 in 2014, Tanzania is on position 151 out of 188 countries and still at the bottom ranks of human development [4, p.214]. It is still far away from the UN Sustainable Development Goal of "ending poverty in all its forms and dimensions in 2030" [5].

In accordance with these measures, access to important infrastructures is still limited and only available for a minor share of the population. The development of critical infrastructures is barely able to keep up with economic but also rapid population growth. Approximately 15.6% of the population had access to improved sanitation facilities in 2015 compared to 11.4% in 2006 [6]. Also the development of electrification lags far behind the expansion of output and population increase. With only 15.3% in 2012 [3], the share of the total population with access to electricity is still one of the lowest in the world. Other measures are slightly more optimistic concerning the Tanzanian electrification rate: According to the Global Tracking Framework [7] approximately 24% of the Tanzanians had access to electricity in 2013[1].

[1] There is no uniform definition and measure of access to electricity or electrification in research. Therefore, there might be high discrepancies between different types of measures of electricity access or electrification rate. Also, many definitions do not include important information regarding quality, reliability or efficiency of access to electricity or electrification.

Apart from this, electrification access is not equally distributed between urban and rural parts. Nearly half of the urban population (46.1% in 2012) is electrified, whereas in rural areas only 3.6% of the people have access to electricity [3]. Other measures defined 71% of the urban population as electrified in 2013, whereas only 4% of the rural population had access to electricity by that time [8].

However, Tanzania has been classified as one of the top 20 electricity access deficit countries in the world [7] and the provision of electrification is not enough to sustain economic growth and development. Electricity still plays a minor role in total primary energy consumption. Only 1.5% of the total primary energy consumption is attributed to electricity, whereas biomass is consumed most (approximately 90%) and fossil fuels amount to 8% of total primary energy consumption [9]. Compared to the international electric power consumption per capita of 3030 kWh or African electric power consumption per capita of 580 kWh in 2013, the Tanzanian electric power consumption is still very low, with approximately 90 kWh per capita in the same year [10].

The Tanzanian energy sector frequently faces shortages of power generation, especially of electricity and suffers from underinvestment and weak technical and financial performance [11]. The aging and insufficient infrastructure for transmission and distribution but also poor power generation capacities- the installed generation capacity is only about 1550 MW [9] - are not capable to match with the increasing demand for electricity. In 2013, approximately one fifth (20.5%) of the output generated has been lost [3]. Climate change is also heavily impacting the power sector. The high dependence on hydro power (more than 30% of total generation capacity in 2013 [9]) becomes especially problematic due to persistent droughts and changed rainfall patterns. This has been observed in the recent years and forced the government to undertake emergency power installations and load shedding, both associated with very high costs [12].

The expansion of the national grid to rural areas is expensive because the Tanzanian population density in rural areas is low and the percentage of poor household disproportionally high and initial electricity consumption levels low. The Investment Prospectus for Rural Electrification estimates that more half of the Tanzanian rural population should be cost-effectively best served by off-grid and/or mini-grid solutions to sustain economic growth [9]. This corresponds to recommendations from the International Renewable Energy Agency (IRENA), 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 [13].

The Tanzanian government strives to modernize the energy sector and to scale up access to modern energy services. Next to putting comprehensive reforms into place[2], it supports the participation of independent power producers (IPP) and small power producers (SPPs). For SPPs with a generation capacity of less than 10 MW, the government implemented “a special regulatory framework with simplified procedures and standardized contracts” [12, p.26].

The Mwenga Hydro Power Project, which is in the focus of the study, is one of the first projects under the SPPA scheme. The 4 MW hydro power based project acts at the interface

[2] Plans include “unbundling the state utility TANESCO into a generation segment (combined with allowing direct contracting between power plants and bulk off-takers), and subsequently transmission and distribution, finally reaching full liberalization of the sector, including the establishment of retail electricity market.” [14, p.15].

between national grid and mini-grid. The majority of its power generated is sold to the national grid (to the state utility TANESCO), but it also sells power to the local tea industry and the rural community. It is owned and operated by the private company Rift Valley Energy and received grant assistance from the EU ACP Energy Facility, and the Tanzanian Energy Development and Access Project (TEDAP) facility from the World Bank before starting its operation in 2012 [15].

The Mwenga Hydro Project is located in Mufindi, in the Southern Highlands of Tanzania, administratively defined as one of three districts of the Iringa Region. Iringa is the second richest region of Tanzania (following Dar Es Salaam) with an GDP per capita of more than 1.200.000 Tshs. in 2012. It also belongs to one of the regions where the regional Human Development Index is slightly higher than in other regions of Tanzania. With 61%, the MPI of Iringa is slightly lower than the national index and only a fifth of the population (22%) is indicated to live in extreme poverty (compared to nearly a third of the population on the national level) [1, p.5]. The Mufindi region lies on an altitude between 1700m and 2000m above sea level and is characterized by its hilly topography, long rainfall and short dry seasons.

LITERATURE REVIEW AND RESEARCH PROBLEM

In research, there is broad consensus concerning the nexus between rural electrification and development and no doubt that rural electrification is a critical factor for socio-economic development [16; 17; 18].

However, the Independent Evaluation Group from the World Bank [18] finds only “a weak evidence base” that rural electrification leads to the expected welfare gains in health, education and income. Expectations concerning welfare outcomes of rural electrification alone should not be too “high” [17, p.21]. To determine the causality or the direction of the relationship between rural electrification and various dimensions of development is a challenge. Researchers face many methodological constraints and barriers when trying to isolate the genuine effect of rural electrification on development.

Bernard [19] is concerned about the general lack of impact evaluations in the field of rural electrification. Especially in research done in the Sub-Saharan African context, he misses robust evidence and external validity. He further discusses difficulties in timing of measurement and attribution in research on impacts of renewables energies and other infrastructures. Torero [20] addresses problems concerning methodologies applied in research trying to measure the impacts of electrification, e.g. by relying on simple with and without approaches or before and after comparisons, which could lead to biased findings due to the influence of unobservable variables on the selection of being connected to electricity. He also discusses the problem of placement endogeneity, which also can lead to confounding results.

However, recently, there are promising impact evaluation studies upcoming that rely on more advanced techniques to address these problems. One of the more advanced and frequently cited study is the one from Khandker et al. [21]. They study the effects of rural electrification on household income, expenditure and education in Bangladesh by addressing endogeneity bias of grid electrification. Khandker et al. find evidence for positive welfare impacts, especially for richer households. In a more recent paper from 2013, Khandker et al. [22] study the effect of a World Bank´s rural electrification program on rural households´ welfare in Vietnam using panel data from two survey waves in 2002 and 2005. By again considering the problem of endogeneity, they detect that the rural electrification program contributes to the welfare of lower and higher income households. Dinkelman [23] studies the effects of rural electrification on the labor market in South Africa and finds evidence that it contributes to an increase of female employment. For the purpose of her analysis, she relies on advanced econometrics by applying the instrumental variables strategy and fixed effects approach. Bensch et al [24] assess the impacts of electrification on households with Solar Home Systems (SHSs) in rural South Senegal. Applying a stratification matching approach to distinguish between control and treatment group, they find evidence that electrified households demand for lighting measured in lumen hours is higher compared to non-electrified households. Their significant results indicate a higher study time of children from electrified households, which could lead to higher educational achievements in the longer run. Also relying on a matching procedure, Arraiz et al. [25] analyze the impacts of rural electrification via Solar Home Systems (SHSs) in rural areas in Peru at community and household level. They find evidence that access to electricity via SHSs contributes to savings on energy expenditures and changes daily activity patterns, especially of women and children. Both spend more time with home businesses or homework. In the case of children it leads to higher achievements on educational level, slightly more years of schooling and higher enrollment rates in secondary school.

Next to methodological constraints in impact evaluation of rural electrification, it is of essential importance to note that the majority of the papers focus on-grid (e.g. [23], [26], [21], [22]) or off-grid electrification (e.g. [25], [24]; [29]) and its socio-economic impacts separately. Additionally, there is more empirical research on the effects of rural electrification done in Latin-American or Asian areas of rural electrification, but less in the Sub-Saharan context [17, p. 9].

The combination of both types of electrification and its impact on the socio-economic conditions surrounding the interconnected projects has rarely been studied. There are many good reasons why the effects of an interconnection should be studied: Off-grid limit electricity supply which restricts the capacity for productive investments. On the other hand, also grid- connected areas suffer from capacity constraints (e.g. through frequent black-out or load shedding) and limit the expansion of productive uses. Further, off-grid systems are frequently threatened by future grid expansion plans and might therefore not implemented at all. If it can be shown that interconnected projects can coexist and be fruitful to the socio-economic conditions and prepare the ground for a higher demand, investors might be more open to support the development of off- and mini-grid systems in rural areas as recommended by the International Renewable Energy Agency (IRENA).

This study tries to fill this gap and to deliver baseline data of a case study based on an interconnected project in the Tanzanian Southern Highlands, which will be the basis for a deeper analysis. For this purpose Baseline data of the Mwenga Hydro Project from 2009 [27] will be compared to (baseline) data collected in 2015, three years after the project started its operation in 2012.

METHODOLOGY

At this stage of research, comparison between the pre-electrification will be based on descriptive statistics and qualitative analysis relying on survey and interview data collected on the field in 2009 and 2015. Secondary sources complement the study concerning the surrounding conditions. The Mwenga Hydro Project Baseline Study from 2009 [27] was conducted by the Tea Research Institute of Tanzania. This study differs from the study of 2015 in terms survey methods (e.g. questionnaires and the additional reliance on the

Participatory Rural Appraisal (PRA) approach). However, there are many overlaps concerning data and qualitative information collected between both surveys, which is why it is useful to discuss them in one study.

The Baseline Study from 2009 was conducted in 14 villages that were supposed to be electrified through the interconnected mini-grid system from the Mwenga Hydro Power Project. In this study 327 households have been interviewed. Additionally, 12 samples of small enterprises were interviewed (see Table 1).

In 2015, surveys with more than 70 detailed questions on socio-economic background and energy use have been conducted in four of the already electrified villages (three of them have also been studied in 2009) and in two not yet but planned to be connected villages. The selection of the villages was not randomly. In order for a village to be selected, it had to be accessible and to have 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") available. It was intended to select villages that share most of these criteria and are mainly comparable in terms of their background conditions. Qualitative information on that level has been obtained by consulting local informants like village leaders or project representatives. Additionally, secondary sources like official reports, other studies and census data supported the selection of the sample villages.

Household and small enterprises selection was based on simple random selection. 52 or 38 randomly selected households and small enterprises were interviewed in the electrified region. On the level of households in the electrified region, approximately 23% of the interviewed households had no connection to electricity which was caused by the random selection strategy. In the not yet connected area, 68 or 34 randomly selected households and small enterprises reported. In total, 120 households and 72 small enterprises were interviewed in both areas in 2015 (see Table 1).

Table 1. Population and number of surveyed entities

	Non- electrified areas 2009		Electrified villages 2015 (4 villages)		Non- electrified villages 2015 (2 villages)	
	Total	Surveyed entities	Total	Surveyed entities	Total	Surveyed entities
Households	6295	327	1653	52(12)[3]	1217	68
Household members	24741	1946	7356	233	5114	294
Small Enterprises	535	12	362	38		34

Sources: [27]; [28]; own data collection 2015

[3] In 2015, 12 households from the electrified area reported not to be connected to the grid.

Before the research team started to interview the households and small enterprises, key informants like village leaders were consulted to get an overview about the conditions in the villages and to support the attribution of household units to different income classes. To complement the surveys, the researcher also interviewed stakeholders such as directors of the Mwenga Hydro Project, employees from TANESCO (the Tanzanian public utility) and agents from development organizations (e.g. GIZ). The interviews took place in October and November 2015.

Because of the small scope of the present study, no causal conclusion on the impacts from electrification via the interconnected mini-grid system can be withdrawn from this analysis. Generalization of the results to the whole population of that area needs to be studied further and requires the identification of control and counterfactual groups for a more profound comparison. This is done in current research, which applies more advanced methods. However, this study gives valuable insight and illustration of the socio-economic conditions before and after electrification took place in 2012.

