Identifying Effective Electrification Approaches and Combinations Thereof to Meet Universal Electricity Access Targets in Eastern Africa

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Abstract

The gains made in increasing electricity access between 2010 and 2018 indicate the benefit of a multi-pronged approach to electrification, which combines on-grid and off-grid electrification approaches and efforts from both public and private actors. The gains still fall short of the rate of increase needed to achieve universal access to electricity by 2030, indicating the need to increase the effectiveness of the multi-pronged approach. To do this the paper applies the triple embeddedness framework theory. Within the scope of Eastern Africa, we consider actors in the delivery of electricity access (irrespective of approach or whether public or private) as delivering similar goods and services, and conceptualize them as a collective entity i.e., firms in the electrification industry. The paper then analyses how these firms are shaped by the industry regime and influenced by the socio-political and economic environments, with a view to identifying where and how external pressure can be exerted to stimulate and facilitate the reorientation and recreation required to make progress towards universal electricity access. Through this exercise we demonstrate that the triple embeddedness framework provides a structured

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S. Groh et al. (eds.), *Electricity Access, Decarbonization, and Integration of Renewables*, Energiepolitik und Klimaschutz. Energy Policy and Climate Protection, https://doi.org/10.1007/978-3-658-38215-5_9

way of laying out the key aspects associated with electrification to create a picture that enables one to 'see the forest for the trees' and identify where and how to achieve more effective complementarity between on and off-grid approaches, and public and private firms.

Keywords

Business models · Delivery models · Electrification · Energy access · Institutional economics · Off-grid

1 Introduction

The Sustainable Development Goal Target 7.1 sets out the global goal for universal access to affordable, reliable, sustainable, and modern energy services by 2030. The target covers access to electricity (7.1.1) and access to clean cooking (7.1.2). Recent years have seen rapid growth in access to electricity after accelerated deployment of affordable electrification options, consisting of both on- and off-grid solutions. While the global population lacking access to electricity dropped from 1.2 billion in 2010 to 789 million in 2018, these gains fall short of the annual rate of increase needed to achieve universal access to electricity by 2030. The world's electricity access deficit is increasingly concentrated in Sub-Saharan Africa; under current and planned policies before the start of the COVID-19 crisis, it is estimated that about 620 million people will remain without access in 2030, 85% of them in Sub-Saharan Africa (International Energy Agency et al., 2020).

The gains made in increasing electricity access indicate the benefit of a multi-pronged approach to electrification. However, to increase the effectiveness of such an approach, it is necessary to understand how different electrification approaches and actors are interconnected and complementary. This suggests a shift from categorizing electrification actors i.e., by public or private, or categorizing electrification approaches (i.e., grid, mini-grid, or off-grid solar) and analysing the categories separately. Instead, a broader understanding of the 'electrification industry' is required. This includes, (1) an understanding of the firms in the electrification industry, their roles and influence with regard to shaping regime rules, (2) the economic and socio-political environment in which the firms in the electrification industry operate and how they respond to the pressures created by this environment, and (3) identifying where and how external pressure can be exerted to stimulate and facilitate the reorientation and recreation required by firms in the 'electrification industry' to make progress towards the goal of universal electricity access.

2 Literature Review

To better understand what is involved in addressing societal problems through substantial industry reorientation, Frank Geels developed the Triple Embeddedness Framework (TEF) (Geels, 2014). The TEF was developed to provide a broad understanding of co-evolution of industries and their environments, and to conceptualize specific causal mechanisms. It aims to unravel the complexity of co-evolution of industries and their environments by distinguishing mechanisms through which different environments exert pressure on firms, strategies firms can use in response to these pressures, and regime elements which enable and constrain the perceptions and strategies of firms-in-industries. This paper aims to apply this framework to the electricity access challenge in Eastern Africa.

