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Research paper

Power struggles: Advances and roadblocks of solar powered mini grids in Tanzania

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ABSTRACT

Rural energy poverty persists in Tanzania, with 77% of the population not having access to electricity. A combination of high solar radiation and slow extension of the national energy grid has raised off-grid solar PV based mini-grids as a potential solution. In this paper, a novel extension to the Technological Innovation System (TIS) function approach is used to analyze the positive and negative trends of solar PV based mini-grid diffusion in the country. This framework, adapted for a Global South context, considers key dynamic processes (functions) and structural components (actors and institutions) that are considered essential for diffusion of technological systems, along with the general institutional infrastructure, informal institutions and other contextual factors that may influence the development and implementation of solar PV based mini-grid systems. Based on a combination of semi-structured interviews with key stakeholders and secondary data, the paper identified negative trends in several functions such as market formation, entrepreneurial activities and guidance of the search. The paper demonstrates a clear link between the worsening conditions for solar PV mini-grids with institutional changes as a result of the new political direction for the energy sector that followed the 2015 presidential election in Tanzania.

1. Introduction

In 2021, only 23% of the rural population in Tanzania had access to electricity (The World Bank, 2023). Given the importance of access to electricity for poverty reduction, access to other public services and business activity, extending access to electricity to the remaining population in the coming years will be essential for Tanzania. Tackling rural electrification is of special importance as 63% of the Tanzanian population was estimated to live in rural areas in 2022 (The World Bank, 2023).

Low population density and large geographical space combined with low organizational capacity has made extending the national grid to rural areas in Tanzania challenging and highly costly (Ahlborg and Hammar, 2014). Off-grid areas often use wood burning and diesel generators for energy generation, with negative health and environmental consequences (Bede-Ojimadu and Orisakwe, 2020). These negative consequences combined with the slow or stagnant extension of the national grid have led to an increased attention towards off-grid Renewable Energy Technology (RETs) systems to complement the existing diesel generators (Katsaprakakis et al., 2009; The World Bank, 2008). The poor outlook of grid extensions for rural areas is not unique to Tanzania, it has been estimated to apply to roughly 70% of the global rural population, further motivating off-grid RETs solutions as a solution to energy poverty (Pedersen, 2016).

The mini-grid alternative is specifically raised as an important strategy to electrify rural areas in the Global South (AMDA, 2022; ESMAP, 2019). According to the 2020 Mini-Grids Partnership (MGP) report, by 2030, mini-grids are estimated to help bring electricity to roughly half of the 238 million households in Sub-Saharan Africa, Asia and island nations that do not have access to the electricity grid (MGP, 2020). Despite the stated potential of renewable energy based mini-grid systems to tackle rural energy poverty, there is limited understanding of the factors that drive and obstruct the diffusion of this technological alternative. While previous research has investigated individual factors such as reliability, operational flexibility (Boyko et al., 2023), financing and affordability of mini-grids (Creti et al., 2021; Falk et al., 2021), broader system analyses that consider the social, economic, political and institutional factors that may positively or negatively influence the diffusion of solar PV based mini-grid systems are limited. This research contributes to filling that research gap.

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The purpose of this paper is to provide a comprehensive analysis of the progress and barriers for the diffusion of solar PV based mini-grids in rural areas of Tanzania, a country with both high technical potential for solar energy (Grothoff, 2014), and one of the best regulatory frameworks for mini-grids in the Global South (Odarno et al., 2017). An extended Technological Innovation Systems (TIS) function approach is used that takes into consideration both key dynamic processes (i.e., functions) and structural components that are considered essential for diffusion of technological systems, as well as the general institutional infrastructure, informal institutions and other contextual factors that can also influence technological diffusion.

The contributions of this paper are twofold. First, it provides a system wide empirical contribution for determinants that influence the diffusion of solar PV mini-grids in a Global South context. As previously noted, energy poverty, particularly in rural areas of the Global South, remains a major developmental challenge and a number of institutional, economic and geographic barriers limit the possibility of extending national grids. The wide range of empirical lessons provided by the system analysis also allows for concrete policy recommendations for the identified system barriers.

Second, it contributes to the theoretical development of the TIS approach, with a focus on the Global South context. A specific novel and theoretical contribution to the TIS approach is the inclusion of the role of informal institutions at the local level in the diffusion of RETs. As highlighted in Blum et al. (2015), by including informal institutional aspects of technological transitions, this paper helps fill a research gap, as informal norms, rules and traditions are often not explicitly considered in TIS literature and can play a role in the diffusion of RETs.

The paper is structured as follows. Section 2 of the paper describes the analytical framework; Section 3 presents the methodology; Section 4 introduces the case study, explains technical specificities for solar PV technology, followed by an overview of the energy mix of Tanzania; Section 5 presents the results from the TIS system analysis applied in Tanzania; Section 6 discusses key findings of this paper and provides suggestions for policies to overcome identified barriers in the system; and Section 7 concludes summarizing the conceptual contributions and how they relate to key empirical findings.

2. Analytical framework

This paper uses an extended and revised version of the Technological Innovation System (TIS) approach, drawing on, and complementing the framework developed in Edsand (Edsand, 2019), to analyze the development and diffusion of solar PV based mini-grid systems in Tanzania. TIS is an analytical framework for analyzing technological transitions. The TIS framework analyzes the "network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology" (Carlsson and Stankiewicz, 1991), p. 94). The actors and networks make up the structural elements of the technological system, and include firms, state and non-governmental actors (NGO), research institutes (e.g., universities), international actors (e.g., bilateral and multilateral organizations) and local actors (e.g., community leaders). This study considers actors at different levels, i.e., local, national and international actors, and their role in the technological transition in the case study country. An innovation in the context of technological transitions does not require a technology to be newly developed but the innovation can be about the diffusion of the technology in a context where it did not exist before.[1]

In addition to actors and networks, the other underlying principle of the TIS is its emphasis on the fact that technological transitions occur under an institutional infrastructure, which may hamper or drive the transition (Bergek et al., 2008; Carlsson and Stankiewicz, 1991; Freeman, 1987; Lundvall, 1992). Despite the central role that institutions occupy in the TIS framework, explicitly mapping essential aspects of the institutional infrastructure has been largely restricted to formal institutions,[2] closely associated with the technology in questions, e.g., legislation supporting the technology (see e.g., (Bergek et al., 2008; Hekkert et al., 2007). Informal institutions, i.e., norms and attitudes concerning the technology in question are, however, not explicitly built into the approach, and thus often not well captured Blum et al. (2015). Moreover, general political and economic institutions and other contextual factors that may influence the success or failure of the off-grid RETs diffusion are not explicitly included in previous TIS functions.

Earlier literature has described a *formative* and *growth* phase of the TIS system (Bergek et al., 2008). In the formative phase, positive feedback loops are harder to establish, which makes the system more susceptible to external "pushes and pulls". In the growth phase, the system is mature and self-reinforcing through feedback loops. Technologies that are relatively new to a country are often considered to be in a formative phase of development. That is the case of solar PV mini-grids in Tanzania. Therefore, considering factors external to the focal TIS (i.e. the technology under study) may reduce the risk of missing important dynamics that may positively or negatively influence its diffusion. The particular relevance of including factors that can be described as exogenous to the technological system in Global South countries has been addressed in previous research (Edsand, 2019; Raven, 2005).

Consequently, the analytical approach used in this paper builds on a previous extended TIS approach, where contextual factors were considered beyond the standard TIS functions (Edsand, 2017; Edsand, 2019). The extended TIS approach (Edsand, 2019) draws on the original function list and indicators developed by Hekkert et al. (2007) and influenced by Van Alphen (2008). The extended framework not only analyzes the functions and formal institutions that directly affect the technological innovation system but also takes into account a number of general institutions and contextual factors, which are not specific to the technology in question but can equally have a driving or hampering effect on the diffusion of a technology. The extended TIS approach has been conceptually motivated in Edsand (2019) and used for empirical analysis of renewable energy adoption in a Global South context in (2017). This paper takes the extended TIS approach one step further. In addition to specific and general formal institutions, this paper's TIS analysis also considers informal institutions. The final framework for this study is summarized in Table 1, including a description of the TIS functions. Next, the additional factors that are considered as part of this TIS analysis are explained.

2.1. Specific formal and informal institutions

The formal institutions captured under the TIS functions are referred to in this paper as *specific formal institutions* as they directly target and influence the technology under study and related technologies, e.g., other RETs. *Specific informal institutions* refer to attitudes and norms concerning the technology under study amongst the population in the case study country. As they specifically influence the technology under study, they will fall under the category of *specific informal institutions*. The specific informal institutions are explicitly incorporated under the creation of legitimacy function (Table 1, function 7b). In contrast,

[1] "The minimum entry level for an innovation is that it must be new to the firm" (OECD/Eurostat, 2005), p. 57). Put differently, "an innovation does not need to be developed by the firm itself but can be acquired from other firms or institutions through the process of diffusion" (OECD/Eurostat, 2005), p. 17).