RESULTS AND DISCUSSION

Household structure and household heads´ educational background

Each household has on average 4.5 members in electrified areas or 4.4 members in not yet electrified areas. This is slightly higher than indicated in the official census data set from 2012 for the Mufindi region. The census report estimated household average size to 4.2 members per households [28, p.104]. The average number of 4.5 also contrasts with the Mwenga Hydro Project Baseline Study from 2009, where average household size was estimated to 6 persons per household [27, p.22].

In terms of gender and average age of the interviewed household heads both areas (electrified and not yet electrified areas) nearly coincide in the shares. In electrified areas approximately 81% of the interviewed household heads are males, whereas in the not yet electrified areas the figure amounts to approximately 82%. This corresponds with the results from the Mwenga Hydro Project Baseline Study from 2009, where also 80% of the interviewed household heads were males, which was seen as a reflection of the general household head composition in the area [27, p.20f.]. The average age of household heads is 43 and 40 for the electrified and non-electrified villages respectively. Also here, the average age of the selected samples is close to the mean age (41 years) as indicated within the Mwenga Hydro Project Baseline Study from 2009 [27, p.21].

Interestingly, more household heads in not yet electrified areas have completed primary school. With respect to higher education levels, one can clearly see that there are more household heads with higher education levels in the electrified area than in the not yet electrified area (see Figure 1). Unfortunately, the education level of household heads has not been studied within the Mwenga Hydro Project Baseline Study from 2009, which is why only the results from data collection in 2015 are illustrated in Figure 1. One could guess that electrification leads to less migration of higher educated persons to urban parts and to more migration to electrified areas, which is why there are more of higher educated household heads in electrified areas than in the not yet electrified areas. In 2015, teachers stated that it is a motivation for teachers to stay in the area, when there is electricity available. However, this needs to be studied further.

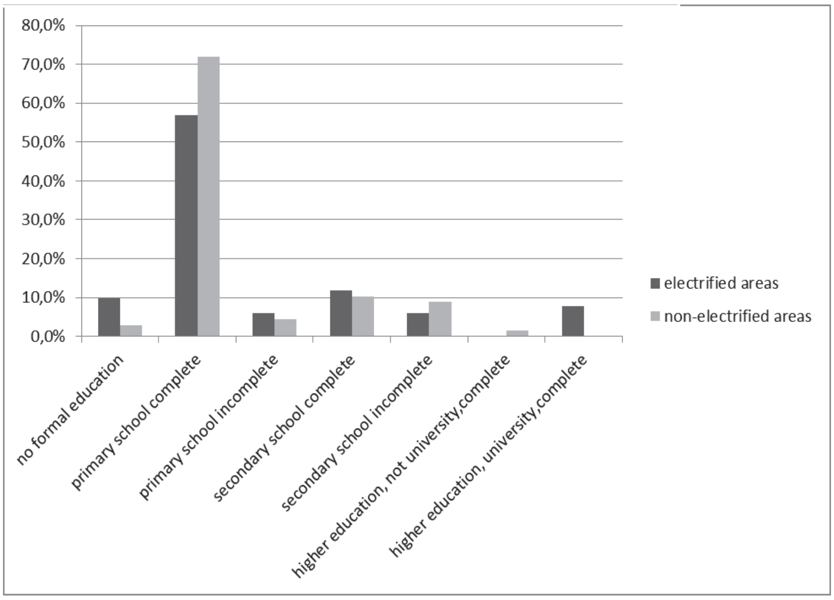

Figure 1. Household heads´ education level as a share of all interviewed households in 2015 in percent

Household heads´ occupation

In both areas, more than 90% of the household heads indicated agriculture, commercial food crops and forestry as one of their main occupations. This corresponds with the results from the Mwenga Hydro Project Baseline Study [27], where 96% of the household heads indicated to be mainly involved in agriculture. The high involvement in this sector reflects the high dependence of the Tanzanian economy on agriculture. Apart from this, in the electrified villages, 11% of the interviewed household heads indicated to be involved in agro-processing, whereas in the not yet electrified area only 1% of the household heads reported to deal with agro-processing. Regarding household heads´ participation in agro-processing in electrified villages, the share (11%) from this study coincides with the share of household heads involved in agro-processing reported in the Mwenga Hydro Project Baseline Study [27]. Consequently, the involvement in agro-processing seems to have stayed the same in the electrified villages since 2009.

More household heads in the non-electrified areas are involved in trade and commerce and services for food (7% and 6% in contrast to 4% and 2% in electrified villages). However, the occupations of household heads in the electrified areas are more diverse than in the non-electrified area. Here, more household heads work in (public) services on education, health and administration (altogether approximately 21%), whereas in the not yet electrified areas only 4% reported to deal with these services. This can also be seen when comparing the shares of occupations not listed in the survey. Nearly a third of the interviewed household heads in the electrified region (29%) indicated to be involved in activities not listed compared to 13% in the non- electrified area. The occupational involvement of household heads in other sectors has been lower in the Mwenga Baseline Scenario [27]. Only 3.7% of the household heads reported to be involved in other activities [27, p.28].

Composition of households´ income and income groups

On average, 2.1 and 2 household members contribute to the household´s income in the electrified and non- electrified villages respectively in 2015. Coinciding with household heads main occupations in the not yet electrified areas, the major share of the households´ yearly average income (approximately 75%) is generated here in the agricultural and the forestry sector (see

Table 2) in 2015. Income generated in the fishing, hunting and livestock, trade and commerce, services on food and education sector represent approximately 12% of annual household average income in the non-connected area, whereby 12% of households income sources relate to activities not listed in the survey. Minor shares of the average household income are generated in the manufacturing, construction and haulage and storage sector.

Table 2. Composition of average annual household income- Shares in percent

	Non- electrified villages 2009[4]	Electrified villages 2015	Non- electrified villages 2015
Agriculture, commercial food, crops and forestry	68	66	75
Fishing, hunting, livestock and other related		3	1
Manufacturing	32	0	0
Construction		0	0
Trade and commerce		3	6
Haulage and storage		0	0
Services for food		1	3
Services on education		5	3
Services on health, social welfare		3	0
Other sources		5	0
Other sources, not listed		14	12

Sources: [27]; own data collection

Compared to the non- electrified areas and corresponding to the occupations indicated by household heads in 2015, the sources of household´s annual incomes in electrified areas are more diverse. Here, less income is generated on average in the agricultural and forestry sector (69% in the electrified villages compared to 75% in the not yet electrified villages, as can be noticed in Table 2). On average, 17% of the household income is sourced from services on food and education, haulage and storage, trade and commerce and other sectors. Approximately 14% of the income is attributed to not listed activities. In comparison to the baseline data from 2009, the agricultural sector is still the most important sector of income generation in both areas. At this stage, it is of crucial importance to mention that households´ sources of income vary by season and opportunities (e.g. temporary employment). This is why the household heads were asked to estimate the share of their income sources on an annual basis. However, even from year to year the household income might fluctuate substantially (e.g. timber trees that need to grow for a couple of years before they can be sold).

Notwithstanding, more households in the non- electrified area responded to belong to the higher income group than in the electrified region[5]. Figure 2 shows that nearly half

[4] The Mwenga Baseline Study [27] distinguished between different income generation groups: Farming "traditional cash crops" and "traditional crops", forestry and natural resource products, livestock & its by-products, service provision and local business, artisan and handcraft works. The figures mentioned in Table 2 have been aggregated.

[5] In the surveys from 2015, income groups were distinguished as follows: Lower income groups encompass households that earn less than 1.200.000 Tshs. per year, middle income groups include households with an income between1.200.000 and 3.600.000 Tshs. per year and higher income groups earn more than 3.600.000 Tshs. per year. Unfortunately, the Mwenga Baseline Study [27] did not collect data on this level.

(approximately 49%) of the respondents in the electrified villages responded to belong to the lower income group. In non- electrified areas only a third (approximately. 29%) of the households indicated to earn less than 1.200.000 Tshs. in a year. This is also reflected in the distribution of households belonging to the middle and higher income groups. The majority of the households in the not yet electrified villages (46%) indicated to be part of the middle class. In electrified regions a third (approximately 31%) responded to earn between 1.200.000 Tshs. and 3.600.000 Tshs. per year and only a fifth indicated to belong to the higher income group with yearly earning above 3.600.000 Tshs. In the not yet electrified region this group represented nearly a fourth of the households. Consequently, even though more households in the electrified regions reported to have new household income sources since 2012 and income sources are more diverse, it does not imply that the households in electrified regions are wealthier in terms of annual income. It is of essential importance to mention again that the household income varies depending on different seasons and opportunities (e.g. “not listed activities” in many cases indicate short-term and non-permanent employment). This is also the reason why the household income was estimated by the households on a yearly basis, even though it is highly probable that it also changes from year to year (see above). However, in this context, it is also important to study the housing conditions and assets owned by the households to get a better reflection of household´s wealth, which is done below.

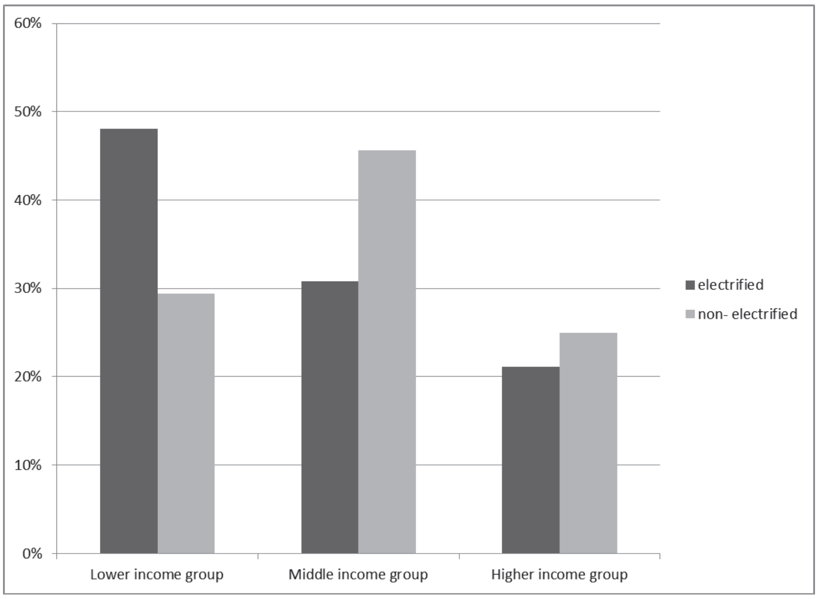

Figure 2. Share of households belonging to corresponding income group in both areas in 2015 in percent

Composition of households´ monthly expenses

The majority of the average monthly expenditures of households in the electrified regions is spent on food (approximately 49%) and education (approximately 24%) (see Table 3). On average the monthly expenditures on transport and health correspond to 9% and 6% respectively. Moreover, the monthly mean expenditures for communication (4%) and other not listed items (4%) are indicated before expenditures for electricity (2%). The expenditures for kerosene and paraffin, dry-cell batteries or firewood are negligible (close to 0% on average). Nevertheless, also the spending on electricity represents only a minor share of the overall monthly expenditures of households.

In the non- electrified villages, also food and education dominate average monthly expenditures. As indicated in Table 3, households spent on average approximately 61% on food and 18% of their expenditures on education. Spending on food is more than 10% higher than in the electrified regions, whereby households in non- electrified areas seem to spend 6% less on education on average compared to electrified households. Interestingly, the households also spend less money on transport and health (5% and 4% respectively). Nearly the same share of expenditures as in electrified areas is spent on communication (4%). Since the households are still not connected to electricity, there are no expenditures on electricity. However, between 3% and 4% of their monthly expenditures is spent on energy sources (kerosene, paraffin, charcoal and dry-cell batteries) on average. To conclude, the average monthly expenditures of a household on alternatives to electricity are higher in non-electrified areas than spending on electricity in electrified villages in 2015.