Other frameworks, notably the multi-level perspective, have been used to analyse the electricity access challenge in countries in sub-Saharan Africa. Bhamidipati et al. uses the multi-level perspective to investigate the role of transnational actors in the development of the off-grid solar PV (OGS) regime in Uganda, they develop a typology of transnational actors and examines their roles in mobilizing the flow of knowledge, capital and technology towards shaping the country's OGS rural electrification regime, and demonstrates the transnational nature of regime development by discussing the role of foreign actors, their underlying motives and shifting importance over time (Bhamidipati et al., 2019). Sergi et al. (2018) also uses the multi-level perspective to illustrate the interactions between state policies, investment in off-grid technologies, and expansion of electricity access. He examines the institutions in the Kenyan and Tanzanian electricity sectors, undertakes a quantitative analysis of investment and development aid transaction data for on-grid and off-grid projects, and demonstrates that these investments reveal the priorities and constraints of different actors across on and off-grid technologies.

Also of value is literature that considers multi-pronged approaches to electricity access and analyses the different environmental pressures exerted on firms delivering electricity access (even though the analysis is not done using a specific theoretical framework).

Using the history of electrification in South Africa, Gaunt demonstrates that electrification has been implemented to meet three significantly different objectives: initially economic, later socio-economic, and recently social. He determines that while different solutions are needed to achieve the different electrification objectives, this was not evident because existing processes, networks, tariffs, and regulations had developed around concepts of electrification driven by economic objectives. He concludes that the experience of electrification in South Africa indicates that identifying the differences between economic and social objectives, and their effect on electrification, electricity tariffs, electricity distribution industry restructuring and regulation, should contribute to better decision-making and greater effectiveness in future (Gaunt, 2005).

Levin et al. argues that the emergence of lower cost distributed technologies has created a fundamental shift in how energy services are being consumed, and that developing countries have a unique opportunity to leapfrog the traditional centralized model and achieve universal electricity access by transitioning to a more distributed approach to electrification (Levin & Thomas, 2016).

Drawing on lessons from successful electrification programs, Barnes shows that complementary solutions, involving both grid and off-grid approaches will be needed for electrification in developing countries. Grid extension should be pursued as a least-cost option in more densely populated and economically advanced areas, where power demand and load densities are high, and where grid extension is not least-cost or reaching remote communities through grid network expansion is economically impractical, off-grid technologies and business models should be adopted to provide basic levels of electricity service (Barnes, 2011).

Urpelainen describes three approaches to electrification and uses India as a case study to illustrate these. These approaches are (1) complete separation, in which off-grid electrification is pursued by private entrepreneurs and designated government agencies in areas that are currently not planned for grid extension, (2) uncoordinated integration, in which both grid extension and off-grid electrification are pursued independently of one another by different agents within and outside the government, and (3) integrated development, in which a consistent electrification policy guides the progress of coordinated off-grid electrification and grid extension. She concludes that explicit integration is the most effective because it prevents coordination failure. She argues that as long as there are ongoing grid extension efforts and offering power to some segments of the rural population through the grid would be expensive, off-grid electrification is a potentially useful complement to the conventional approach (Urpelainen, 2014).

Pedersen et al. investigates the practices and business approaches of private mini grid developers in Kenya. The paper's analytical focus is how private mini grid developers are influencing the electrification regime to strengthen and expand the niche for private mini grids (Pedersen & Nygaard, 2018).

Bhattacharyya reviews funding needs and financing mechanisms for off-grid electrification to find whether the funding for these activities has been adequate, whether sufficient funding is likely to be available to meet the needs of universal energy access, and whether innovative approaches can be used in funding. He finds that the size of investment required is significantly higher than traditional levels for energy access provisions, and that development assistance will not be sufficient. He concludes that developing country governments and private sector will have to play a significant role. Governments will have to commit funds and create an enabling environment for private businesses, micro-finance organizations, and for the management and implementation of energy access activities in a timely and orderly manner (Bhattacharyya, 2013).

3 Methods

This paper considers actors in the delivery of electricity access (irrespective of approach or whether public or private) as delivering similar goods and services. This enables us to then conceptualize them as a collective entity i.e., firms in the electrification industry, and then ask the broader question—What shapes and influences the electrification industry? The paper focuses on the electrification industry in Eastern Africa, primarily considering Kenya, Ethiopia, Uganda, Tanzania, and Rwanda. We then apply Geels's Triple Embeddedness Framework (TEF) theory, which argues that firms are shaped by industry regimes and influenced by external environments (i.e., economic and socio-political), to answer this question (Geels, 2014).