[2] This paper follows the definition of institutions by North (1991). North distinguishes between formal and informal institutions, the former referring to *laws and regulations* and the latter to *societal codes of conduct, customs, traditions, and taboos*. In this paper, informal institutions will be referred to as *norms and attitudes*.

Table 1
Extended TIS framework.

Actors and Networks	
Actors	National (e.g. firms, state, non-governmental actors, research institutes); international actors (e.g., bilateral and multilateral organizations) and local actors (e.g., community leaders and community members).
Networks	Organizations working towards improving the conditions for the mini-grid sector (e.g., lobbying groups and sector specific associations)
TIS Functions (Includes *Specific Formal and Informal Institutions*)	
Entrepreneurial Activities	Activities/interest shown by companies for new technologies, e.g., started and planned projects
Knowledge Development	Existing and new knowledge regarding the technology, e.g., R&D or research projects
Creating Adaptive Capacity	Human capacity related to the technology (e.g., technical skills)
Knowledge Diffusion	How and to what extent knowledge about the technology is shared amongst actors
Guidance of the Search	Actions by government or companies that affect expectation of the technology (e.g., regulations or specific targets)
Market Formation	Specific mechanisms that facilitate market entry of the tech. (e.g., tax exemptions, pricing policies)
Resource Mobilization (Domestic)	Financial resources allocated by the government or companies for tech.
Resource Mobilization (International)	Financial and technical assistance by international actors for tech.
Creation of Legitimacy (Formal Lobbying)	Lobbying activities affecting legitimacy and support for tech. by established groups with economic and political weight
Creation of Legitimacy (Informal Lobbying)	Activities affecting legitimacy and support for tech. by the general public. Existing and changing norms and attitudes towards tech (*Specific Informal Institutions*)
General Institutional Infrastructure and Contextual Factors	
General Economic Institutions	Overall business environment (ease of doing business)
General Political Institutions	Corruption; Quality of Government
General Informal Institutions	Cultural norms and attitudes
Other Contextual Factors	Ability to pay (affordability); Climate Change; Political Change and Leadership; and Other Sectors' Influence

Source: Adapted from (Edsand, 2017; Hekkert et al., 2007; van Alphen et al., 2008).

general informal institutions are general norms and attitudes amongst the population that may influence the technology under study but also have broader influence on society. The inclusion of general norms and attitudes in Tanzania follows suggestions from previous TIS research in the Global South, which has emphasized the importance of explicitly considering culture as an influencing factor (Blum et al., 2015).

2.2. General institutional infrastructure and contextual factors

Drawing on the definition of systems boundary by Edquist (1997), as being "all important economic, social, political, organizational, institutional, and other factors that influence the development, and use of innovation", this paper will also consider the *general institutional infrastructure* and *contextual setting* that may act on the TIS. *General institutions* refer to institutions that are not specifically targeting the technology under study but that may equally have a positive or negative influence on the system in question. *Contextual factors* are aspects that may assert influence on the development and diffusion of the technology but would not fit within the definition of institutions, such as poverty and political changes. The TIS functions, the specific formal and informal institutions, the actors and network as well as the general institutions and contextual factors delimit the system under analysis. As the focus of this paper is solely on mini-grids where solar PV is the main supply of energy, this constitutes another boundary of the study.

Since context vary across countries, a final list of general institutions and contextual factors included for each TIS study can never be predefined but should be decided on a case by case basis, by conducting a pre-screening of the country context under study. Only selecting factors that are presumed likely to have an influence on the technological transition would allow for a comprehensive analysis while maintaining a manageable empirical undertaking.

For this case study, the following general formal economic and political institutions, general informal institutions and contextual factors have been chosen to complement the TIS function approach. Firstly, the overall business environment, i.e., *ease of doing business*, is mapped as a proxy for estimating the general economic institutions in Tanzania. For general political institutions, the following proxies are used, namely, the *ICRG* (Indicator for Quality of Government), *Political Corruption Index*, *Public Trust in Politicians*, and *Bribery Incidence* (% of firms experiencing at least one bribe request).

The contextual factors included in the analysis are *ability to pay (affordability)*, *Climate Change*, *Political Change and Leadership*, and *Other Sectors' Influence.* The potential relevance of the selected general institutions and contextual factors for a well-functioning innovation system has been well established in the literature and will not be individually described here.[3] As the mentioned general institutions and contextual factors included in this study are hypothesized to be determinants of solar PV mini-grid diffusion in Tanzania, they are considered endogenous to the system.

3. Methodology

Tanzania was selected as a case study given the low levels of energy security in rural areas and the potential of the country for solar PV based mini grid systems. Primary and secondary data were collected to analyze the above TIS system. Primary data collection consisted of structured and semi-structured interviews with key actors in Tanzania which took place between 2019 and 2020 in Dar-es-Salaam and online. We carried out a total of 22 interviews with experts from various actor groups related to the solar PV based mini-grid sector in Tanzania. The actor groups included domestic and international firms, government agencies, NGOs (domestic and foreign), research institutes and donor organization (multilateral and bilateral organizations). The semi-structured interviews were complemented by written interview forms that were filled-out and submitted by key actors via Google forms. The purpose of this written forms was to complement with details the information collected through the interviews as well as to reach key actors who were not available for interviews and preferred to answer the questions by writing.[4]

After analyzing the primary and secondary data using the analytical framework (Section 5 – Results), we proceeded to identify blocking and driving mechanisms for solar PV based mini-grids diffusion (Section 6 – Discussion). Based on the results of the analysis, we provide policy suggestions in the areas where we identified blocking mechanisms for the diffusion of solar PV based mini-grids (see Fig. 1). The policy recommendations are aimed at improving system performance, i.e. diffusion of the technology in the case study country.

[3] See for example: Ability to pay (Affordability) (The World Bank, 2018); Business Environment (The World Bank, 2020); Corruption (Edsand, 2017; Edsand, 2019); Trust (Peters et al., 2007); Other Sector Competition (Bergek et al., 2015); Climate Change (Edsand, 2019).

[4] Note that primary data collection was completed before the passing of late president John Magufuli. The primary data has therefore been complemented by the latest available secondary data.

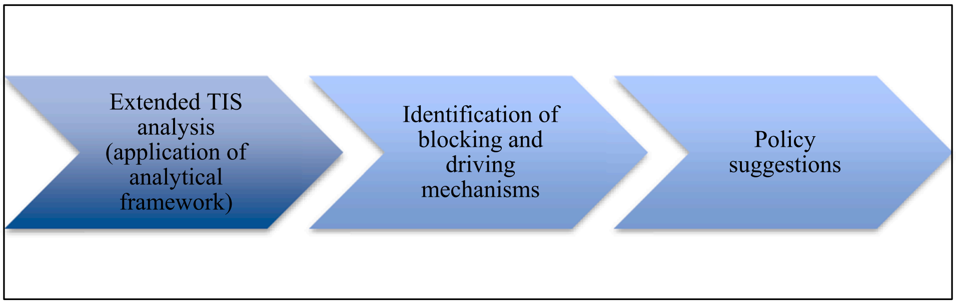

Fig. 1. Workflow of the analysis.

4. Case study introduction

4.1. Photovoltaic (PV) panels: technological specificities

Solar PV modules are a manufacturing-intensive technology, due to the complex development process, requiring knowledge from multiple disciplines, high manufacturing skills and tacit know-how (Schmidt and Huenteler, 2016). The significant capacity requirements along with high initial investment costs of manufacturing of solar PV cells, implies that manufacturing the technology is in most cases out of reach for countries in the Global South (Algieri et al., 2011; Barua et al., 2012). On the other hand, the design aspect, i.e., integrating PV power systems requires relatively limited capabilities and not very advanced equipment (Seel et al., 2014). The same is true for the assembly, installation and maintenance, which would allow for Solar PV diffusion in countries with restrained technical human capacity, where the foreign manufactured panels can be imported.

4.2. Mini-grids

While a single definition for what constitutes a mini-grid does not exist, mini-grids are characterized by the size of its generating capacity along with the ability to operate independent from the main electricity grid (MGP, 2020). A common generation capacity range for mini-grids is between 1 kilowatt (kW) to 10 megawatts (MW) (IRENA, 2018). Other solar PV-based installations include pico system (1–10 W), Solar-Home-System (SHS) (10–100 W), Stand-alone 'institutional PV systems' (50–500 W) and large-scale solar parks (1–50 MW) (Hansen et al., 2014). The focus of this paper is on solar PV based mini-grids that may be complemented by energy storage (i.e., batteries) and/or diesel generators as a back up to the solar PV system. Mini-grids using solar PV technology generally usually aim at powering a village with a local grid that is disconnected from the main national grid.