Table 3. Composition of average monthly household expenses- Shares in percent

	Non- electrified villages 2009	Electrified villages 2015	Non- electrified villages 2015
Education	34	24	18
Water		1	0
Food	44	49	61
Kerosene, paraffin, charcoal		0	2
Firewood		0	0
Dry cell batteries		0	1
Electricity		2	0
Financial services		1	0
Communication services	22	4	4
Rent for housing		0	0
Health		6	4
Transport		9	5
Other items		4	5

Sources: [27]; own data collection

In comparison to baseline data from 2009, spending on education and food is still highest monthly financial burden of households in both areas. However, whereas more money was spent on education on average (34% of monthly expenditures) by then, less money was spent on food on average (44% of monthly expenditures) during that time. Average monthly spending on "energy sources" amounted to 5.5% of total household expenditure [27, p.30f.]. This is slightly higher than the share of expenditures of energy on the total expenditures in the non-electrified villages in 2015. However, it has to be interpreted carefully, because expenditures on energy sources have not been studied separately as in the surveys from 2015 and might for example include the expenditures on fuels for transport, which in 2015 have been included in the expenditures for transport.

Housing conditions and drinking water sources

On average, each household possesses two houses in both areas, where main building has on average 4 rooms, whereas the second house has on average approximately 2 rooms. This has not changed since 2009 [27, p. 24]. In 2015, virtually all of the main buildings have an iron roof top (100% in the electrified villages and 99% in the non- electrified areas). In 2009, fewer households reported to have an iron roof top (88%) [27, p.26] and more main houses still had a grass thatched roof top (12%) during that time. An iron roof top is and has been seen as a status symbol and is also a pre-condition to get electrified due to safety reasons in case of fire. However, also households at the lower end of income classes from the recent surveys reported to own a house with an iron roof top, which questions its use as an indicator for status or wealth. The major floor type of houses is cement in electrified and non-electrified areas (50% and 75% respectively). Approximately 44% of households in the electrified reported to have an earth/sand floor, whereas only 25% of not electrified household indicated to have such a type of floor in their main building. However, in electrified areas there are also few households with different types of floor like ceramic (2%) or others (4%). In 2009, more houses had floor made of earth/ sand (58%) and less floors were made of cement (43%). The housing conditions are also in terms of wall material quite similar in both areas. Approximately 77% but 74% of the electrified and non-electrified main houses are made of baked bricks. This share has been higher in 2009, where 82% of the interviewees reported to have houses made of baked bricks. Many main buildings are built with sun-dried bricks (15% and 23% in 2015 respectively and 12% of the main houses in 2009). Few main houses in the electrified regions have higher standards and are built with cement bricks (4%), which also has been indicated by 4% of the households in 2009 [27, p. 26f.].

Regarding drinking water sources, the households rely on several sources in both areas. In 2015, the drinking water sources used are more heterogeneous in the non- electrified villages than in the electrified areas. These sources also include sources with a higher standard or quality like piped water or water collected from public taps or standpipes. However, the majority of the households catch their water from an unprotected spring in both areas (90% in the electrified areas and 49% in the not yet electrified villages), which underlines that water supply is still inadequate in both areas. Water fetching is mainly done by women and/or children in the electrified and non-electrified regions.

Households ownership of consumer and potentially productive durables

Table 4 shows assets owned by households on average in both regions in 2015. The households in the non- electrified villages own slightly more radios, motor cycle and hand hoes on average. However, one can clearly see that more electric devices are owned by households from the electrified region- this encompasses the average number of mobile phones, colour TVs and computers or laptops. This is also reflected by internet facilities (not included in Table 4) which are owned by very few electrified households.

Table 4. Mean and median ownership of assets by households from the electrified and non-electrified region in 2015

	Electrified villages 2015		Non- electrified villages 2015	
	Mean	Median	Mean	Median
Radio	1	1	1.1	1
Mobile phone	1.8	2	1.6	2
Bicycle	0.3	0	0.2	0
Motor vehicle	0.1	0	0.0	0
Motor cycle	0.3	0	0.4	0
Colour TV	0.4	0	0.2	0
Computer/Laptop	0.1	0	0.0	0
Hand hoe	3.5	3	4	4

Sources: Own data collection 2015

Also in terms of ownership of bicycles and motor vehicles, households from the connected area tend to possess more than non-connected households. Nevertheless, the median might be a better reflection of the real asset ownership of households (see Table 4). It seems that the level of ownership of radios and mobile phones are comparable in both areas, whereas the ownership of hand hoes is higher in the non- electrified areas, where a higher share of annual household income is generated in the agricultural sector.

Approximately 85% of households in the electrified and 87% of the households in the not yet electrified region indicated to possess at least one radio. More households (88%) in the electrified villages reported to have at least one mobile phone compared to 81% in the non-connected area. At least one colour TV is owned by 42% of households in the electrified region and 15% households in the non- connected area. More households in the not yet electrified area reported to have at least one motor cycle (40%) compared to 31% in the electrified villages.

On the other hand, 12% of the households from electrified villages indicated to possess at least one motor vehicle while in the not yet electrified villages only 4% of the households own a motor vehicle. Also, approximately every tenth household in electrified villages owns at least one computer or laptop whereas in the non-connected villages it is only one in every hundred households. All households in the not yet electrified areas indicated to possess at least one hand hoe compared to 96% of households in the electrified areas. 4% of household from the connected areas indicated to own an electric mill, whereas in non-connected villages no household reported to own one.

Interestingly, 8% of the households in the electrified areas reported to own a manual sewing machine- no household owned an electric one- and no household in the not yet electrified area possessed a sewing machine. Rarely or even not owned at all by households in both areas are assets like refrigerators, water heaters, electric cookers, irons and stoves, power tillers, washing machines and fans. However, in the next section the ownership of some electric assets will be discussed more in detail and differenced with respect to solar PV system ownership.

Household users of electricity and solar PV systems- income groups and ownership of electric assets

In 2015, 10% of the households in the electrified villages own a solar PV system and even 6% of the households rely on electricity and solar PV system combined. Consequently, only 4% of the households in that area rely on solar PV systems alone. As shown in Table 6, the majority of the households using electricity belong to the lower income group (43% of total households), whereas 35% or 23% of total households with access to electricity belong to the middle or higher income group. This is a quite good reflection of the distribution of income groups in the electrified villages, which has been discussed above. On the other hand, 40% of the lower but also 40% of the higher income group use a solar PV system in connected villages.

In not yet connected areas, 46% of total households own a solar PV system. The majority of them belongs to the higher income class (45%), whereas 29% or 26% of the users are attributed to the middle or lower income group.

In 2009, only 4% of total households reported to own a solar PV system [27, p.8], which shows that the ownership of solar panels has grown drastically since then. It also implies that nowadays households from non-connected areas might be better prepared for the arrival of the grid, even though there are technical challenges to overcome.

Table 6. Household users of electricity and solar PV systems and their related income group in 2015- Shares in percent

	Electrified villages 2015		Non- electrified villages 2015
Income group[6]	Solar PV system	Electricity	Solar PV system
Lower income group	40	43	26
Middle income group	20	35	29
Higher income group	40	23	45

Sources: Own data collection 2015

However, as can be studied in Table 7, households that own a solar PV system in the non-connected area are prepared in terms of ownership of electric assets. Approximately 94% of the solar PV system owners reported to possess at least one radio or mobile phone, whereas only 83% or 69% of the non-solar PV system users indicated to possess at least one of these assets.

Table 7: Average ownership of electric assets by households and shares of at least owning one of the assets in percent in 2015

Non-electrified villages in 2015				
Solar PV system owners	Radio	Mobile Phone	TV	Computer/ Laptop
Average no. per Household	1.4	1.6	0.2	0.01
Share of HH owning at least one…	94	94	28	3
Non solar PV system owners	Radio	Mobile Phone	TV	Computer/ Laptop
Average no. per Household	0.9	1.2	0	0
Share of HH owning at least one…	83	69	0	0
Electrified villages in 2015				
Solar PV system owners	Radio	Mobile Phone	TV	Computer/ Laptop
Average no. per Household	1.4	1.8	0.6	0
Share of HH owning at least one…	100	100	60	0
Non solar PV system owners	Radio	Mobile Phone	TV	Computer/ Laptop
Average no. per Household	1	1.7	0.4	0.1
Share of HH owning at least one…	83	87	40	10

Sources: Own data collection 2015

[6] In the surveys from 2015, income groups were distinguished as follows: Lower income groups encompass households that earn less than 1.200.000 Tshs. per year, middle income groups include households with an income between1.200.000 and 3.600.000 Tshs. per year and higher income groups earn more than 3.600.000 Tshs. per year.

This is also reflected in the average number of assets owned. On average, each solar PV system user possesses approximately one radio and two mobile phones. Non-solar PV system users own approximately one radio and one mobile phone on average. The average ownership of TV and Computer is slightly higher for PV system owners. Nearly a third of these households in the non-connected area reported to have a TV and 3% even indicated to own a Computer or Laptop. On the contrary, non- solar PV system users have not indicated to own a TV or Computer or Laptop. On average, ownership of a radio, TV or mobile phone is slightly higher for solar PV-system owners in electrified villages than for non-solar PV system owners (see Table 7).

On the contrary, 10% of the households in the electrified area reported to own a Computer but not a solar PV system. All solar PV system owners reported to possess at least one radio or mobile phone. 60% of them indicated to have at least one TV, which is much higher than non-solar PV system owner indicated (40%). However, in both areas, solar PV system owners tend to possess more electric assets on average than households that do not own a solar PV system.

Enterprise users of electricity and solar PV systems- income groups and ownership of electric assets

Approximately 62% of the enterprises in the non-electrified areas reported to use solar PV-systems, whereas in the electrified areas only 11% of the enterprises indicated to rely on solar PV systems. However, all of the enterprises in connected areas reported to rely on electricity and solar PV system combined. As can be seen in Table 8 below, the majority of enterprise owners and PV system users belong to the middle or higher income group in both areas. In contrast to households as discussed above, enterprising relying on electricity belong mostly to the middle or higher income classes.

Table 8. Share of enterprise owners using solar PV systems and their related income group in 2015- Shares in percent

	Electrified villages 2015		Non- electrified villages 2015
Income group[7]	Solar PV system	Electricity	Solar PV system
Lower income group	0	28	29
Middle income group	25	28	38
Higher income group	75	44	24

Sources: Own data collection 2015

Approximately half of the enterprises owning a solar PV system in the not yet connected area reported to use it for operating equipment. On the contrary, no enterprise possessing a solar PV system in the electrified area indicated to run electric equipment with solar power. All solar PV system owning enterprises use the system for lighting. As can be studied in Table 9,

[7] In the surveys from 2015, income groups were distinguished as follows: Lower income groups encompass households that earn less than 1.200.000 Tshs. per year, middle income groups include households with an income between1.200.000 and 3.600.000 Tshs. per year and higher income groups earn more than 3.600.000 Tshs. per year.

solar PV system owners tend to possess more electric assets on average than non- solar PV system users in both areas.

Additionally, the share of enterprises of possessing at least one of the assets is higher for solar PV system users in electrified and not yet electrified area. The difference in ownership is especially striking in the non-electrified villages, where non solar PV system owners indicated to possess less electric appliances on average than solar PV system using enterprises.

However, at this stage of research it needs to be mentioned that the electric assets indicated in Table 9 - radio, TV and mobile phone- are not necessarily applied for productive uses but have implications for electric use and are owned by most enterprises in the areas.

Table 9. Average ownership of electric assets by enterprises and shares of owing at least one of the assets in percent in 2015

Non-electrified villages in 2015			
Solar PV system owners	Radio	Mobile Phone	TV
Average no. per enterprise	0.8	0.9	0.1
Share of enterprises owning at least one…	80	50	10
Non solar PV system owners	Radio	Mobile Phone	TV
Average no. per enterprise	0.2	0.3	0
Share of enterprises owning at least one…	17	17	0
Electrified villages in 2015			
Solar PV system owners	Radio	Mobile Phone	TV
Average no. per enterprise	1	1.8	0
Share of enterprises owning at least one…	100	75	0
Non solar PV system owners	Radio	Mobile Phone	TV
Average no. per enterprise	0.5	1	0.1
Share of enterprises owning at least one…	43	63	9

Source: Own data collection 2015

CONCLUSION

This study gives valuable insight in the socio-economic conditions of households in electrified and not yet electrified areas in the Mufindi Region in Iringa, Southern Tanzania and compares them with baseline data from 2009. Next to data on household level, this study also analyzes electric asset ownership and income groups of small enterprises and its owners. In 2009, when the first Baseline Study of the Mwenga Hydro Project has been conducted, very few households or enterprises reported to own solar PV systems. Since then, the prices for solar PV systems have declined and the markets further developed. In 2015, many household and enterprises in the non-connected area indicated to possess solar PV systems, therefore already to have access to electricity, even though limited. However, this has an effect on the situation of households and enterprises, which may be better prepared for the arrival of the grid or grid-quality access. It has been detected that households and enterprises who own a solar PV system possess more electric appliances and in case of access to electricity sometimes combine the usage of electricity and solar PV system. Additionally, solar PV system owners- enterprises and households- tend to belong to higher income groups in electrified and non-electrified areas compared to non-solar PV system owners. On the contrary, electricity users do not necessarily belong to higher income classes, especially on household level. Further research is needed to identify control and counterfactual groups for a more profound comparison of electrified and non- electrified units and a causal conclusion.