The paper is divided into four sections. The first section identifies and describes firms in the electrification industry. The TEF distinguishes firms in industries into three types: core firms (which have the power to discipline other firms and shape regime rules to suit their interest), firms 'in the middle', and peripheral firms (fringe actors or new entrants for whom it is relatively easier to deviate from regime rules) (Geels, 2014). The second section describes what shapes the firms in the electrification industry i.e., the industry regime. This includes their core capabilities e.g., technical knowledge and competency, shared mindsets—that shape interpretations of external environments and influence strategic choices and decisions, industry mission and identity—beliefs that actors have about themselves and their role in society, and regulations, laws, and standards—that shape electrification markets and innovation activities and reduce the set of choices available to firms in the electrification industry. The third section describes the socio-political and economic environments that firms in the electrification industry are operating in and how they are strategically responding to these environments i.e., how are they positioning themselves within this environment, attempting to shape the environment or reorienting and/or recreating themselves to fit better within it.

The fourth section synthesizes and analyses the previous sections to identify if, where and how external pressure can be exerted to stimulate and facilitate the reorientation and recreation required by firms in the 'electrification industry' to make progress towards the goal of universal electricity access. Reorientation involves substantial changes in technology and market strategy, while recreation additionally entails substantial changes in core beliefs and values (i.e., a foundational rethink). Reorientation of firms requires increasing pressures from economic and socio-political environments, without which firms are likely to be locked-in to existing industry regimes (Geels, 2014).

The paper is based on information sourced from: (1) the electrification strategies and plans for the five Eastern African countries under consideration, which detail the institutional environment and anticipated roles of public and private firms in electrification, (2) primary and secondary legislation relevant to electrification (2) off-grid solar market trend reports—a series of biennial assessments of the global off-grid solar market that provide information on the market environment for off-grid solar, the landscape of private firms and how they are responding to external pressures, (3) implementation reports for public electrification projects funded by the World Bank and governments, which provide information on how public firms are responding to external pressures, (4) other off-grid solar and mini grid market reports and (5) academic literature on electrification in sub-Saharan Africa and literature that analyses different electrification approaches.

4 Results

4.1 Firms in the Electrification Industry

In the 1990's, as a result of the power crisis facing many countries, development finance institutions prompted governments to adopt a set of standardized power sector reforms with the offer of conditional financing. The need for reforms arose from two primary concerns: dissatisfaction over the poor technical, financial, and managerial performance of the state-owned electricity utilities, and the inability of utilities and the government to mobilize sufficient investment capital for the electricity subsector's development and expansion (Bacon & Besant-Jones, 2002). The five major reform options implemented in sub-Saharan Africa include: (1) unbundling/restructuring—the process of separating vertically integrated utilities into independent generation, transmission and distribution companies, (2) management contracts—contracting out the management of a utility to a private entity with the utility remaining the owner of the assets, (3) corporatization/commercialization—transforming a state-owned utility into a limited liability corporate body often with the government as the main shareholder, (4) independent power producers (IPPs)—creating an opportunity for private sector investment in the wholesale power market by e.g., providing for long-term power purchase agreements backed by suitable guarantees, (5) electricity law amendment—to e.g., remove the monopoly of the national utility—a major barrier to private sector participation, provide for the establishment of an independent regulatory body for the electricity subsector, and create a provision for a rural electrification programme and/or fund.

Power sector reform is the origin of national electricity utilities and rural electrification agencies in many countries in sub-Saharan Africa today. The key objective of corporatization was to ensure that utilities ran their operations to maximize profits by adopting principles such as: separating the utility from the ministry, creating a clear accounting framework, cost recovery in pricing, reducing, or eliminating subsidies, and enforcing revenue collection. Rural electrification agencies were essentially established because these principles of profit maximization were incompatible with rural electrification, which aims to provide affordable electricity services in areas often characterized by low population density, lower incomes, low electricity consumption and high operating costs. Once electricity utilities were corporatized, it was no longer possible for governments to depend on them to achieve their rural electrification objectives.