4.3. Energy access, supply and consumption in Tanzania

Access to electricity in urban areas of Tanzania reached 77% in 2021 (The World Bank, 2023). Despite a significant increase in electricity access in rural areas from 2% in 2013 to 23% in 2021, nearly eight out of ten people living in rural communities do not have access to electricity (The World Bank, 2023). While the percentage of the population living in rural areas has continuously declined from 92% to 64% between 1970 and 2021, the absolute number of people living in rural areas has increased from 12.5 to 40.7 million people in the same period. Consequently, in 2021 approximately 31.3 million people did not have access to electricity in rural Tanzania (The World Bank, 2023). There is, therefore, a need to significantly increase rural energy supply if targets to eliminate rural energy poverty are to be met (The World Bank, 2023).

The latest available data shows that the Tanzanian energy mix for electricity production predominately consists of natural gas, hydroelectric (predominantly large hydro) and oil (see Fig. 2). Compared to the average per capita electricity consumption in sub-Saharan Africa (550kWh) or the world (2500 kWh), electricity consumption in Tanzania can be considered very low (108kWh). The per capita demand is, however, estimated to increase with 10–15% per year (TanzaniaInvest, 2019). The added demand for electricity from the roughly 1.5 million new inhabitants per year, together with the persisting lack of access to electricity, would require overcoming a significant challenge of augmenting and extending generation, transmission and distribution of electricity to the Tanzanian population.

4.3.1. Renewables

Tanzania has a high technical potential for renewable energy sources such as solar PV, small hydro and wind energy. For example, areas with average annual wind speeds of 8.8–8.9 m/s have been reported (2015). Small hydro was the first form of renewable energy source utilized in Tanzania, and as of 2017, the estimated installed capacity of small hydro was roughly 42 MW. Electricity generation from Solar PV has seen a steady increase since 2013. Tanzania has between 2800 and 3500 h of sunshine per year and a solar insolation of 4–7 kWh/m^2 per day (Bishoge et al., 2018; Sarakikya et al., 2015). In a global comparison analyzing photovoltaic (PV) power potential, Tanzania is considered to have an "excellent PV power potential", which provides a "great opportunity for PV power development" (ESMAP, 2020), p. 39). Thermal and electricity generation from photovoltaic panels is frequently being used across rural areas in the country, with the largest implemented solar installations being found in the Lindi, Njombe, Mtwara, Katavi, and Ruvuma regions (Bishoge et al., 2018).

Installations of Solar-Home-Systems have led this sharp increase in the solar energy usage in Tanzania, with an estimated 4000–8000 systems sold every year (Hansen et al., 2014), totaling 65,000 SHSs in 2015 (IRENA, 2016). Investments and sales data from the Global Off-Grid Lighting Association (GOGLA) show continuous demand for solar lanterns, SHSs and charging stations (USAID, 2019). Moreover, data from the International Renewable Energy Agency (IRENA) depicts an increase in installed capacity from solar photovoltaic energy in Tanzania from 3.67 Megawatt (MW) in 2013–23.64 MW in 2019 (IRENA, 2022).

4.4. Installed solar PV mini-grids in Tanzania

As an organization tasked with monitoring and updating the activities in the solar PV mini-grid sector does not exist, the actual number of installed systems in Tanzania is not well known. However, a first attempt to survey the mini-grid landscape was completed in 2017 by a Tanzanian NGO, Tanzania Traditional Energy Development Organization (TaTEDO), and the World Resource Institute (WRI). They identified 109 mini-grids, 13 of which were solar PV based mini-grids, commissioned between 2015 and 2016, with a total installed capacity of 234kw. [5] All installed mini-grids are estimated to connect a total of 912 households or 1153 costumers across the six regions, namely, Dodoma,

[5] The remaining mini-grids consists of 3 hybrid (e.g., solar PV and Diesel), 19 Fossil Fuel, 25 biomass, and 49 hydro based (Odarno et al., 2017).

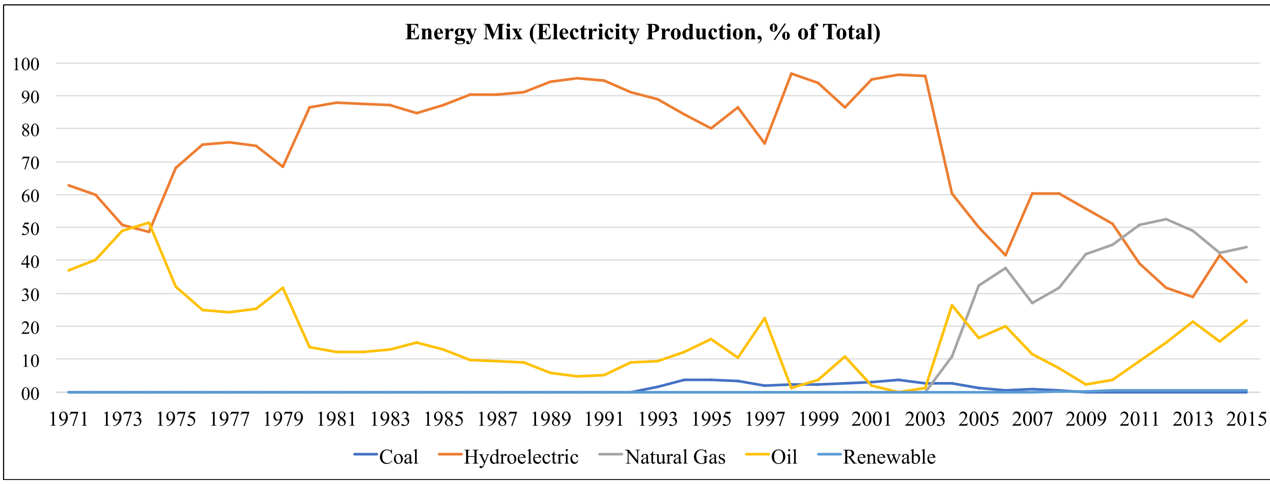

Fig. 2. Tanzanian Energy Mix (1971–2015).
Source: (The World Bank, 2023).

Tabora, Katavi, Tanga, Pwani and Arusha (Odarno et al., 2017).

It should be noted that the reliability concerning the data on installed solar PV based mini-grids is poor. For example, Merl Group, an Austrian organization, reported that they installed a total of 14 solar PV based mini-grid systems in 10 rural villages between 2014 and 2015 (Merl, 2022).[6] Two additional hybrid systems, solar PV/Gasifier (46kw) and PV/diesel (90kw) were mentioned in the TaTEDO and WRI report, operational in the Mbeya and Mwanza regions, where solar PV generation makes up 60kw and 25kw, respectively. The data provided by TaTEDO and WRI, show clear dominance in the mini-grid sector for hydro and diesel generated systems, both in terms of number of systems and estimated connections.

The TaTEDO and WRI report (Odarno et al., 2017) represents an important first step for demonstrating activities in the mini-grid sector, yet the authors emphasize that their report can only confirm that at least the listed mini-grids are operational in Tanzania, rather than providing a comprehensive understanding for the actual number of installed solar PV based mini-grids. Interviews with actors involved in the solar PV based mini-grid sector, suggest that the actual number of installed solar PV based mini-grids is much higher than indicated in the report. These interview results concerning other installed and planned solar-based mini-grids in rural areas will be further discussed in the system analysis section, under entrepreneurial activities.

5. Results: technological innovation system analysis

In this section we analyze the factors that have contributed and hindered the diffusion of solar PV mini-grids in Tanzania using the proposed analytical framework as a guiding framework.[7] We begin by discussing the general formal and informal institutions (i.e. those not directly linked to the technology but that can influence its diffusion). We then analyze the factors that are directly linked to the technology or to the implementation of solar PV mini-grid projects in the country.

5.1. General institutional infrastructure in Tanzania

5.1.1. General economic institutions

To assess general economic institutions, the World Bank measurement for business regulations, *Ease of doing business (EDB)* is used as a proxy. The EDB measurement is based on 41 indicators for 10 topics relating to doing business in a specific country. The average doing business score in Tanzania has marginally increased in the later years, e.g., from 49.7 in 2016–54.5 in 2020, however, their ranking has not reached beyond 131st place out of the 190 countries measured (The World Bank, 2016, 2020). Despite changes in individual indicators such as *number of procedures and days to start a business,* which reduced from 13 to 10 procedures and from 36 to 29.5 days between 2004 and 2020, the accumulated ranking puts Tanzania on a 162nd place (out of 190) for starting businesses (The World Bank, 2004; The World Bank, 2020).[8] Worth noting regarding the number of days to start a business is that after a gradual decrease since 2004, the number of days it takes to start a business increased for the first time between 2019 and 2020 from 27.5 to 29.5 days (The World Bank, 2004, 2019, 2020). (In addition to the EDB, actors interviewed describe the barriers to start and operate a business in Tanzania as moderate to high. In short, the general economic institutions analysis shows a persisting comparative disadvantage for Tanzania that may negatively influence foreign investment and entrepreneurial activities in the country, including the energy sector.