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6. Socio-economic impacts of rural electrification in Tanzania

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Socio-economic impacts of rural electrification in Tanzania

Annika Groth*

Department of Energy and Environmental Management (EEM-SESAM), Interdisciplinary Institute for Environmental, Social, and Human Studies, Europa-Universität Flensburg, Munketoft 3b, 24937 Flensburg, Germany

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

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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

[1]Corresponding author - e-mail: annika.groth@uni-flensburg.de

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):

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

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

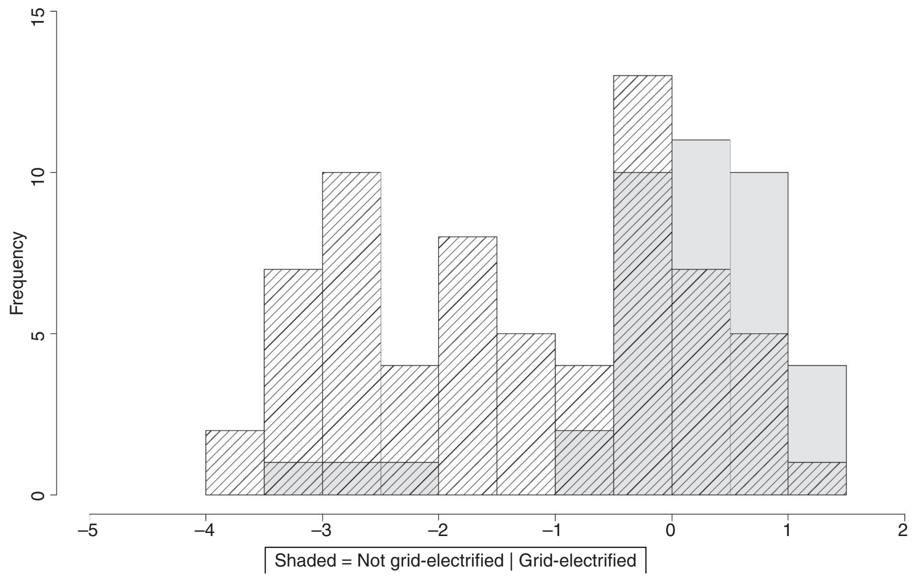

Figure 2: Distribution of linear propensity scores
Source: Author

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.

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Overcoming One-way Impact Evaluation of Rural Electrification Projects

Annika Groth*

Europa Universität Flensburg, Germany. *Email: annika.groth@web.de

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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,

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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:

$$(Y_1, Y_0) \perp D|X; \tag{1}$$

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:

$$0 < P(D{=}1|X) < 1. \tag{2}$$

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:

$$ATT = E(Y_1|D{=}1) - E(Y_0|D{=}1); \tag{3}$$

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:

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

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:

$$\Delta = ATT + SB; \tag{5}$$

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%	$\chi^2=0.17$
Share of businesses dealing with agriculture	47%	52%	$\chi^2=0.01$
Share of businesses dealing with manufacturing	11%	0%	$\chi^2=1.96$
Share of businesses dealing with trade	61%	42%	$\chi^2=1.65$
Share of businesses dealing with services	21%	33%	$\chi^2=0.80$
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.

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

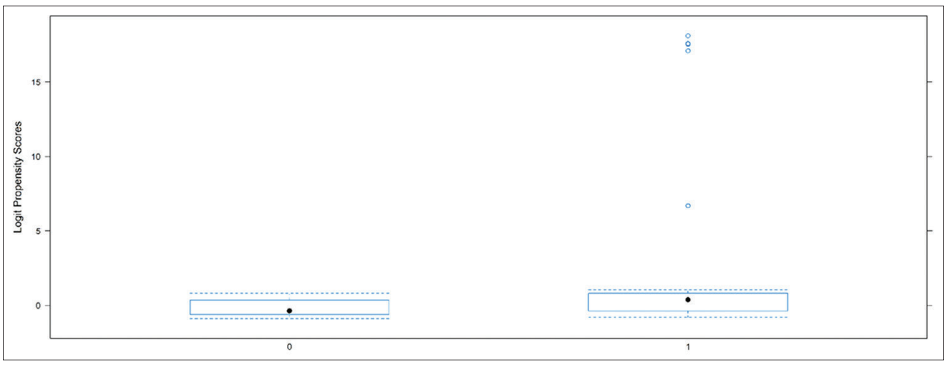
5.5. Evaluation of Covariate Balance of the Different Matching Techniques

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.

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



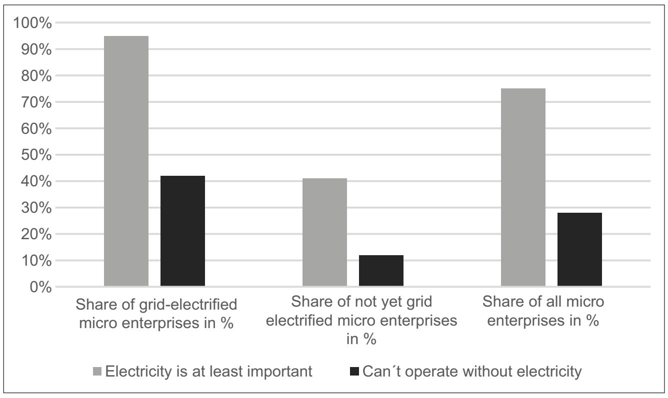
5.6. Estimation of Treatment Effects

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)

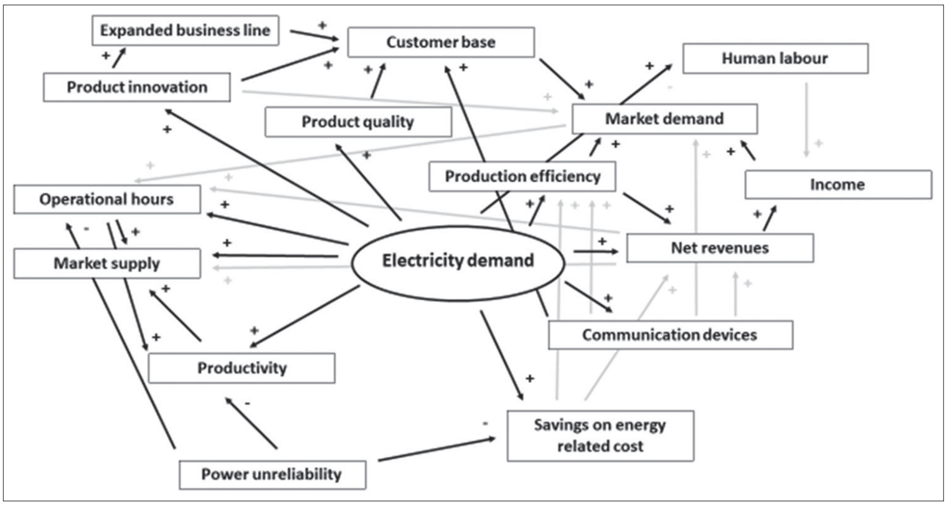
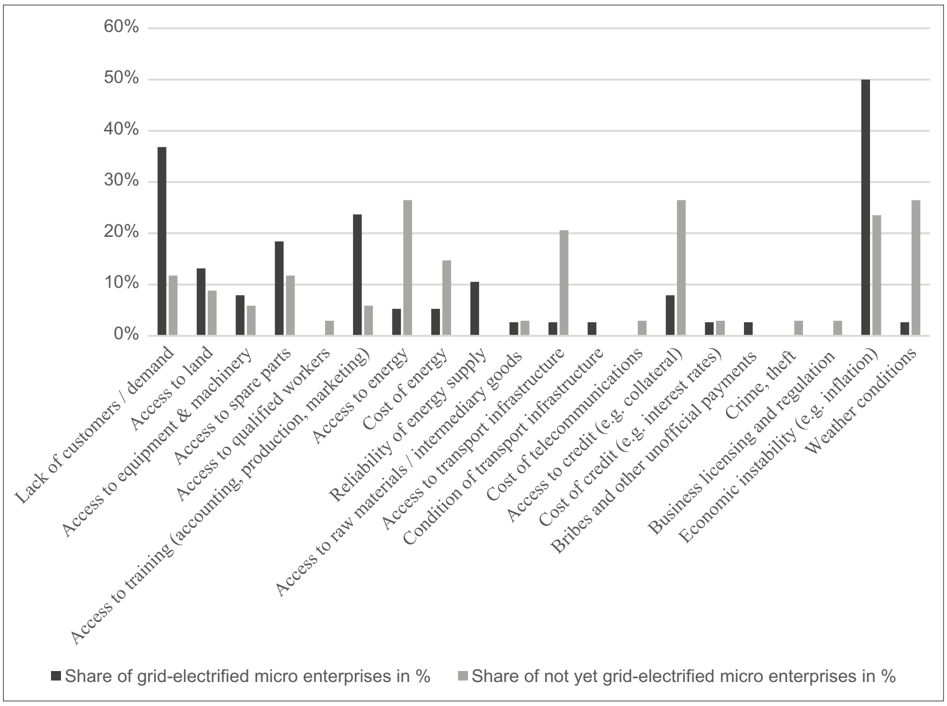


Figure 5: Perceived major business constraints of grid-and non-grid-connected micro enterprises in %



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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8. Impacts of electrification under the perspective of the Multi-Tier-Framework in Southern Tanzania

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

Annika Groth

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

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

A. Groth (✉)
Department Energy and Environmental Management, Interdisciplinary Institute for Environmental-, Social- and Human Studies, Europa Universität Flensburg, Flensburg, Germany
e-mail: annika.groth@uni-flensburg.de

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11.1 Introduction

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

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

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

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

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

11.2 Background

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

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

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

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

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

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

11.3 Methodology

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

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

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

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

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

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

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

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

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

Source Own elaboration based on [18]

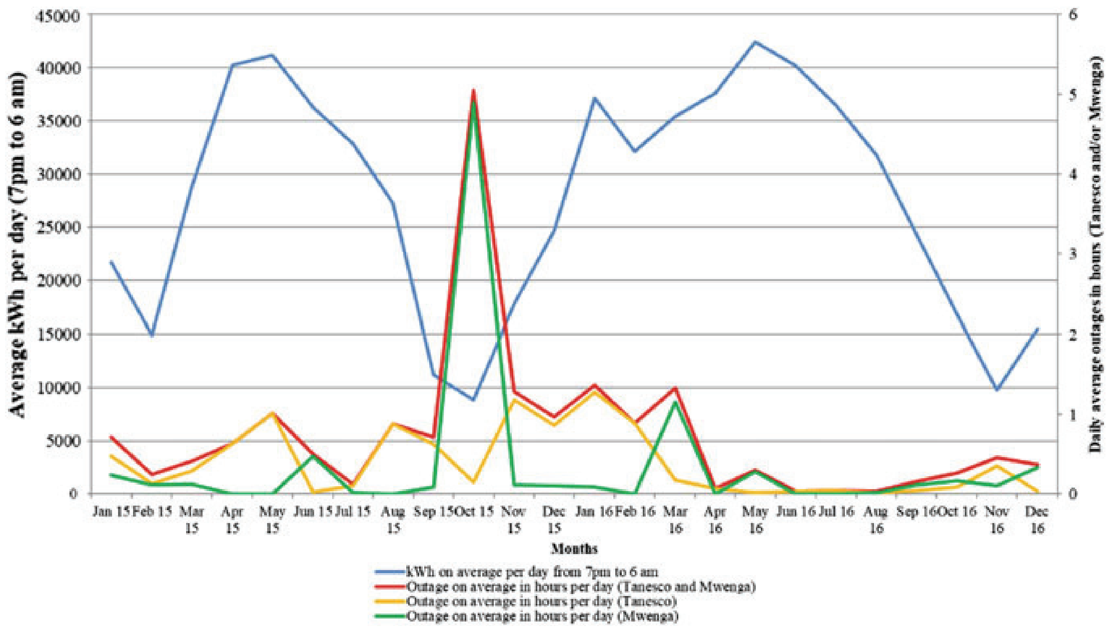

Fig. 11.1 Daily mean power outages in hours and distributed kWh (7 p.m. to 6 a.m.). *Source* Own elaboration based on [18]

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

11.4 Results and Discussion

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

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

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

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

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

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

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

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

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

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

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

Table 11.2 Households average lighting hours per day

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

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

Source Own elaboration based on [14, 18]

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

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

Source Own elaboration based on [18]

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

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

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

11.5 Conclusion and Recommendations

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

Annex

See Tables 11.4 and 11.5.