Until recently there has been little coordination in Eastern Africa between rural electrification agencies, national electricity utilities and private firms to deliver electricity access. Historically, governments have focused on grid-based approaches (and diesel-powered mini grids to a lesser extent) implemented using public funds and through rural electrification agencies and national electricity utility companies. Where rural electrification agencies and national electricity utilities government have been unable to provide electricity connections and reliable electricity services, private sector has used this as an opportunity for value creation; commercially offering off-grid solar products and electricity services through renewable energy based mini or micro-grids.

The firms in the electrification industry can be categorised as follows:

4.1.1 Rural Electrification Agency

Typically, a dedicated government agency responsible for developing and monitoring rural electrification plans, as well as managing the rural electrification process and the funds dedicated for rural electrification. Their tasks include prioritizing areas for electrification, determining the electrification technology options to use based on their suitability for different areas, and clustering of electrification projects to optimize economies of scale. Kenya, Uganda, and Tanzania have established government agencies that are dedicated to rural electrification agencies. Although structured differently, Rwanda is similar, rural electrification is implemented as a program (the Energy Access Rollout Program (EARP)), which is managed by a department that is situated in the Energy Development Corporation Limited (EDCL), which is responsible for non-revenue generating infrastructure development (The World Bank, 2020b). Ethiopia on the other hand has a Directorate of Electrification within the Ministry of Water, Irrigation and Energy (Ethiopian Ministry of Water, Irrigation and Energy, 2019).

4.1.2 National Electricity Utility

A limited liability company, often with the government as the main or sole shareholder that is primarily engaged in the distribution of electricity. It is usually the sole buyer of electricity from the transmission company or directly from generation companies, has national coverage and is effectively a natural monopoly. In Kenya, Tanzania, Rwanda and Ethiopia, the national electricity utility is the electricity distributor. Uganda employs a different approach; through a concessional arrangement, the national electricity utility has leased its distribution assets to a private company who then distribute electricity. Unlike the other utilities, the Tanzanian utility is still vertically integrated; in addition to generation, it also performs the functions of electricity generation and transmission.

The national electricity utilities are characterized by a large customer base, with customer numbers as follows: Kenya—7 million, Ethiopia—2.7 million, Tanzania—2.3 million, Uganda—1.5 million and Rwanda—0.7 million (Source: Utility websites). In addition, most of their revenue (44%–56%) comes from less than 1% of customers who fall in the large commercial and industrial categories. While rural electrification is the remit of rural electrification agencies, where financially viable, national electricity utilities are usually responsible for investments in urban electrification. If necessary, customers must pay connection charges or additional monthly fees to contribute to investment costs that cannot be recovered through standard tariffs. To accelerate urban electrification, governments have also directly funded national electricity utilities.

4.1.3 Private Electricity Generation and Distribution Companies

This category includes (1) private companies who develop, own and/or manage small, isolated electricity generation and distribution systems, and (2) private companies who manage publicly owned electricity grids under a concessional agreement (e.g., grid expansion projects implemented by the rural electrification agency); they purchase electricity in bulk from the national utility or transmission company for resale to consumers. Electricity customers on these privately owned or managed distribution grids range from as low as 50 (in micro grids) to tens of thousands (in distribution grid concessions). A 2020 mini grid market study commissioned by Sustainable Energy for All (Mini-Grids Partnership et al., 2020) estimates that Tanzania has 209 private isolated mini grids, while Uganda has 34, and Kenya has about 40 isolated mini grids (NewClimate Institute & EED Advisory, 2019). The private mini grid sector in Rwanda and Ethiopia is still in its early stages of development, Rwanda is estimated to have 66 private mini grids (although 59 of these are owned by one company and are micro grids below 4 kW) (Power Africa Off-grid Project, 2019a), while Ethiopia has about 6 (Power Africa Off-grid Project, 2019b).

4.1.4 Off-grid Solar Companies

These are private companies marketing standalone solar PV solutions. These solutions range from solar lanterns to solar home systems kits (pre-designed systems sold as a complete package that include appliances) to component-based systems (custom designed to meet the consumers specific requirements). Special attention is paid to solar lanterns and solar home system kits (collectively referred to as off-grid solar products) because of the significant growth in global annual sales from less than 1 million units in 2010 to almost 40 million units in 2019 (Lighting Global et al., 2020).