5.1.2. General political institutions

After independence on December 9, 1961, Tanzania became a one party state under the leadership of Julius Nyerere. Nyerere, known as the father of the nation, and his Tanganyika Africa National Union (TANU) party, enacted a form of 'African socialism' (*Ujamaa*), and introduced Kiswahili as its official language to enhance unification across a country with multiple religious and tribal affiliations. TANU, which in 1977 merged with the Zanzibari Afro-Shirazi (ASP) party to create the CCM (Chama Cha Mapinduzi), has remained in power since independence, despite introducing a multiparty democracy in 1992. The political decision-making in CCM has been described as highly centralized, and concentrated amongst select elite groups, restricting inclusion of diverting views from outside of this political space (Anyimadu, 2016).

During the 2015 campaign, the soon to be president John Pombe Magufuli[9] ran on breaking with the past, promising to tackle corruption in his own party, bureaucracy and businesses. Once in power, the

[6] Each system had a 210 Kilowatt (kW) peak, together bringing electricity to 65 approximately households.

[7] We highlight and underscore the function that the analysis relates throughout the text.

[8] For comparison, in the *Doing Business 2020* report, the OECD average number of procedures and days of starting of starting a business was 4.9 and 9.2, respectively (The World Bank, 2020).

[9] President Magufuli passed away on March 17, 2021, and was replaced by his vice president Samia Suluhu Hassan, who took office on March 19, 2021. Samia Suluhu Hassan is expected to serve out Magufuli's five-year term, which began in 2020.

government of Magufuli would steer the efforts of rooting out the alleged widespread corruption. Magufuli stated that motivation for cleaning out corruption in Tanzania stemmed in an ambition to restore the agenda of Julius Nyerere. While Nyerere had advocated for "socialism and self-reliance", Magufuli's own program would emphasize state-led development, national self-reliance without a dependence of foreigners along with occasional South-South collaboration (Paget, 2021). The implementation of the nationalistic agenda to transform Tanzania into an independent African nation began to take shape under Magufuli's presidency, as substantiated in the 2015–2016 budget that aimed to lessen reliance on international aid. In addition, Magufuli's rein also resulted in that several senior officials were fired from multiple government departments in an attempt to instill his campaign promise of "work and nothing else" *(Hapa Kazi Tu, in Swahili)*. Interviews with government officials reveal that the renewal of personnel also included removal of senior experts in Solar PV technology. A proven intent of exercising additional oversight over public servants combined with an increased selection of permanent secretaries led to concerns over power consolidation and control over policy implementation (Anyimadu, 2016).

Although scarce, quantitative data exists providing a rough overview of changes in the general political institutional landscape in Tanzania, in terms of corruption and quality of government. For example, the ICRG (International Country Risk Guide) indicator for *Quality of Government* assesses level of corruption, law and order and bureaucracy in a given country. The indicator, which ranges in value between zero and one, depicts a second order of the political institutions in Tanzania, where a higher value indicates higher quality of government. The data shows a minor improvement from 0.44 in 1990–0.47 in 2018. In a Global South context, Tanzania fairs slightly better than many other countries according to the 2018 data, e.g., Kenya (0.43), Zambia (0.42), Angola (0.34), Brazil (0.39) or Mexico (0.38) (Dahlberg et al., 2019). However, the distance to the Global North, in terms of Quality of Government is still significant, e.g., France (0.75), Germany (0.89) or Denmark (0.97). Dahlberg et al. (2019) have also assessed corruption in the private sector by measuring incidences of bribery in firms. The assessment found that 21.7% (2006) and 20.8% (2013) of Tanzanian firms have "experienced at least one bribe payment request across 6 public transactions dealing with utilities access, permits, licenses and taxes" (Dahlberg et al., 2019).

5.1.3. General informal institutions

While the existing trust in Tanzania for politicians has been described as low,[10] gaining trust as a foreign firm in Tanzania could have its added difficulties. According to interviewed mini-grid developers, as a consequence of a highly decentralized power structure that involves multiple community leaders at the village level, they must gain the trust of local communities and village leadership for the community to see the benefits of a proposed project. As put by an international solar PV mini-grid firm, "doing business in Tanzania is not easy because they don't trust 'Mzungu' (*Swahili for foreigner)* companies even though we have run a few projects, some with private investment." Another international company expressed it as "it is not only more expensive with only foreign staff, but also, sometimes when it comes to communicating with authorities, if you have a Tanzanian on the inside, the person can really go through the door, easier than when you do". Despite these added complexities, interviews with international mini-grid developers confirmed that by building trust of local communities combined with clear communication of the benefits of the mini-grid system, these obstacles could be overcome.

An additional potential obstacle for solar PV mini-grid developers is the described Tanzanian culture of preferring ownership to continuously paying for a service. Thus, the added difficulty for solar PV based mini-grids as compared to SHS is the necessity to convince the local leadership that people in their village are better off continuously paying for the service provided by the developer, rather than owning the SHS after certain number of payments. A mini-grid system can provide electricity to a whole village, including community-related infrastructure and services (e.g. common areas and public lighting) while the SHS would limit the benefits to the households that purchase the system.

Additional discussions over general formal and information institutions that were found to have a more direct influence on the solar PV mini-grid sector will be discussed under the function analysis section.

5.2. Domestic energy and mini-grid actors

The power sector in Tanzania has been state controlled and private involvement has only recently been allowed for specific investments and purposes. The key state players are the national utility (TANESCO), the Ministry of Energy (ME), the Rural Energy Agency (REA), the Electricity Regulatory Authority (EWURA), and the National Environmental Management Council (NEMC). Although REA's role comprises a number of functions, its main mission is and will remain the hosting and managing of the Rural Energy Fund (REF). The Rural Energy Fund (REF) was established under the 2005 Rural Energy Act, for the purpose of providing grants to rural energy projects.

EWURA is an autonomous multi-sectoral regulatory authority established by the EWURA Act of 2001. It is responsible for the technical and economic regulations of electricity, petroleum, natural gas and the water sector. The EWURA Act granted authority for most regulatory tasks, such as licensing, standards, tariff regulations, performance monitoring and enforcement of compliance with the law and its standards. The requirement of holding a license for mini grid operators has recently been introduced. NEMC is the body that approves the Environmental and Social Impact Assessments (ESIAs) for developments and plants that have environmental and socio-economic impact.

In addition, a local NGO, the Tanzanian Renewable Energy Association (TAREA) brings together stakeholders in the renewable energy sector to promote renewable options and mini-grids. The Tanzania Traditional Energy Development and Environment Organisation (TaTEDO) has been promoting access to sustainable energy since the early 1990s.

In terms of domestic universities, as of March 2023, there were 49 public and private universities and university colleges registered in Tanzania (TCU, 2023). A limited research output relating to energy and mini grids can be found in the College of Engineering and Technology (CoET) and the University Business School (UDBS) at the University of Dar es Salaam.

5.3. Specific institutions and TIS functions

5.3.1. Awareness building and emergence of solar PV and mini-grids

An important initial step to start aligning the formal and informal institutions to support the development of solar PV in Tanzania was the creation of awareness for the relatively new technology in the country. Awareness creation about the technology is linked to the *Knowledge Diffusion* and *Creation of Legitimacy (Informal Lobbying)* TIS functions. While electricity generation from solar PV began in 2003 in the country, interviewees described high prices and low awareness for solar-based technologies in Tanzania until 2008. Interviewees identified several initiatives by international actors as having played an essential role in the eventual rise in solar PV diffusion in Tanzania. For example, an extensive national program funded by Sida followed a UNDP pilot project launched in 2004 in the Mwanza region. The Sida program addressed a number of issues relating to the growth of the rural PV market. The emphasis was on supporting the private sector in extending businesses outside the larger cities. For example, awareness campaigns were initiated that included various actor groups, such as government

[10] In a 2016 survey, participants in Tanzania were asked to "rate the level of public trust in the ethical standards of politicians in your country, from 1 (very low) to 7 (very high), the results was 2.9 (Dahlberg et al., 2019).

officials and end users in rural areas. Interviewed actors that are active in the rural areas confirmed that now there is high level of awareness and overall positive attitudes towards the solar PV technology amongst end users. However, interviews with firms also described local attitudes that consider that any energy that comes from the sun should be free, suggesting that there are still awareness gaps amongst end users regarding the technology's benefits but also its installation, operation and maintenance costs.