Table 11.4 Household survey on energy sources and usage

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

*Home based work

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

Table 11.5 Household survey on lighting devices and daily average usage

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

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

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9. Synthesis

Being classified as a general-purpose technology (GTP), electric power is a crucial and necessary (but insufficient) requirement to advance socio-economic development in the Global South, and it is widely believed that electrification projects should replicate the success stories of the West. To date, there is no consensus regarding the direction and type of relationship between economic development and electric power consumption (see 141 and 144), which also includes research on the matter in SSA countries. There is broad agreement, however, that both factors strongly correlate with each other and carry transformative socio-economic potential.

To enable a deeper understanding of the context of a SSA country, Chapter 4 of this thesis conducted an analysis of the relationship between electric power consumption and GDP in Kenya on the macro level. Aside from relying on an augmented econometric approach to study the data, this section also discussed the difficulties of deriving meaningful policy recommendations for decision-makers based on a highly aggregated data set that can be impacted by structural breaks, which can hide or miss essential information. This reflects, overall research trends and the position of this thesis, underlining the need for research at the micro level in order to reflect reality at the “bottom” and to serve as a basis for measures addressing poverty reduction.

Following experiences in the West, grid electrification is still the preferred method for electrifying a region, including efforts in Kenya and Tanzania. This approach may become uneconomical and unfeasible, however, when implemented in difficult terrains with low population densities and energy consumption levels, which is the situation of rural areas in these two countries. The preferences for grid extensions are also reflected in research on the impacts of rural electrification, whereby the majority is conducted in the context of grid electrification and higher tiers of electricity access (174–176), while there is less focus on off-grid systems and interconnected energy systems (177, 155, 156). The same applies to research on the impacts of electrification in general (134: p.6) and in the SSA setting (178, 105). In addition, many studies lack well-founded empirical approaches and evidence (105).

Recently, the evaluation of the impacts of electrification based on rigorous methods has become increasingly common. This thesis contributes to the growing body of research in this area by studying two cases from SSA and analysing the impacts of (pre-) grid electrification on households and small enterprises. Furthermore, this thesis describes different modes of electrification and distinguishes between grid electrification and interconnected mini-grids (Chapter 8), and interconnected mini-grids and off-grid electrification (Chapters 5, 6, and 7).

The study on the macro level in Chapter 4 strives to answer the following questions:

Is there a causal relationship between electric power consumption and economic output? If so, what is the type and direction of the relationship, and is it impacted by structural breaks? What implications can be drawn from this?

To address these questions, Chapter 4 sought to establish whether a causal relationship between electric power consumption and GDP in Kenya can be traced between 1970 and 2014, under the consideration of structural breaks. Key macro indicators such as GDP growth or GDP per capita suggest that Kenya is among the fastest growing economies in East Africa, whereby the pace of electrification has increased in recent years. However, the aforementioned heterogeneity in terms of causality and the direction of the relationship is also evident in this work. Time series data on economic output and energy consumption are interrupted by events such as droughts and severe economic crises. It is assumed that their existence could bias the results of the empirical analysis and therefore impact any statistical inferences based on these results. As anticipated, the statistical analyses in the case of Kenya yield different results, depending on whether or not the structural breaks in the time series data between 1971 and 2014 are taken into account. While no causal relationship between the two variables can be established for the entire sample period, at the subsample level, a unidirectional relationship running from electricity consumption to GDP can be detected. In the case of the first result, changes in Kenyan GDP or electric power consumption should not affect each other. Thus, policies or shocks (such as energy conservation policies or losses in economic output) should not have any negative implications for GDP or electricity consumption. However, the analysis of the subsample shows that there is a one-directional relationship between electricity and GDP. As a result, a shortage of electric power consumption can have negative effects on the expansion of economic output. The findings underline the importance of controlling for structural breaks when studying a relationship. Their existence may significantly change the direction and type of the relationship established between GDP and electric power consumption and, consequently, any resulting policies. Moreover, the study in Chapter 4 critically reflects on the availability and validity of highly aggregated data. Access to long-term and continuous time series data is critical for a robust empirical analysis.

To reflect on the effects of electrification on the micro level, the thesis aims to find answers to the following overarching questions:

To what extent do access to and use of different modes of electrification and their parallel existence affect the socio-economic conditions of households and micro enterprises in the SSA context? Can causality be established?

The study in Chapter 5 presents the findings from a comparison of baseline data of an interconnected mini-grid project in Mufindi, in the Southern Highlands of Tanzania. It is the first out of four studies on the Mwenga Hydro Power mini-grid system and allows the reader to gain a deeper understanding of the project and the socio-economic conditions in the research area. The findings from the present study can be seen as a reference for the subsequent studies in Chapters 5 and 6. However, it should be noted that the results on the socio-economic conditions of households and enterprises may differ from chapter to chapter, since the results of the present study are based on qualitative analysis and descriptive statistics, whereas the results in Chapters 5 and 6 are determined by an empirical methodological approach that compares the research units based on their propensity scores. The starting point of the analysis in Chapter 5 is a baseline study on the project from 2009. In 2015, further data were collected as a basis for analyzing the socio-economic impact of grid electrification. At that time, four of the six sampled villages had been electrified by a mini-grid system for three years. Particular emphasis was placed on the households and enterprises that indicated owning a SHS irrespective of their grid connection status. The study in Chapter 5 reveals that heads of household are primarily occupied in the agricultural sector and generate a major share of their annual income there, which reflects the lasting importance of this sector for the whole Tanzanian economy (see also Section 1.2 above). Moreover, the income generation sources of households have been identified as being more diverse in grid-electrified villages in comparison to villages that are not yet grid-electrified. However, more of the latter households indicated that they belonged to the middle and higher income classes. In both areas, the ownership of SHS has increased substantially in recent years. Whereas in 2009 only 4% of the households indicated owning an SHS (196), by 2015 this figure had increased to 47% in not yet grid-connected villages and 10% in grid-electrified villages. It is further observed that households and enterprise owners from the higher income class are more likely to possess an SHS and tend to own more electric appliances, regardless of grid connection status. Thus, the descriptive data suggest that pre-grid electrification statuses are mainly related to the higher income groups of households and enterprise owners. On the other hand, more than 40% of households in grid-connected villages reported having access to grid electricity and belonging to the lower income class. The findings of the study suggest that the socio-economic statuses of rural households determine (pre-grid) electrification, which could in turn imply that inequalities between the different income groups could increase or intensify if not properly addressed by policy makers. Therefore, it is recommended that a more detailed analysis of the socio-economic effects of (grid-)electrification on households should also consider the distributional effects of (subsidized) electrification on different income groups.

In order to reflect on the causality of the relationship between electricity access and socio-economic development, the thesis aims to answer the following question:

To what extent do access to and use of electricity from an interconnected mini-grid project affect the socio-economic conditions of households and micro enterprises in rural SSA areas, in comparison to not yet grid-connected but potentially pre-electrified, off-grid home-scale system users?

Based on the findings in Chapter 5, Chapter 6 offers an analysis of the socio-economic impacts of grid electrification on households in the Mufindi region of Tanzania. A special focus was placed on the pre-grid-electrification status of households because the penetration rate of SHS has accelerated in recent years (see Chapters 1 and 5) and needs to be reflected in research on the impacts of rural electrification. In order to establish comparison groups, the study in Chapter 6 makes use of PSM. The estimation of propensity scores is based on the gender and educational level of the head of household, the number of household members, and members contributing to income, as well as the main source of household drinking water and the household´s main building floor type. Overall, the empirical results suggest that the electricity consumption of households is relatively low and focuses on only a few electric appliances.

Accordingly, the ownership of electric appliances (or “indirect connection costs”) in grid-electrified households turned out to be only slightly higher compared to not yet grid-electrified households. In general, electricity consumption is mainly focused on lighting, communication, or entertainment, and correspondingly less on productive uses. As expected, the most notable effects of the usage of grid electricity were detected in lighting and the quality of lighting. Improved lighting can be seen as an intermediary impact of electricity, due to its relevance to many household activities. Regarding the weekly usage of and expenditure on energy sources, the results after matching indicate that grid-electrified households have lower weekly usage and expenditures for dry-cell batteries than not yet grid-electrified households. If adequate disposal of dry-cell batteries cannot be guaranteed, this finding may suggest that households with access to grid electricity are less likely to be exposed to health risks and that their environment is also less likely to be burdened by the inappropriate disposal of batteries. On the other hand, the non-significant difference in terms of weekly consumption of and expenses for paraffin and kerosene after matching may indicate that these fuels are less commonly used in both areas. In off-grid villages, this finding could be attributed to the accelerated penetration of solar-based technologies, but also to lighting devices that are powered by dry-cell batteries. The study determines that firewood is still mainly used for cooking in both grid- and not yet grid-connected areas. Households from both areas are not just ascending the energy ladder, but do seem to be combining traditional energy sources with higher quality fuels such as electric power. Essentially, households in the Mufindi region seem to stack fuels. To sum up, the results suggest that households combine different technologies in order to power their appliances. Based on these findings, the chapter advocates for a better reflection of the pre-grid-electrification statuses of households in planning for rural electrification. Planners should study the electricity requirements of off-grid households in detail, and consider the need for complementary infrastructures to spur electricity consumption. Additionally, the supportive role of rapidly evolving and disseminating off-grid technologies and systems in meeting basic electricity demands should not be underestimated.

Chapter 7 deals with the dynamics between the electricity consumption and local market production of micro enterprises in the Mufindi region. The heterogeneity of business types makes it difficult to identify and generalize the impacts of grid-electrification. For example, some businesses rely heavily on energy inputs (e.g. mills), while others mainly rely only on electric lighting (e.g. small kiosks). Therefore, the impact study focuses on daily lighting and lumen hours, as well as on operation hours during times of darkness. The analysis of the average treatment effects of electrification relies on PSM, while the investigation into the dynamics is done on a qualitative level. In line with the observations from Chapter 5, the majority of the businesses are agricultural, reflecting the importance of this sector for the entire economy. Many micro enterprises are in the fields of trade and services, while a smaller number deal with manufacturing. Most of their products and services are sold and consumed locally, which reflects their lack of access to markets further afield. The estimation of propensity scores is based on dummy variables for agriculture (indicating whether businesses are dealing with (saw) mills or not), manufacturing, trade (indicating whether businesses are dealing with trade, such as retail shops, or not), services (indicating whether businesses offer services or not), and the gender of the owner. Additionally, the estimation relies on the real capital endowment of businesses used as a proxy for the pre-grid electrification business size and profitability of the enterprise. In terms of daily lighting and operational hours, the impact study infers that the number of discrepancies between off-grid and grid-connected micro enterprises is not very high. No statistically significant differences in terms of real capital endowment – including electric appliances – were detected. Overall, small grid-electrified business owners indicated that a lack of customers, access to markets and capacity-building measures as well as economic imbalances are major constraints for the development of their businesses. In contrast, not yet grid-electrified enterprises identify insufficient access to energy sources, transport infrastructures, and credit, as well as economic disturbances, to be constraining factors for their business development. While problematic access to energy sources may underline the need for not yet grid-connected enterprises to access grid electricity, it should be kept in mind that access to grid electricity alone may not be sufficient to address the constraints. The importance of complementary structures and activities for the full development of the potential for electrification was reaffirmed. Again, it becomes evident that planners should consider the supportive function of off-grid systems in meeting the basic electricity demands of micro enterprises and counterbalancing power interruptions.