4.2 What Shapes Firms in the Electrification Industry—The Industry Regime

4.2.1 Core Capabilities

To describe the knowledge and skills that reside in the electrification industry, we consider on-grid, mini grid and off-grid solar electrification technologies and implementation experience.

On-Grid

We consider the scope of on-grid electrification as electricity distribution i.e., the final stage in the delivery of electricity from the transmission system to individual consumers. Distribution sub-stations lower the transmission voltage to medium voltage (1–33 kV). Primary distribution lines then carry this medium voltage power to distribution transformers. As a rule of thumb, multiplying the capacity of the primary distribution line by a factor of two gives an indication of how far it can be extended without negatively affecting voltage quality e.g., a 33 kV line should not be extended by more than 66 km from the distribution sub-station to the distribution transformer. Distribution transformers typically serve consumers within a 600 m radius via secondary distribution lines. Domestic and small commercial consumers are connected to secondary distribution lines through service drops, while large commercial and industrial consumers are connected directly to the primary distribution lines. The medium voltage network is considered the backbone for electricity distribution, and therefore for on-grid electrification.

On-grid electrification approaches can be categorized into: (1) grid densification—service drop installations and extending secondary distribution lines to connect unserved customers within reach of existing distribution transformers, (2) grid intensification—short extensions of the medium voltage network and installation of distribution transformers to connect housing clusters within 2.5 km of the existing medium voltage network, and (3) grid extension—longer medium voltage network extensions to connect settlements that are further away from the existing medium voltage network. In the countries considered, the average per connection costs for the different on-grid electrification approaches determined during the development of their electrification plans, are as follows: grid densification US$ 160–747, grid intensification US$ 600–1057, and grid extension US$ 732–1273.

There has been experience with low-cost grid electrification technologies and approaches such as: (1) low-cost house wiring techniques—e.g., ready boards, which provide a standardized light and socket point for consumers who can afford to pay to wire their premises and incorporate a meter (Golumbeanu and Barnes, 2013), (2) single wire earth return technology (SWER)—suited to powering relatively small loads over long distances at low cost by cutting the quantity of conductors and insulators required and reducing labour requirements for line construction (Swiss Centre for Development Cooperation in Technology and Management, 1992), and (3) Shied Wire Systems—that run along existing high-voltage transmission lines and can supply household electricity to communities located within 20 km of the high-voltage corridor at a fraction of the cost of new substations or independent medium-voltage lines (ESMAP, 2017).

Having access to electricity at the normal tariffs does not confer on households the ability to afford to use it, which has necessitated the adoption of tariffs to support the social objectives of electrification. Gaunt outlines key specifications for a social tariff: (1) includes a subsidy to reduce the costs to customers to levels below a fully cost-reflective tariff, which may include the profits of a privatised utility. The subsidy will not be so large as to damage the economy and be derived from a source that can sustain it (e.g., a cross-subsidy), (2) promotes perceptions of fair pricing by incorporating geographic uniformity, (3) may restrict the terms of the service provided, such as by limiting the maximum current, (4) provides enough energy to make a difference in respect of the purpose for which it is intended, (5) enables beneficiaries to increase their power and energy consumption (when ready and able) without having to make a significant capital investment to access additional capacity (unlike off-grid solar products), (6) delivers the benefits to the targeted beneficiaries, with as little as possible leakage to those outside the group, (7) is structured a simple way to promote understanding and reduce the costs of implementing the tariff, and (8) is implemented in a way that does not reinforce long-term social dependency e.g., the tariff has a structure that provides flexibility for 'managing' it as conditions change (Gaunt, 2005). Lifeline tariffs are a good example of a social tariff. They are targeted subsidies based on the consumption level of households (i.e., subsidized rates based for a first block of consumption enough to cover basic needs). The domestic electricity tariffs for the countries considered, assuming a monthly consumption of 30kWh, are as follows: Ethiopia—US$ 0.02/kWh, Kenya—US$ 0.2/kWh, Rwanda—US$ 0.23/kWh, Tanzania—US$ 0.07/kWh, and Uganda—US$ 0.2/kWh (The World Bank, 2017a).

Area coverage, a blanket electrification strategy based on connecting and supplying all potential customers, is also appropriate for social electrification and complements a social tariff. Restricting grid access to those customers who can make the greatest economic or socio-economic use of electricity, or who can afford connections, denies the benefit of a social tariff to the households most in need of the support (Gaunt, 2005).