In addition to raising the awareness for solar PV technology itself, the Sida program also focused on the aspect of accessibility, i.e., improving access to buying panels in regional and district towns. These early interventions of technology awareness and accessibility positively influenced the legitimacy of the solar PV in Tanzania and can be seen as an important transition pathway, which started with SHS followed by Pico solar, and finally leading to the introduction of solar PV based mini-grids in the country.

While the awareness for the solar technology in the form of SHS is high and the technology is widely accepted in Tanzania's rural areas, specific awareness for solar PV based mini-grids is at an early phase. While facilitated by the general awareness of the solar technology in rural areas, the relative novel use of solar PV based mini-grids requires continued good communication with village leadership and rural population concerning its benefits.

5.3.2. Incentivizing mini-grid development and private sector participation

5.3.2.1. Emerging alignment of specific institutions. To understand aspects that affect the *Guidance of the Search*, which reflects actions by government or companies that affect the expectations around technology, and *Market formation* functions, we explore electricity provision, energy-related policies and funding. TANESCO, the national utility, holds state monopoly of utility provision in Tanzania and, to date, it remains the only licensee for both transmission and distribution activities linked to the national grid. However, many steps have been taken to allow and encourage private sector participation in energy production, and specifically, to promote mini-grid development (Peng and Poudineh, 2016).

The revised 2003 energy policy plan took a first step in this direction, which encouraged private sector engagement in electricity generation. This was followed by the 2008 electricity act, which provided legislated rights and rules under which private actors could participate in the development of the energy sector. A framework for small power producers (SPP) was also adopted in 2008, which provided the first guidelines for mini-grid developers, including a standardized power purchase agreement (SPPA) between TANESCO and the SPP. This first generation SPP framework, which only applied to projects of 1 MW or greater, allowed for simplified negotiations and long-term agreements (15–25 years) with TANESCO (Odarno et al., 2017). The agreed upon feed-in tariff and an ability for long-term planning and cost recovery represent an important first step for private sector involvement in the mini-grid sector. However, as the feed-in tariffs did not take into consideration the varying costs of different technologies, the first SPP framework provided a larger benefit for the more established technologies such as hydro, compared to the relatively newer technology of solar PV based mini-grids.

Consequently, a second SPP framework was introduced in 2015, which included technology specific feed-in tariffs, while also expanding the size range of what is consider a SPP mini-grid developer to 100 kW-10 MW. This updated framework provided a regulatory structure, contributing to alignment of the specific institutional infrastructure for solar PV based mini-grid developers (Odarno et al., 2017). The improvements in the regulatory framework for mini-grids are reflected in the Regulatory Indicators for Sustainable Energy (RISE) score, which increased from 17.7 in 2015–78.75 points in 2020.[11] The first year with no improvements in the RISE mini-grid framework score for mini-grid was between 2020 and 2021. By comparison, the Tanzanian framework for grid extension saw an improvement from 83.3 points in 2015 to reach 100 points in 2018, where it has remained since then (ESMAP, 2023).

5.3.2.2. International actor influence. International resource mobilization has been crucial in the early formative stage of solar PV mini-grids. The first projects were community-based, dependent on international funding, e.g., the fourteen projects donated and installed by the Merl group (Merl, 2022). Challenges that have ensued some of these projects have been poor revenue collection as a consequence of inability or unwillingness to pay for donated systems, combined with insufficient supply of electricity for all the villagers (Odarno et al., 2017).

Multilateral and bilateral actor support have had a large presence in renewable energy projects. This is also the case for mini grid projects, which receive large financial support by international organizations (Aly et al., 2019). *Sustainable Energy for All* (SE4ALL), the Swedish International Development Cooperation Agency (Sida), and the United Kingdom's Department for International Development (DFID) have all been instrumental by supporting REA's mini grid program.

Bilateral agencies directly involved in Tanzania include Sida, DFID, Power Africa, Danish International Development Agency (DANIDA), EU and Norwegian Agency for Development Cooperation (NORAD). The actual funding of projects is complex and comprises a mix of grants, matching grants, performance grants, Result-Based Financing (RBF) and credit lines. In fact, in 2016, the Result-Based Financing (RBF) scheme, part of which was directly aimed at supporting mini-grid developers was initiated. This collaborative effort by DFID and Sida, dedicated approximately 45 million USD between 2017 and 2019 towards support for mini-grid development. In the RBF programs, which are implemented by REA, grants ranging from 25 to 600USD[12] are provided to firms for each connection made to a household from the mini-grid. Private sector actors describe RBF financing as essential for the solar PV mini-grid sector. As stated by an interviewee, "building the plant is not an issue but the power lines, distribution, meters, etc. managing and operating the system make the investment costs very high, which will make the tariffs 3–4 times higher than TANESCO".

Other than RBF-based projects, multilateral and bilateral funding organizations also provide funding to REA for the project preparation phase in the form of a grant that mini-grid developers can apply for. As explained by an international actor, "dependence on multilateral and bilateral funding persists, although to a lesser extent than before".

5.3.2.3. Domestic resource mobilization: domestic banks and mini-grid developers. The continued dependence on funding from international organizations relates to a continued reluctance from Tanzanian banks to finance renewable energy projects. Solar PV mini-grids are still considered a relatively new technology and a new form of electricity generation, thus local banks hesitate to finance them. As put by a private sector actor "I can go to a bank and say, I want to do that many mini-grids in

[11] The RISE score for mini-grid framework ranges between 1 and 100 and is based on indicators such as *access to finance, workable regulations, regulatory authority and institutional capacity, training and skills.* For more information see RISE ESMAP analytics.

[12] The amount per connection is decided based on peak available capacity (W), duration (hrs), evening supply (hrs), affordability, legality and quality (voltage). E.g., a mini-grid company providing $>$ 2000 W (peak), for $\geq$ 16 h, and have $\geq$ 4 h evening supply and that fulfills the remaining criteria will receive 500USD per connection (REA, 2017a).

that area and since I will charge the users 1 USD per KwH, and they will consume 100KwH per week the return of the investment is three years. Well, the things that I said, cannot be verified. It is just an assumption that cannot be verified and therefore a bank does not understand the investment and when the investment is not understood, they are not going to finance it".

To overcome this obstacle, several actors have suggested the need for well-calibrated risk assessment tools to be developed. Despite the challenges of *domestic financial resource mobilization*, private sector actors do express optimism that Tanzanian banks will begin to see the potential of renewable energy projects in the form of a cleaner energy source that can support the future growth of the economy. A current attempt to tackle the financing issue is a World Bank supported credit line that runs through local banks. This initiative is, however, reported to be facing complications as a consequence of long transaction periods and low interest amongst local banks in smaller energy projects.

5.3.3. *Entrepreneurial activities*

As no central database exists regarding the exact number of active solar PV mini-grid developers, it is challenging to provide a precise overview of the engagement in the sector. For firms involved in solar technologies in Tanzania, the 2016/2017 TAREA actor directory lists 50 members, although most of them are engaged in pico solar and SHS. According to the Smart Solar Tanzania Information Platform, there are five mini-grid companies active with offices in Dar es Salaam, Mwanza and Arusha (2018). Private sector mini-grid development investments are dominated by international companies (REA, 2017b), though there are international investors who have entered into joint ventures with local companies. Based on interviews and secondary data analysis, two local companies have been highlighted as successfully moved from SHS sales into the design and implementation of mini grids.

Given the high initial cost for establishing solar PV mini-grids, the REA assessment for RBF provides a good estimation of the number of developers active in Tanzania. The analysis of the first call shows a total of 8 different mini-grid companies that passed the REA assessment, which proposed six solar, diesel, battery hybrids projects, one solar and biomass hybrid and one solar and wind hybrid project. A total of 67 sites, 17,102 connections and 1672 kW of power will be installed if all the projects become operational (REA, 2017b).

Online news and actor interviews confirm ongoing construction of 11 new mini-grids, giving 80,000 people access to electricity in the islands of Lake Viktoria, with additional plans of doubling the number of mini-grids in the same region in the coming years (Africa, 2019). Another company has announced having received financing of USD 5.5. Million for the development of 60 solar powered mini-grids that will provide electricity to a total of 34,000 homes and businesses (TanzaniaInvest, 2019).

5.3.3.1. Design and business innovations. As will be discussed in the section on human capacity and knowledge diffusion, very limited R&D exists in the solar PV sector in Tanzania, and the private sector development is largely, if not exclusively, diffusion oriented. There is, however, business innovation occurring to minimize costs and improve the competitiveness of the solar PV mini-grid companies. As described by a private sector actor, "the knowledge creation of mini-grid operators is not on the technology, it is on the way that you use the technology". One mini-grid developer suggested altering the construction design of the system, "to have a shared production, instead of putting all of the generation inside a plot, having the generation spread around your mini-grids, to minimize the costs of mini-voltage lines, avoiding voltage drops and decreasing the dimension needs of cables". In addition to innovative construction design to minimize costs, business innovations in other sectors that positively influence local affordability have also contributed significantly to the mini-grid sector.