Power outages are a frequent phenomenon in Tanzania and have effects on access to electricity and therefore on socio-economic conditions. As a result, Chapter 8 studies the impacts of power interruptions in the Mwenga mini-grid system. The study focuses on lighting as it represents the main purpose of households' electricity usage. To reflect the reliability of the Mwenga power system, the study takes into account the duration and frequency of power interruptions. Power outages are defined as the time end-consumers do not receive electricity delivered by the interconnected mini-grid system between 7pm and 6am. The running mode of the mini-grid system (interconnected with the main grid or running in an isolated mode) is not considered here. Hence, the analysis only takes into account unplanned power outages from the main grid and power outages due to occurrences within the mini-grid system. For the purposes of comparison and to reflect on the increased significance of off-grid systems, the analysis further considers lighting powered by off-grid devices in not yet grid-electrified households. Based on the descriptive statistics, the study concludes that the interconnection of the national grid and mini-grids significantly enhances the reliability of access to electricity. The interconnected system is able to adapt its distribution to seasonal or extraordinary events. This applies in particular to the use of electricity for basic energy services, such as lighting. Furthermore, the qualitative data suggest that the interconnection of systems can help to counterbalance the effects of extraordinary events and power outages by stabilizing the power supply and thereby also contribute to the enhanced performance of connected businesses. Despite being affected by power outages, the lighting hours of grid-connected households are still significantly higher than off-grid households. This highlights the advantage of grid-based systems. Based on the findings of this study, planners should consider the counterbalancing potential of interconnected systems in rural electrification, and the complementary role of off-grid systems in particular. More data and rigorous data analysis are needed to substantiate qualitative statements.

9.1 Discussion

Through the course of this work, it has become clear that data constraints represent a major barrier for researchers, limiting their scope as well as affecting the reliability of their findings (also discussed by Bacon et al. (2)). This is especially true for research relying on data on a highly aggregated level. The quality of aggregated data is determined by the availability of the data and (financial) capabilities, but can also be “subject to political instructions” (15: p.13, p.16). In particular, African development statistics lack validity and reliability, which may call into question their applicability for the allocation of resources (e.g. by governments or international organizations) (15: p.16).

What appears meaningful on the aggregated macro level is not inevitably reflected on the micro level: Aggregated data sets in the area of electricity access and economics may not necessarily reflect local daily realities. As previously reflected on in Chapter 1, pure reliance on GDP indicators as a prosperity measure was questioned three decades ago and has become increasingly outdated. Since then, it has been widely acknowledged that most people “evaluate their respective countries’ economic progress not by published GDP growth statistics but by changes in their households’ standard of living — a multidimensional phenomenon that encompasses income, employment opportunity, economic security, and quality of life” (179). Economic development measured by the mere expansion of economic output (GDP) may be too narrow to reflect the general well being of the population in the research areas, when it excludes socio-cultural or political conditions or informal sector activities. The latter are of significant importance to most African economies but numbers are difficult to capture due to the informal nature of the work.

Likewise, in Chapter 4 it has been discussed that records on electric power consumption that only consider grid electricity consumption – without including off-grid electricity consumption – miss a large part of the real electricity consumption in Kenya. For example, electric power access and needs could be enhanced and improved by technologies that are not necessarily officially registered and policy-driven but are instead unrecorded and market-driven solutions. Since 2015, this has been at least partly addressed by the introduction of the SEforALL’s Multi-Tier-Framework (MTF) from the World Bank (180), which defines electricity access not as binary but as multi-dimensional[9]. The main idea of the MTF is to better capture the multiple modes and natures of access to electricity. However, data collection using global baseline surveys has only begun recently, and the database is to be expanded to allow for a more robust capture of the “granularity of electricity access” (10: p.27), off-grid reports, and comprehensive time series data analysis. This, of course, also refers to data measuring well being. Tracking progress is a challenging and expensive task, however, especially when the data systems need to be developed

[9] The MTF classifies different levels of access to electricity ranging from tier 0 to tier 5. Tiers are distinguished by the following attributes: capacity, availability, reliability, quality, affordability, legality, health and safety (180).

and implemented, and it has been estimated that the expansion of data and statistical systems to monitor SDGs in developing countries requires annual investments of $ 1 billion USD (133).

Apart from the technical constraints to measuring electricity access or well-being, there is an ongoing debate concerning conceptual approaches. While there is consensus that traditional concepts are weak in monitoring progress, whether the focus should be on comprehensive multidimensional indexes or on a set of indicators (such as the MDGs or SDGs), or on a “dashboard” of isolated indicators is still under discussion (55, 113). Recent research calls for a stronger emphasis on the micro level for the development and assessment of effective poverty reduction measures (98). This includes (quasi-) experimental research methods such as RCTs or PSM, which is the focus of the present thesis (Chapters 3, 6, and 7).

Electricity demand projection is a key element in rural electrification planning because it determines the (financial) viability of electrification projects. Electricity demand forecasters need to identify the institutional, socio-cultural, financial, and technical drivers of and barriers to electricity consumption, which depend to a large extent on the local context and conditions. Many planners rely on energy use surveys to project electricity demand in developing countries. However, these projections may be susceptible to errors and can thereby contribute to over- or under-sized energy systems, threatening the technical and financial sustainability and viability of electrification projects (as critically discussed and surveyed by Blodgett et al. (181) and Peters et al. (182). Major sources of error in electricity demand projection in developing countries can be attributed to a lack of historical data as well as a general lack of knowledge and experience concerning energy users and electricity usage (181, based on 183 and 184).

Experimental research, such as RCTs, can help to better understand the underlying drivers of and barriers to electricity consumption and quantify the social welfare consequences of rural electrification. Experimental research findings can support policy makers in prioritizing projects and adapting the allocation of (financial) resources accordingly. In this context, it should be noted that experimental studies such as RCTs may not answer the “big questions of development” that “strive to enhance economy wide effects of good institutions or good macroeconomic policies”, (98: p.236f, based on 185). However, “careful thinking and rigorous evaluation can help “to design systems to keep (..) inefficiency in check. (…) Incremental progress and the accumulation of these small changes (…) can sometimes end in a quiet revolution” (98: p.237). Thus, the contribution of case studies to the understanding of “development”, such as the one presented here, should not be underestimated.

Relying on a (quasi-) experimental method, the studies on the socio-economic impacts of electrification in the Southern Highlands of Tanzania in Chapters 6 and 7 contribute to this research field. The findings suggest that the electric appliance uptake of households and micro enterprises three years after grid electrification is at comparatively low levels, and households’ daily usage of electric appliances is still at a subsistence level. Moreover, the discrepancies between grid-connected and not yet grid-connected households in terms of electric appliance ownership are relatively low and the effects of grid electricity are mainly related to higher lighting quality (also observed in Chapter 8) and a higher daily usage time of a few electric devices. The same has been detected for micro enterprises (Chapter 7). Officially recorded data from the mini-grid distribution confirm the observed low consumption levels: approximately 80% of rural customers consume less than 50 kWh per month, and their average consumption amounts to only 16 kWh per month (186). This is much lower than the subsistence level of electricity consumption, which amounts to 30 kWh per month. However, with a daily mean electricity consumption higher than 200 Wh, the average consumption level of those customers corresponds with Tier 2 from the MTF, while a mini-grid system capacity would allow for higher tier electricity services. The low electricity consumption levels of the rural community may underline the dependency of the Mwenga mini-grid distribution on its anchor customers (Tanesco and the local tea, coffee, and timber industries) to support its financial viability. This could change when more households and micro enterprises from the rural community become connected to the grid[10], an issue that requires further study.

In not yet grid-electrified villages, 47% of the households indicated owning and using an SHS (see Chapter 5). The data suggest that the average SHS capacity of households amounts to 60 W, while median SHS capacity is roughly 50 W. Households spend on average approximately $ 230 USD acquiring such a system. These costs reflect the final prices households indicated to have paid, thus potential subsidies or tax and (import) tariff exemptions are already reflected here.

Compared to the subsidized average grid connection costs, however, SHS acquisition costs are much higher and do not include maintenance and replacement costs. The comparatively high acquisition costs could explain why SHSs are primarily purchased by higher income groups. Mean or median SHS capacity levels correspond to Tier 1 and 2 from the MTF (180), which shows that off-grid households from the rural community have access to an electricity supply that goes beyond basic electricity needs (includes general lighting, phone charging, TV and fan). This electricity access level is equivalent to the electricity consumption level of grid-electrified households (see above) and may explain why average discrepancies in terms of electricity usage between grid and not yet grid-electrified households are relatively low. While both the off-grid SHS capacity levels and the electricity consumption levels of grid-electrified households may be too low for productive purposes (Tier 3 and above in the MTF (180)), newer generation SHSs may have higher capacities and allow for higher loads at affordable prices. Yet, the question of how to induce electricity demand that meets the systems' capacities remains. More research is needed to capture the drivers of and barriers to electricity demand in this area.

In Chapter 5, it has been determined that households from lower income classes also rely on grid electricity, whereas SHS ownership and usage is mainly restricted to households from the middle to higher income classes. At this stage, it should be kept in mind that the distribution costs of the mini-grid system are subsidized. Average costs of a new connection to the grid amount to approximately $920

[10] There is an on-going project expansion of rural electrification in the nearby Kihansi Basin.

USD. However, subsidies lower the costs per connection to $70 USD (186). Tariffs on (prepaid) grid electricity ($ 0.03 per kWh) are cross-subsidized by higher tier customers ($0.13 per kWh) (186). Hence, subsidized connection costs and tariffs of the mini-grid system seem to be affordable for poor households in the Mufindi region and allow them to access higher tier electricity services. However, connection costs may still pose a major barrier when households have to pay an extra fee for their connection to the grid due to their remote location (in 2015, >30 m distance from the transmission line). This could also be the case for indirect connection costs, such as electric appliances, which would explain at least part of the low uptake of electric appliances after grid electrification. Donor funding having the effect of reducing connection costs may distort the long-term financial sustainability of the project and should be addressed in future research. Donor funding to expand rural community connections and guarantee facilities becomes even more important when one takes into account the frequent payment defaults of the main customer Tanesco. Regular defaults may threaten the financial viability and sustainability of the Mwenga mini-grid system distribution (186).

Moreover, subsidies for connection costs and tariffs on grid electricity could have distributional effects on villages, as subject which should be examined in more detail in a future study. It would be interesting to know whether subsidies could counterbalance inequalities between households of different income classes. In contrast to SHS, subsidized grid electricity appears to be affordable for lower income groups. On the other hand, it is worth knowing what would happen if connection costs and tariffs were not subsidized or were subsidized to a lesser extent. Would households still aspire to gain access to grid electricity? For example, Postepska and Blimpo (187) found that the level of income of SSA households is a key factor in electricity uptake, but irregularity and unpredictability of income represent major barriers. Conversely, if electricity consumers overestimate their own future solvency, e.g. their expectations concerning the development of their income after grid electrification may be too high. This could lead to welfare losses on the individual, household, community, regional and/or even national levels.

Improved living quality through access to higher tier and more reliable electricity (see Chapter 8) should not be underestimated. On a qualitative level, it was observed that many people aspire to and desire access to grid electricity because they consider it to be a tool that has the potential to move them out of poverty, enhance their social status, and enable them to participate in "progress" and, thus, improve their standard of living. To further illustrate this, I cite an example from a head of household from a not yet grid-electrified area: "(Grid-) Electricity is very important for us. We are waiting for your (the Mwenga mini-grid distributer's) action to deal with our problems with not being connected to the grid for such a long time. We see it as a dream (…)". The increased penetration rate of SHS in off-grid Mufindi areas indicates that many households already have experience accessing electricity and could, therefore, estimate their (future) electricity needs. Yet, the data analysis suggests that even when the dream of electrification is fulfilled, the electricity consumption of households and micro enterprises remains at comparatively low levels (see Chapters 6 and 7). However, the above statement emphasizes the hope and aspirations associated with having access to grid electricity and underlines the social dimension of being connected to higher tier electricity access.

Overall, the findings of this thesis reflect several lessons: electrification via grid expansion does not encounter totally “infrastructure-less” spaces, but rather rapidly changing contexts where a random collection of different energy services, although still rudimentary and limited, already exists. Thus, based on the results of the case study, we can assume that off-grid rural SSA areas do not necessarily lack electricity and that at least the basic needs can be met to a substantial extent by solar-based, decentralized technologies. Consequently, up to a certain threshold, living conditions can already be improved through access to these technologies and the treatment effects of grid electrification can be expected to be less pronounced (also observed by Bensch et al. (155) in the rural Tanzanian context).

However, regulatory hurdles are frequently cited as hampering off-grid system development, such as solar mini and micro-grids (102). Project partners from the Mwenga Hydro Power Project reported the difficulties they had to overcome in realizing the mini-grid project. As one of the first projects under the Small Power Producers program, they had to secure over 30 documents (permits, licenses, and agreements), which led to significant delays before the project became operational in 2012 (186). This shows the importance of firm political commitments and supportive regulatory and enabling frameworks that allow new forms of energy supply to flow.

Despite these challenges, the penetration rates of off-grid and mini-grid energy systems are on the rise. In Tanzania, the capacity of solar lights and SHS increased from 0.272 MW in 2011 to 17.438 MW in 2016 (188). This figure corresponds to approximately 1% of the total power generation capacity installed. On the other hand, the mini-grid system capacity accounts for approximately 10% of total power generation capacity installed (189). International and local private enterprises have contributed to the acceleration of mini-grid system implementation in recent years (189). In Kenya, the capacity of solar lights and SHS increased from 0.408 MW in 2011 to 11.974 MW in 2016 (188).

Accelerated penetration rates of solar-based technologies may underline the power of market-driven solutions, which are not necessarily supported by governmental actions. Yet, as mentioned above, it has to be acknowledged that the abolition of the value-added tax on solar panels in Kenya and Tanzania has significantly contributed to these developments (6: p.109). Furthermore, the role of donors in simplifying (financial) access to these technologies should not be overlooked. The interaction between the public and private sectors and public-private partnerships is responsible for the accelerated off-grid system development (6). This suggests that market-driven solutions alone are not yet sufficient to drive (off-grid) electrification.

A consumer-driven (pre-grid-) electrification may be applicable to the (basic) electric service of lighting. LED technologies are widely available and affordable even for poor households in SSA (12). According to the Energy Access Situation Report on Tanzania, approximately 54.4% of rural households rely on rechargeable devices for lighting. This is also attributed to, inter alia, recent increases in kerosene prices (48).

The shift from unhealthy energy sources, such as kerosene and paraffin, to healthier and more efficient lighting sources has also been observed in the Mufindi areas studied in Chapters 6 and 7 and by Bensch et al. (12) for rural areas in SSA. Thus, the positive impacts on the health of household members due to less exposure to indoor air pollution by relying on grid-electrified lighting devices are expected to be less pronounced and have not been considered in great detail in this research. Based on these observations, exposure to indoor air pollution and its negative impacts on health should be more intensely studied in the context of cooking. Irrespective of grid connection and income statuses, households from the Mufindi area rely mainly on firewood for cooking (see Chapters 5 and 6). This confirms observations at the national level, where firewood represents the predominant cooking source for households (48).

The penetration of off-grid energy systems in rural SSA regions has benefitted from worldwide technological and financial innovations, cost reductions in solar PV systems and improvements in energy efficiency. Higher penetration of off-grid systems may also reflect the growing role of trade partnerships of SSA countries with emerging countries, in particular with China, which was discussed in Chapter 1.

To further illustrate this, Figure 13 reveals the increasing importance of Chinese imports in the field of photosensitive semiconductor devices to Kenya and Tanzania in 2000 and 2017. It is apparent that the magnitude of the trade value of imported photosensitive semiconductor devices from China has increased substantially over the last two decades. In Tanzania, the trade value grew from $ 2,420 USD in 2000 to $ 17,274,336 USD in 2017 (42). In Kenya, it grew from $ 23,044 USD to $ 23,446,507 USD during the same time period (42). In 2017, Chinese imports accounted for more than 80% of the overall trade value of these imports in both countries, whereas in 2000 it was only around 1% of the overall trade value.

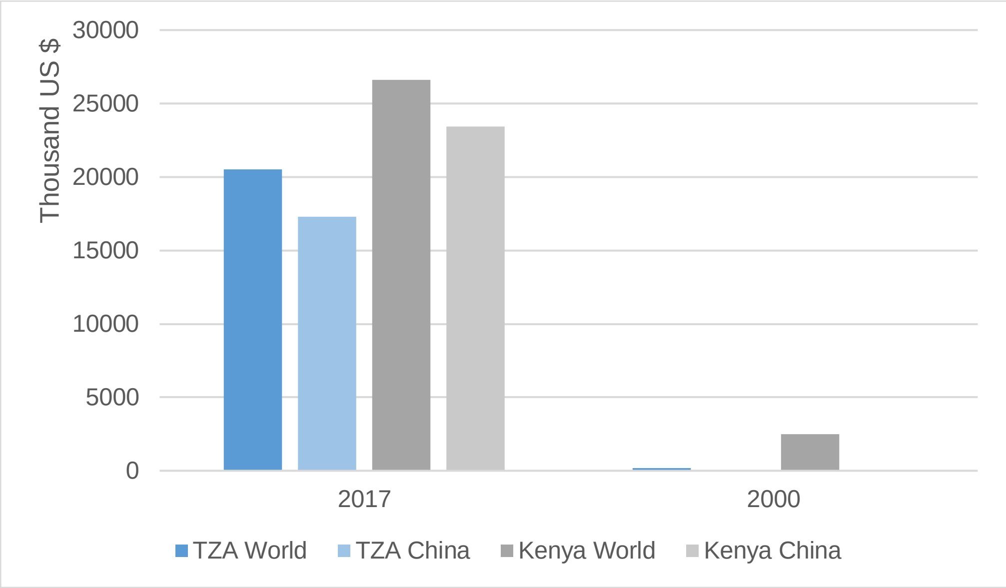

Figure 13. Trade value (in US $) of imported photosensitive semiconductor devices[11] in Tanzania and Kenya in 2000 and 2017

Source: Author, based on (42)

It should be noted that non-branded products do not necessarily have to be a less sustainable alternative. Recently, Bensch et al. (191) compared non-branded to branded SHS in rural Burkina Faso. Based on their results, it seems that off-grid energy technology markets in SSA are booming even without the support of comprehensive marketing initiatives and that the measures and quality of non-branded products are not necessarily inferior. The findings suggest that non-branded technologies can be “cost-effective” and achievable for lower income and poorer households (191). In both countries, however, it has been observed that the rapid penetration of solar-powered off-grid products also led to an increased influx of poor quality technologies (10). More research is needed in order to substantiate this.

Across all micro-level analyses (Chapters 5 to 8), it becomes clear that the period of (grid) power access plays a major role in enhancing socio-economic impacts. Lighting belongs to the most direct impact of electrification, hence the effect of grid electricity on lighting can be studied immediately after grid electrification. It is important to note that the considered period of three years of access to grid electricity may be too short for households and micro enterprises to be able to sufficiently harness the technology. This corresponds to the modern productivity paradox, as discussed by David (192). The uptake of electricity and electric appliances does not necessarily imply an immediate impact on productivity growth, which is crucial for structural transformation, economic development and competitiveness. Experiences from the West have shown that it took several decades until complementary technologies

[11] Includes photovoltaic cells whether or not assembled in modules or integrated into panels and LEDs

were developed and the effects of electrification became visible on a broader scale (e.g. in the United States (192).

However, the replicability of (and therefore maybe also the comparability with) the Western model for energy access expansion in developing economies is questionable, and this does not only relate to tackling climate change. In recent years, the development and diffusion of technologies and innovations – such as machine learning systems – has accelerated. Communities are faced with rapidly changing environments. The number of areas completely cut off from the rest of the world is rapidly decreasing, and information asymmetries and related transaction costs are much lower compared to the past. For example, as discussed above, the current "pre-grid-electrification" statuses of rural households and small enterprises in SSA, even though still mainly limited in terms of capacity, are significantly more developed, achievable, and affordable than a decade ago.

In particular, the most notable innovations driving the penetration of decentralized technologies include mobile platforms and new business models such as mobile banking (e.g. M-PESA) and prepayment, or pay-as-you-go (PAYG), systems, which drove the participation of the private sector. These systems can help lower transaction costs, overcome asymmetric information barriers, and prevent payment defaults. Today, it is much easier to gain access to modern electricity services than a decade ago, even for poorer, previously "non-bankable" households.

However, technological jumps and innovations also need space to allow them to develop and achieve their full potential in a sustainable manner. With regard to (off-grid) energy systems, this includes the fields of operation, management, and maintenance, but also the recycling and disposal of materials. Institutional frameworks and conditions play a major role in driving and maintaining the expansion of electrification. There is a need for complementary inputs and innovations (such as technologies and infrastructures) that allow GTP to harness their full potential in terms of enhancing welfare.

Despite the accelerated penetration of off-grid systems in rural SSA areas, the observations of Barnes (193: p.7) from 2007 that "electrification efforts" need to be "properly coordinated with complementary programs or implemented under the right regional conditions to increase productivity and improve the quality of rural life" is still highly relevant. This may underline the relevance of recently emerging technologies and services such as PAYG, which can help to overcome certain constraints (e.g. access to financial services). Moreover, electrification strategies should focus not only on access to "productive energy" but also on the uptake of "energy consuming productive activities and technologies" (9: p.3). For example, to address electricity load constraints, Tanzanian authorities allow mini-grid developers to finance productive-use appliances through on-bill financing (194: p.37). Vocational training and information campaigns regarding electricity usage can help to maximize electrification efforts (195). Capacity building measures should also include women because of their high level of entrepreneurship engagements (194: p.20). Best practice examples of private sector engagements in off-grid electrification have shared the following characteristics: "Consideration of the demands, interest, and restrictions of local customers, including the desire to pay with mobile payments systems; strong partnerships along the whole supply chain, from the government and utilities to private sector service providers; and adaptation of market dynamics to local conditions to support successful, sustainable clean energy solutions" (195: p.68).

Mwenga's mini-grid distribution already meets some criteria. It deals with a mobile prepaid system, started awareness campaigns informing the rural community of the usage of electricity (e.g. kettles, see Chapter 6), and undertook and supported studies (e.g. 196) to better understand the needs of the communities.

However, in the SSA context, it should be noted that electrification measures meet a difficult environment in enhancing productivity levels. As previously discussed in Chapter 1, and also confirmed for the case of rural Tanzania in the studies on the micro level in Chapters 5 to 8, rural SSA economies are mainly based on agriculture. Many agricultural products are sold and consumed locally, and export market access is mostly limited to unprocessed products and commodities.

On the global level, most of SSA economic sectors still lag behind in terms of their labour productivity (growth) and their informal sector activities are comparatively high (8: p.144f). It is assumed that the informal sector absorbs a high share of the (unskilled) labour force (8: p.144f). Pressure caused by the high number of young people entering the labour market every year is immensely high. Thus, even if electricity contributes to improved productivity, certain trade-off effects of productivity gains should be considered, e.g. losses on the labour markets. Moreover, the distributional effects of productivity gains should be taken into consideration because the purchasing power of local customers may not necessarily change. These circumstances continue to make it difficult for SSA countries to compete in world markets, bring about structural changes, and sustain economic growth.

This is why anchor customers who already have a critical level of electricity demand (e.g. Tanesco or the coffee and tea industry) can play an important role in supporting the financial sustainability of (mini-) grid distribution. While the electricity needs of the internationally integrated tea, coffee, and timber companies of the Mwenga project may benefit from a more reliable electricity distribution (see Chapter 8), rural communities can benefit from access to electricity for the first time (see Chapters 5 to 8) and from spill-over effects. However, the long-term effects of access to mini-grid distribution need to be studied further.

To summarize this research, my subjective experiences from reading the literature and conducting fieldwork in Tanzania taught me various lessons, but the most important one is the following: when development policy strives for a one-by-one transfer of a Western lifestyle to the context of African rural areas, it is doomed to fail if it ignores local circumstances. A good example of this is cooking. Regardless of grid connection status, there was almost no household that did not cook with firewood (see Chapter 6). In the cities, I observed that firewood and electricity were used in combination for cooking. The availability of electricity does not necessarily lead to an implicit changeover, even if the monetary means are available.