5.3.3.2. Local affordability and cross-sector business innovations. The ability of end users to afford solar-based electricity service is another aspect that solar PV mini-grid developers have to confront. Several strategies and innovations from both governmental and private actors in other business sectors have contributed to tackling the affordability issue. For example, government funds are directed to support small and medium enterprises (SMEs) in order to raise income-generating activities. As explained by a local actor, "from the revenue that the local government collects, they give 5–10% to women and young people so that they can do some minor businesses. Then after some period they are supposed to pay it back". This support offers inhabitants in rural areas an opportunity to generate income and address a lack of affordability for goods and services, including energy consumption.

An essential business innovation, highlighted by multiple actor groups, has been the pay-as-you-go (PAYG) system, which allows costumers to pay for the electricity they use, rather than a fixed monthly price. This increases affordability in an incremental manner dependent on the relative income of individual households. This payment option has also greatly benefitted from innovations in the information communication technologies (ICT) sector, which allows payments to be done via mobile phones, through companies offering this option, such as M-Pesa, Tigo-pesa, Airtelmoney, Easy-pesa and Halo-pesa. The rapidly rising mobile phone usage in Tanzania, reaching roughly 80% in 2016 (Wilson and Mbamba, 2017), has thus provided payment options for rural communities that aid mini-grid developers in the collection of payments, especially when implementing a PAYG system.

5.3.4. *Human capacity and knowledge diffusion*

The existing level and trends concerning the human capacity for solar PV based mini-grids is described amongst actors as both positive and negative. Interviewees state that formal training institutes for solar PV based mini grids specifically are non-existent in the country. On the other hand, technical and vocational education and training (TVET) that could benefit future growth of the solar PV sector, e.g., in the form of electricians and knowledge of renewable energy technologies, show a positive trend. In fact, the number of vocational education and training centers has increased from 672 in 2013–822 in 2022. Similarly, there were 440 registered technical institutions in 2021, which is an increase of about 32% since 2017/18 (NACTVET, 2022).

In addition to TVET, the Dar es Salaam Institute of Technology (DIT) was mentioned in actor interviews as another formal institute offering vocational training. Moreover, TAREA, together with the Arusha Technical College, is running a solar training center, funded by the government of the Netherlands. For the specific set-up of mini-grids using solar PV for power generation, private sector actors rely on an internal training strategy for new employees. Private actors highlight that collaboration between universities and the private sector is non-existent, in terms of recruitment and training. Therefore, by initiative of private firms, they reach out and offer internships to university students, which are followed by on-the-job training by the firm in question. A desire for a more structured partnership has been expressed from private sector actors, whereby Master's and PhD students could also be able to conduct research at their facilities.

Both the University of Dar es Salaam and the University of Dodoma offer master's degrees in renewable energy, which teach theoretical aspects of renewable energy solutions. However, interviews reveal an articulated mismatch between private sector needs and the course curriculum in the academic programs on renewable energies. Private actors express a concern that universities are not revising their curricula based on the needs of the mini-grid sector, which they claim is a result of a lack of communication between the universities and the private sector. Moreover, interviews with university actors describe poor knowledge diffusion between departments within the same university.

Research related to renewable energy technologies is limited to the University of Dar es Salaam (UDSM), according to interviewees. This confirms earlier findings by Bailey et al. (Bailey et al., 2010) who claimed that a limited research output relating to energy and mini grids can be found in the College of Engineering and Technology (CoET), and the University Business School (UDBS) at the University of Dar es Salaam. Bailey et al. (Bailey et al., 2010) further argued that research in UDSM was neglected while targeting financing towards undergraduate teaching. Data on publications from Tanzania, however, show a sharp increase in publications, from 3 publications in 2010–59 in 2022, within the field of renewable energy, sustainability and the environment (SJR, 2023).[13] Interviews with actors from UDSM indicate that publications from the CoET are predominantly of a technical engineering focus. They, however, confirmed that in recent years studies analyzing the adoption and diffusion of technologies have become part of the research agenda. The UDBS has also studied the diffusion and impact of access to modern energy, e.g., through the research projects as part of the Sida-SAREC PhD program, which ran between 2011 and 2016.

To conclude, access to technical skills was not described as a bottleneck amongst private sector actors, however, with a caveat concerning a persistent lack of priority for mini-grid specific training. Despite the expressed lack of communication between universities and mini-grid developers, the overall trend in knowledge and interest in renewable energy technologies can be seen as positive, as reflected in the increasing vocational training courses, higher RETs degrees, and increased publications per year within the field of renewable energy, sustainability and the environment.

5.3.5. Policy shift and market uncertainties

Tanzania has committed to international agreements through, for example, its 2012 *National Climate Change Strategy,* aiming to reduce greenhouse gas emissions and promote sustainable development. Moreover, Tanzania was amongst the first fourteen African countries to join the Sustainable Energy for All organization (SE4ALL), which in partnership with the United Nations, aims to accelerate the achievement of Sustainable Development Goal (SDG) number 7 on energy, i.e., to expand the access to affordable, reliable, sustainable and modern energy. As part of the SE4ALL, the Tanzanian government committed to having a renewable energy share of more than 50% (in terms of total final power consumption) by 2030 (Ministry of Energy and Minerals, 2015). The aims for diversifying the energy mix by utilizing renewable energy sources are stated in the 2015 National Environmental Policy (Odarno et al., 2017). Specific references to mini-grid systems are also included in the latest government reform, where the goal was to extend electricity access to the remaining 7873 villages (out of a total of 12, 268) by 2021. The ambitions to achieve this goal include expansion of the national grid, development of decentralized (small) networks using renewable sources of energy, development of mini and micro grids, and installation of stand-alone systems (REA, 2018). However, while mini-grids are mentioned as an alternative energy source in government documents, no specific target for solar PV based mini-grids as part of the future energy mix is mentioned. A prior review of REA operations also documented this lack of clear *guidance of the search* for renewable energy off-grid developments (Bågens et al., 2012). Instead, REA-financed projects show a trend of increasing the percentage of their budget spent on grid extension, i.e., 55% in 2011 and 60% in 2016 (REA, 2011; REA, 2016).

Interviews with multiple actors confirm a sharp shift in government focus regarding priorities for energy policy since the now late John Magufuli took office in November of 2015.[14] Governments prior to Magufuli's were described as augmenting the support for mini-grid solutions, which led to an enabling environment for mini-grid investments and development. Under Magufuli's leadership, actors describe a clear prioritization towards grid-extensions, diverging from the previous emphasis on mini-grid solutions for tackling rural electrification. Moreover, interviews with private sector actors confirm that no plan exists to explain where and when TANESCO will arrive with the grid extensions, thus creating uncertainty for private sector developers. As expressed by a private sector mini-grid developer, "the problem with the government's commitment to rapid rural grid extension. You are not really sure where they [TANESCO] were starting the extension. We dropped a number of clusters, a number of villages, because we were too close to the lines of TANESCO. The extension never happened but still, a private investor would never bear that cost".

The uncertainties created by a lack of plan for when and where the grid will arrive is exacerbated by the low state-subsidized TANESCO tariff, which for most mini-grid developers is below the level needed to recover their investment. Therefore, when TANESCO arrives to a village with a solar PV based mini-grid system, the alternative of remaining in the village and selling electricity to TANESCO would make the cost-recovery difficult as the feed-in-tariff in most cases is much lower than the current renewable energy feed-in tariff (REFIT) (Mdee et al., 2018). The other alternative given to mini-grid developers is to move their mini-grid to a more remote area without electricity, however, without an understanding of the continued expansion of the grid, mini-grid developers encounter a continued uncertainty that the relocation would enable them to recover their investment. In short, the lack of information regarding grid extensions, combined with the low TANESCO tariff, provides a disincentive for entrepreneurial activities in the solar PV based mini-grid sector.

In addition, the changed political prioritization has also negatively affected the business environment for mini-grid developers, both in terms of formal and informal institutions. Concerning specific formal institutions, a foreign private sector mini-grid developer expressed, "it is becoming much more difficult for a foreign company to operate, every year it gets more difficult". Another private sector mini-grid developer specified some of the challenges, "in general, the government used to be quite friendly to mini-grid developers, but it's shifting…it has become more complicated these days, e.g., customs are stricter, items that were exempted in the past are not any more". In terms of general informal institutions, one foreign firm described a changing business environment in Tanzania in that "we are not from Tanzania, we will never be accepted, we are tolerated, to a degree, it is very apparent that we have become less welcomed."

While certain disincentives and market uncertainties for mini-grid developers have occurred following the priority towards grid extensions and large-scale energy developments, certain opportunities for mini-grid developers persist. RBF schemes continue to assist private sector developers in managing the cost recovery concern, while the government has invited mini-grid investments to islands and remote areas where the grid arrival is not considered feasible in the near future. As described by an international actor, "what you need is to have a good understanding of the technical and political situation. But if you manage to find where it is technically feasible and the grid is very far away, and you have a very good grasp of the local political situation, you can still work it out."

5.3.5.1. Creation of legitimacy and market formation. After active *lobbying by firms*, Tanzania introduced in 2005 a duty import reduction on solar panels and associated equipment, along with VAT exemptions (Hansen et al., 2015). These market incentives have been acknowledged amongst actors as playing a positive role in the rapid growth of the solar PV sector in Tanzania. In an attempt to increase revenues for government spending, the government under the late president Magufuli ordered the tax authorities to collect additional taxes. As a consequence of

[13] Note that 81% of the publications between 2010 and 2022 were completed with international collaboration (SJR, 2023).

[14] There is no indication the current president Samia Suluhu Hassan that is serving out the term of John Magufuli has changed the energy policy direction set out by the late president. In fact, announcements made in 2023 by the new president confirm a continued focus on large-scale energy projects and grid extensions (Mhagama, 2023).

the new tax policies, solar PV firms got approached by tax authorities with a demand for retroactively paying VAT for sold products over the last five years. Firms worked together with international actors to resist the demand for retroactive payments. While the demand for retroactive payments were eventually avoided through negotiations, new regulations to remove the VAT and duty import exemptions became active during the summer of 2018. The reintroduction of an 18% VAT on certain items such as cables, LED lights and wires, added additional costs to firms engaged in the energy sector (The Citizen, 2018). However, the added costs on imports coincided with a continued fall in solar panels prices, which compensated the added costs, allowing firms to remain in business.

Despite the challenges, actors in the solar PV mini-grid sector continue to meet in an attempt to improve the conditions for the sector. A number of channels to influence policy exist in the form of industry associations, the main ones being TIPA (Tanzanian Independent Power Producer Association), AMDA (African Mini Grid Association) and TAREA (Tanzania Renewable Energy Association). These associations bring actors together, allowing for new information regarding rules, regulations and tariffs to be discussed and shared. Moreover, they provide a unified voice in their communication with the government regarding desirable regulation for mini-grid developers. TAREA is described amongst actors as an active and influential association for negotiating and creating awareness about the concerns and potential of the mini-grid sector amongst members of the parliament. Interviews with firms also describe ongoing quarterly meetings between TAREA and international actors to discuss the general trends in the solar PV industry, including the mini-grid sector. Interviews with TAREA confirm that they organize workshops in collaboration with REA, in order to reach non-members that are operating in the solar PV mini-grid space and that would be affected by regulatory changes.

Through the representation of TAREA, ongoing lobbying attempts include issues of tax incentives in the area of import duties and VAT. Additional desired regulation from the private sector actors includes quality control of imported products, motivated by large imports of substandard solar panels, which distorts the market and consequently threatens the businesses of serious actors. International actors corroborate this concern (Ipsos, 2017). Through ongoing discussions with Tanzania Bureau of Standards and TAREA, private sector actors attempt to instill a required certificate for quality assurance of solar panels, while also demanding that origin of the product is marked on the products. Thus, *knowledge diffusion* and *formal lobbying* occur between private sector, international and industry associations and government actors concerning the existing and desired specific formal institutions governing the solar PV mini-grid sector in Tanzania.

6. Discussion: key findings and policy suggestions

Based on the results of the application of the extended Technological Innovation Systems (TIS) function approach from the previous section, this section highlights key findings concerning drivers and barriers of the Tanzanian solar PV based mini-grid systems. When applicable, we provide policy suggestions to remedy identified blocking mechanisms for the solar PV based mini-grid sectors at the end of each sub-section.

6.1. Changing political objectives and TIS functions

The inclusion of the general political institutional infrastructure in the system analysis has provided a deeper understanding of the ideological motivation behind new political prioritizations that have occurred in Tanzania from 2015 and onwards. In an attempt to implement a renewed agenda of Tanzania's Father of the Nation Julius Nyerere, consisting of state-led development and a national self-reliance independent of foreigners, several changes can be observed in the general and specific institutions.

Under the political direction of Magufuli, several TIS functions were negatively impacted (see Fig. 3). In an ambition to collect more taxes, the late president attempted the enforcement of retroactive payments from solar PV firms. While this was eventually prevented after extensive negotiation between the government, international actors and firms, the removal in 2018 of VAT and duty import exemptions on essential items for the solar PV mini-grid sector impacted the market formation function.

Another election promise of Magufuli was to combat corruption, which resulted in the removal of multiple senior government officials. Interviews with government officials describe how several senior experts on solar PV technology were removed from their positions, resulting in less trained personnel in charge of solar PV solutions to tackle rural energy poverty.

Moreover, in an ambition to strengthen domestic energy production, large-scale energy projects and grid extension received renewed focus by the Magufuli government. By setting up an ambitious goal of rapidly electrifying the entire country through grid extensions, the consequence has been an increased investment uncertainty for mini-grid developers. The added risk for investing in solar PV mini-grids was exacerbated by the lack of clear government plans for when and where the grid extensions would occur. The high initial investment costs and the required longer cost recovery period for developing solar PV based mini-grids makes the sector vulnerable to sudden changes, such as a sudden arrival of the grid. Moreover, the alternative to stay and sell electricity at the very low TANESCO tariff makes it difficult to recover initial investments.

While the sudden shift in policy was shown to discourage several private sector actors, who decided to move their businesses to other countries, a number of solar PV mini-grid companies remained in Tanzania. Our analysis shows that private sector actors with sunk costs decided to remain until the grid arrives and recover as much of their investment as possible. Some firms engaged in cautious planning and focused their investments in the most remote areas in Tanzania in order to minimize the risk of grid arrival, as can be seen with the development plans on the islands in the Lake Victoria district.

If, as most actors believe, the goal of nationwide grid extension does not succeed, a reduced entrepreneurial activity in the mini-grid sector combined with an unfinished grid, risks leaving rural areas without electricity for the foreseeable future. A policy suggestion to overcome this would be to provide private sector developers with a realistic and concrete timeline and geographical map of when and where the grid will arrive. This would give stability to the market and allow private sector actors to plan their business strategies.

6.2. Changes and influence of informal institutions

The extended TIS framework also allowed analyzing the role of informal institutions. The analysis showed that informal institutions have both positive and negative effects on entrepreneurial activities (see Fig. 4). After many years of awareness building from national and international actors, the solar PV technology enjoys a high level of acceptance in rural areas, although an attitude that energy from the sun should be for free continues. This means that locals are open to solar PV installations but are less willing to pay for their installation, service and maintenance. Another challenge is the general cultural preference of ownership over continuously paying for the service, which would initially favor SHS as rural Tanzanians will own their SHS after a certain number of paid installments. Private sector mini-grid developers must therefore counteract this cultural preference by explaining the personal and communal benefits of mini-grids over SHS, such as electrification of schools, health clinics and business ventures, along with the potential for scalability. Furthermore, as shown in Fig. 4, private sector actors expressed a negative change in the general informal institutions in recent years, manifested by a less welcoming business environment for foreign mini-grid developers.