Another interesting observation I made is on an anecdotal level, namely that the circadian rhythms of villagers seemed to be aligned with their environment. Villagers reported that they get up just before sunrise to go to the fields and return home before it gets dark. They seemed to have a relatively regular sleeping schedule. Exposure to artificial light, e.g. through high-intensity LEDs emitting large amounts of blue light, can disturb the sleep-inducing hormone production of melatonin and thereby contribute to sleep disorders, which can have adverse health effects in turn (197, 198). In general, the impacts of artificial lighting with superior lumens per watt on the ecosystem and its organisms – from birds, fish and insects to human beings – and its long-term effects need to be studied more in detail (for example, 199, 200).

I am convinced that technological advancement, such as gaining access to reliable and affordable electricity and electrical devices, can lead to an increase in the quality of life in these villages. However, I consider it just as important that the habits and (cultural) traditions that have survived for many centuries, perhaps even millennia, should be carefully studied and considered and perhaps even combined with modern practices and techniques to achieve sustainable high-quality living standards in the long term. Above all, perhaps the most important perspective that needs to change to drive "developmental transformation" is the one in our minds. We may need "a change in mindsets that recognizes that change is possible and welcomes change" (55: p.33).

9.2 Outlook

"We are at an inflection point for off-grid power. The early markets are maturing and new models and markets are emerging."[12]

In 2017, 537 million people in SSA regions still had no access to electricity. Achieving the target of universal access to energy services by 2030 seems highly unlikely in these countries. In some areas, population growth will outpace electrification gains (21). According to the IEA´s New Policies Scenario more than 580 million SSA will lack access to electricity by 2030 (21). The IEA estimates that annual investments of $52 billion USD are needed to achieve universal access to electricity by then (6). Decentralized systems, including solar PV technologies in off-grid and mini-grid systems, are identified as the lowest-cost solution for more than 70% of new electricity connections in SSA countries (6: p.12). Approximately 95% of the global annual investment requirements should be undertaken in the region (6). However, between 2015 and 2016 only $5 billion USD was invested in electricity projects in the SSA region (202: p.16). Approximately half the financing came from bilateral and multilateral development finance institutions (202: p.51). This is well below the annually required investment level, and reflects overall dependence on donor actions as well as the financial gap in resources of these countries. For

[12] (201)

example, international development organizations support project developers to offset upfront development costs and thereby contribute to lower investment risks (136: p.68f). This again underlines the fact that private (but also public) sector actions alone is insufficient to drive the electrification of these countries.

For the time being, Kenya and Tanzania still belong to the top 20 access deficit countries. Yet electrification efforts have accelerated in recent years; for example, in Kenya, electrification gains were comparatively high, with above 6% annual average access changes between 2010 and 2017 (203, 204). The population without access to electricity amounted to 18 million in 2017, while the electrification rate increased to 73.4% in 2017 (203, 204). In Tanzania, where 38 million people still lacked access to electricity in 2017, the electricity access gains were not as well pronounced as in Kenya, and electrification grew on average by 2.6% annually between 2010 and 2017 (203, 204). In 2017, 32.8% of the Tanzanian population had access to electricity (203, 204). Despite recent progress, data suggest that it is unlikely that Kenya will achieve universal access to electricity by 2020, while Tanzania is not expected to have electrified half the population by that time.

Grid extension plays and will continue to play a major role in electrifying SSA countries. This is reflected in recent investments that have been undertaken. Between 2015 and 2016, $1.6 billion out of $5 billion USD was invested in fossil fuel plants (202: p.50). A major recipient of investments (approximately $1 billion USD) was Kenya, with the planned installation of the Lamu Coal Power Station. Tanzania also received substantial investments in gas-powered generation plants. While in Kenya grid-connected projects dominated the investments (almost $1.6 billion USD), investments in Tanzania focused more on transmission and distribution (approximately $300 million USD). However, in Tanzania, more than $200 million USD in investments was directed towards grid-connected projects.

In this context, it is important to again note that China is and will continue to be one of the leading financial lenders for large-scale power infrastructure projects in SSA (202: p.37). As mentioned in Chapter 1, China announced in 2015 that it intends to provide African countries with up to $60 billion USD in loans, grants, and equity funds (205). Among the areas that will benefit from these investments are “poverty reduction” and “green development” (205: p.1). Between 2015 and 2016, Chinese investors provided $1.1 USD for energy projects in Kenya, Uganda, and Ethiopia (202: p.50). However, most of the Chinese investments are aimed at conventional energy projects (202: p.50).

Overall, financing off-grid electricity projects is still at comparatively lower levels, with $200 million USD in SSA countries between 2015 and 2016 (202: p.50). Recently, however, their share in the overall investments in electricity projects increased substantially and is mostly focused on large and mature off-grid markets such as those in Kenya and Tanzania (202: p.50). It is expected that global solar-based technology prices will continue to fall, from which SSA (off-grid) markets may benefit. This downward price trend could also impact the prices of systems with higher capacity systems. The costs of mini-grid key components, especially those related to solar-based technologies, fell substantially in the last decade (194: p.6). Benefitting from the booming solar rooftop industry and the growing electric vehicle market, the costs of solar panels, inverters, batteries, and smart meters fell by 62-85% in this period (194: p.22). Other mini-grid systems relying on other types of renewable energy have also experienced cost reductions, and Energy Sector Management Assistance Program (ESMAP) expects that the costs of solar-based mini-grid systems will further decrease until 2030 (194: p.6).

With the increasing importance of decentralized technologies in electrification (6), the integration of these systems is also gaining importance. Nowadays, the national electrification strategies of Kenya and Tanzania involve a combination of grid, mini-grid, and SHS.

Striving to become a middle-income and semi-industrialized country by 2025 (206), Tanzanian authorities explicitly consider the importance of private initiatives and investments that take advantage of local energy sources in the 2015 National Energy Policy (48). A considerable increase in private investments in mini-grid businesses serving households and enterprises has been observed in Tanzania (6: p.84, based on 48). Mini-grid specific regulatory frameworks, such as the Tanzanian Small Power Producers (SPP) framework, which allow private investors to generate, distribute, and retail electricity in not grid-connected areas, have supported private sector participation in recent energy system developments (194: p.33). A recent slowing of private sector participation in mini-grid systems has been observed, which is due to implementation and enforcement problems as well as some problems with SPP regulations (194: p.60). Additionally, a lack of transparency from national utilities regarding energy sector development or national grid extension is still cited as a major barrier to mini-grid developers in planning their investments (207: p.3).Yet, according to the ESMAP, over 280 new mini-grid systems are planned to be installed in Tanzania by 2022 (208).

By the end of 2018, the Kenyan government introduced a new national electrification strategy (KNES) that aims to achieve universal access to electricity by 2022. Thereby, it aims to support the Kenyan "Vision 2030", which aims to make Kenya a middle-income country by 2030. According to KNES, mini-grid and stand-alone systems will play a crucial role in electrifying remote areas and intensifying grid-connected systems (208)The strategy also acknowledges the important role of private investments (IBID).

While the output of new business models dealing with decentralized technologies is still at low levels (see investment levels in off-grid systems above), they have considerable potential to contribute to electrification and to take advantage of digital, information, and communication technologies (6: p.46, based on 209: p.86). Among new business models are those that make use of mobile phone technologies or PAYG financing schemes, which lower the access barriers of difficult-to-reach customers (6: p.47). Mobile applications help to lower transaction costs (e.g. customers can reduce the travel needed to buy vouchers of electricity), but also inform customers in case of planned outages and other updates. On the other hand, this simplifies the collection of payment for electricity and prevents customers from defaulting on their payments. Moreover, newer technologies, such as remote-controlled management systems, cloud-based metering and software platforms, can help to expand services and spur productive electricity use (6: p.47). New business models are increasingly driven by venture capitalists and social entrepreneurs (6: p.35). Finance and investment companies addressing off-grid and mini-grid systems offer several new modes of financial services, such as “early-stage corporate investment, working capital, asset management, portfolio aggregation, and securitization” (195: p.68).

The implications presented in this thesis suggest that research and planning must adapt in order to better reflect reality and capture changes that take place at a much faster pace. These changes include not only the diffusion of new technologies, but also structural conditions and dynamics. Therefore, the increased usage of technologies, such as geospatial portfolio planning tools together with high-resolution satellite imagery and data storage, could be of crucial importance for electrification planning (207). For example, they could help overcome difficulties in predicting and anticipating electricity consumption and contribute to adequate revenues to cover costs accordingly. Furthermore, they could also help to lower the costs of preparation and planning (194: p.24).

While most of the discussion in this thesis has focused on rural electrification, it should be noted that urban electrification in SSA countries will also gain importance. Urban densification will continue and may put the existing grid infrastructure under pressure (21: p.21). This may lead to limited access to electricity in urban areas, and must also be addressed by electrification measures.

9.3 Future research

The Iringa region, which is in the focus of the present thesis, is one of the richest regions in Tanzania. Mufindi has a vibrant forestry sector and coffee and tea industry. Future studies should study the impacts of access to the mini-grid system on bigger scale enterprises with access to national or international markets. More specifically, it would be interesting to know the effects of mini-grid electricity on productivity and profitability of the local tea, coffee and timber industry but also to the employment and quality of life of workers who live in the area. Mini-grid electricity might have enhanced reliability of their electricity access which might have spurred their efficiency and productivity. Moreover, they may have cost savings through replacement of fossil fuels. This includes the replacement of diesel powered generators that ran in case of outages. But it should also study the effects of access to mini-grid electricity on the replacement of mobile diesel powered sawing machines used by the timber logging industry. By the end of 2015, Mwenga project partners reported that they plan to establish centers, where timber can be processed with devices relying on electricity. Future research should also consider trade-off effects. For example, enhanced productivity could imply that less low skilled workers are employed. On the other hand, replacement of fossil fuels could contribute to less air pollution. A future study should therefore also consider environmental impacts of access to mini-grid electricity.

As discussed above in chapters 5 to 7, uptake of electric devices remained limited three years after grid-electrification. However, age and efficiency of those technologies has not been studied more in detail. But their efficiency is critical factor in determining electricity consumption. Especially off-grid technologies could benefit from a higher usage of more efficient appliances. This should be studied more in detail.

Moreover, it would be interesting to know more about the effects of grid-electricity on the productivity of local SMEs that got access to grid-electricity for the first time and related spill-over effects. Due to data constraints it was not possible to study and to compare the productivity between different types of enterprises. Thus, a high sample size of different types of SME´s is advisable. Future analysis could also study the effects of access to more reliable electricity through the mini-grid distribution on the profitability of SME´s. Future research should also study the effects of access to mini-grid electricity on institutions such as schools and hospitals to allow for a more comprehensive overview on the socio-economic conditions. A more comprehensive overview is given if also social relationships and gender related inequalities but also institutional (e.g. identifying regulatory barriers and drivers), political and macroeconomic conditions are reflected to a much better extent. For example, the role of tariffs for industrial and commercial purposes in SSA are among the highest in the world. It would be interesting to know about implications of these tariff levels for the development of productive energy/electricity uses.

Future research studying of electrification on household income should also consider distributional effects. It should be noted that effects on income are difficult to capture due to the irregularity and informality of many income sources. This study should also reflect on the role of subsidies and (public) funding (from abroad) as both played an important role in electrifying the rural community. This also includes the impacts of tariffs and tax exemptions on off-grid technologies. Furthermore, the role of other on-going interventions should be considered to better capture socio-economic conditions. For example, the indicator of health might be influenced by awareness campaigns and medical treatment of AIDS. Persons suffering from AIDS in the Mufindi area reported that they have access to medical treatment, which was subsidized by an international aid organization. Signs on the plantations warned against the dangers of AIDS. In general, the overall situation of the rural community might have changed since 2015, the year of data collection. This is why upcoming research might deepen the impact study. The present thesis could serve as a starting point.

On a macro-scale, it would be interesting to know more about the role of new trade partnership in electrification and socio-economic development, such as the nexus between Asian, African and Latin American countries. This includes research on the whole value chain of off-grid technologies which might reveal where a major share of the value is generated.

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