The negative effects from the general and specific informal

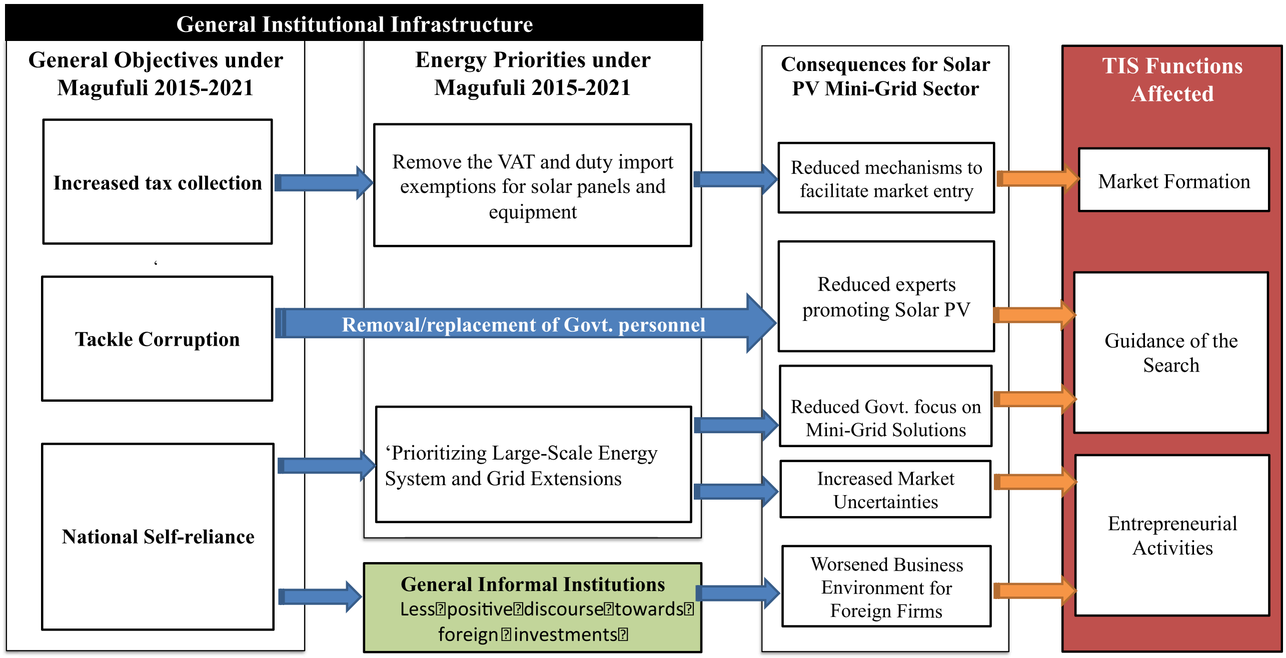

Fig. 3. Demonstrated links between the general institutional infrastructure and TIS functions.
Source: Authors.

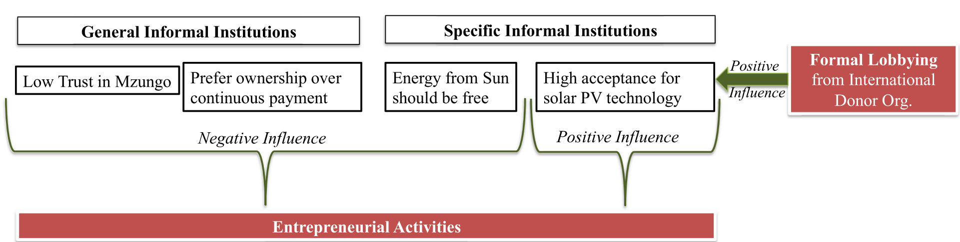

Fig. 4. Positive and negative influence from informal institutions.
Source: Authors.

institutions could, however, be counteracted by thoroughly communicating to the community about individual benefits from opting for a solar PV mini-grid system at the community level. Foreign companies could overcome potential trust issues by assuring that Tanzanian nationals are part of their team. A policy suggestion to overcome potential negative influence from general and specific informal institutions could be for the appropriate government departments to provide an information package to international firms, which describes norms, attitudes and local cultures in Tanzania. This would allow international firms to take these informal institutional aspects into consideration when planning for solar PV mini-grid developments.

6.3. Knowledge generation, technical skills and diffusion amongst actors

Limited amount of research within the field of renewable energy was identified in one major Tanzanian university. Indications of positive knowledge development trends include the existence of Master's programs at universities, along with a rise in domestic publications within the topic of RETs. As shown in Section 5.3.4, a positive knowledge trend was also found in the increasing number of established Technical and Vocational Education and Training facilities, contributing to creating adaptive capacity for solar PV related sectors.

Mini-grid developers, however, emphasize that they recruit primarily from universities and train individuals on the job for the technical specialization required for solar PV mini-grid installations and maintenance. Private sector actors stress the need for improved communication between firms and universities. Specifically, an aspect of concern was an existing disconnect between what is being taught and researched at university programs with the actual needs of the private sector. This disparity in skills and knowledge demands additional time and resource investment for the private firm to adequately train its personnel. Similarly to how private sector actors meet other private sector actors to lobby for regulatory reform, university led conferences where private sector actors are invited could enable a closer collaboration and could help reduce the existing mismatch. Private sector actors voiced the aspiration that a closer collaboration could result in future partnership research programs that would benefit the solar PV mini-grid sector. A policy suggestion for decision makers at the universities would be to dedicate funds and personnel towards arranging events that could facilitate better collaboration.

6.4. Quality control

An additional concern raised by multiple actors was the issue of the solar PV market being flooded by products of varying quality. Although it is mostly the SHS market that has been adversely affected by poor quality panels, a lack of quality control may spill over to the mini grid sector and there is a risk that the attitude (acceptance) towards solar PV based mini-grids may be negatively influenced. A policy suggestion is to enact and enforce a regulatory framework for quality control in the form of certificates for guarantying standards of imported solar PV products.

6.5. Positive trends

A number of innovations (*other sectors' influence)* in other sectors have significantly aided mini-grid developments. The pay-as-you-go (PAYG) system, which allows users to pay only for the energy used rather than a fixed monthly payment, helps address the inability to pay concern that exists in many poor rural dwellings in Tanzania. Allowing payments to be made via mobile phones, combined with a high and rapidly rising mobile phone usage in Tanzania, further facilitates purchasing energy.

The function Creation of Legitimacy (formal lobbying) can be described as strong with multiple groups consisting of firms and international actors, actively lobbying the government for more favorable conditions for the solar and mini-grid sectors. Despite lowered guidance of the search and market formation, firms continue to lobby, particularly through TAREA, for better tax incentives, import duties and VAT exemptions.

Finally, despite the less favorable environment for solar PV mini-grid developers that followed the new government direction towards large-scale energy projects and grid extensions, entrepreneurial activities persist. By targeting extremely remote areas where grid extensions are unlikely to arrive in the foreseeable future, the solar PV mini-grid sector still has an important role to play in the electrification of energy poor rural pockets of Tanzania.

7. Concluding remarks

This paper has analyzed the progress, status and trends of solar PV mini-grid diffusion in Tanzania. In addition, by applying an extended TIS approach to an empirical study in Tanzania, the paper has aimed at making a conceptual contribution to the TIS approach in a Global South context. By including in the analysis the general institutional infrastructure and other contextual factors as endogenous to the system, this paper has identified determinants that could positively or negatively influence the solar PV mini-grid sector; factors that, otherwise, may have been missed in a strict function analysis. In addition, general and specific informal institutions have been explicitly included in order to capture any potential barriers or drivers found as part of the norms and attitudes towards the technology in question.

The comprehensive socio-technical system analysis applied rests on the traditional TIS function analysis but also considers aspects that may be considered exogenous to the focal TIS function approach. This iteration of an earlier attempt (Edsand, 2019) to adapt the TIS framework to improve its applicability in the Global South has made a separation of general and specific structural components and considered them as endogenous to the system. By doing so, it allows for an explicit analysis of wider institutional changes that may act upon the focal TIS (i.e. solar PV mini-grids), and positively or negatively influence its diffusion. By explicitly including the general institutional infrastructure into the analysis, this framework reduces the possibility of missing important determinants that may have been overlooked in a strict TIS function approach.

This paper has also expanded the TIS analysis by including informal institutions. Although the TIS framework has considered institutions as central to the approach of systems analysis, the institutions considered are focused on formal institutions that specifically target the technology in question, e.g., tax laws and regulations. General and specific informal institutions have been explicitly included in order to capture any potential barriers or drivers found as part of the norms and attitudes towards the technology in question. This inclusion can give additional information regarding the complexities of technological transition at the local level, enabling private sector preparedness required for new firms to overcome obstacles at the local level related to norms and culture. The theoretical contribution of this paper is thus both to expand the potentially influential institutions, referred to as the general institutional infrastructure, while also explicitly incorporating informal institutions into the approach.

Empirically, the analysis found weaknesses and negative trends in TIS functions, such as market formation, entrepreneurial activities, and guidance of the search. It also showed the influence of political changes on the institutional infrastructure in which the solar PV mini-grid sector operates. Specifically, the paper identified a link between the change in the general economic and political institutional infrastructure that coincided with a political change in Tanzania after the 2015 presidential election and a worsening climate for solar PV mini-grid developers. Following the ambitions of president Magufuli, a new prioritization for large-scale energy projects and grid extensions led to market uncertainties and less favorable conditions for the solar PV mini-grid sector. In addition, the nationalistic agenda to make Tanzania independent from foreign funding and influence has contributed to a less welcoming environment for international investors and companies. Despite several negative trends for the solar PV mini-grid sector, the established small power producers regulatory framework together with the introduction of results based financing, has contributed to lower costs for solar panels and to the continued commitment of several firms to solar PV mini-grid developments in areas that are unlikely to be reached by grid extensions.

CRediT authorship contribution statement

Edsand was responsible for conceptualization, methodology, validation, formal analysis, investigation, data curation, writing (original draft and review & editing, visualization, supervision, project administration and funding acquisition for the paper. Bångens contributed with contacts in the field (resources) as well as the formal analysis and writing of the original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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