Mini Grids

Mini grids are generation and distribution systems that can provide electricity to a few customers in a remote settlement, or hundreds of thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to isolate themselves from the grid. Mini grids interconnected to the main grid can e.g., purchase power in bulk from the main grid to distribute and retail to customers on the mini grid, generate power to supply their customers and sell excess power to the main grid via a power purchase agreement or net-metering arrangement.

Nearly all current centralized electricity grid systems started with isolated mini grids, which gradually interconnected. These first-generation mini grids were key to the early development and industrialization of most modern economies. A second generation of mini grids is widespread in many low-income countries today. These systems are typically small and isolated, powered by diesel or hydro, and built by local communities or entrepreneurs to provide access to electricity to households, primarily in rural areas that have not yet been reached by the main grid. Mini grid developers are now leveraging transformative technologies and economic trends to build third-generation mini grids with the potential to provide high-quality, affordable electricity at scale. A typical third-generation mini grid is an alternating current (AC) mini grid that consists of a solar-hybrid generation system that includes solar panels, batteries, charge controllers, inverters, and diesel backup generators and is designed to interconnect with the main grid. These mini grids typically use smart, remotely controlled electricity meters that allow customers to prepay for their electricity, and deploy remote monitoring systems to manage the status of the system in real time from a distance (ESMAP, 2019). Third generation mini grid developers are also stimulating electricity demand by implementing or facilitating activities that provide their customers with access to and financing for income generating appliances. Some directly invest in equipment, that uses the electricity they generate, to provide services such as refrigeration, water purification and milling for a fee (Absolute Energy, 2021).

Mini grid capital costs have been declining and are expected to continue a downward trend through 2030. The costs of key mini grid components, such as solar panels, inverters, batteries, and smart meters, have decreased by 62–85% because of innovations and economies of scale in utility-scale solar projects, the booming rooftop solar industry, and the growing electric vehicle market. This is expected to bring down the capital costs from US$ 3900/kW in 2018, to below US$ 3000/kW by 2030 (ESMAP, 2019). In the countries considered, the cost for establishing mini grids, as determined during the development of their national electrification plans, ranges from US$ 630–1712 per connection.

ESMAP modelling, indicates that a well-designed solar-battery-diesel hybrid mini grid serving more than 1500 people has a levelized cost of energy (LCOE) of about US$ 0.55/kWh when it serves household customers, giving it a load factor of about 22%. As the cost of efficient income-generating machines and equipment decreases and developers increase demand for income-generating uses of electricity during the daytime, mini grids can increase their load factor to more than 40%. An 80% load factor can be achieved by inclusion of a water pump with storage tank and an anchor load, such as a telecom tower. As a result of declining capital costs and increased load factor, the per kWh cost of mini grid electricity is expected to decrease to US$ 0.20/kWh by 2030.

While most mini grids installed are AC, solar mini grids can also be configured to be direct current (DC) mini grids (often referred to as micro-grids) that integrate DC electricity supply with DC distribution and DC electrical appliances. DC micro-grids possess significant energy efficiency and cost advantages over AC distribution systems because of the lack of a need for energy conversion (i.e., DC-AC inverters), and are well suited to rural communities with low power demands. Where future grid interconnection is unlikely to be technically or financially feasible, DC micro-grid designs can be far more optimal due to lower capital costs and greater reliability, particularly in settings where settlements are more compact and long-distance energy transmission or higher energy business uses are not a factor (Mini-Grids Partnership et al., 2020). In Tanzania, for example, Devergy has been implementing DC micro-grids that are based on interconnecting small modular generation units, which are added as, when, and where needed to meet growing electricity demand and new customers. This approach enables the developer to expand the coverage and capacity of the micro-grid organically and affordably e.g., by developing multiple clusters of micro-grids over time as opposed to having to develop a single large mini grid at once.

Off-grid Solar

Price reduction in solar PV modules and balance of system components, as well as technological advancements in LED lighting, Li-Ion battery technology and efficient appliances, enabled the development of a new generation of high-performance low cost off-grid solar solutions i.e., single light solar lanterns and multi-light solar systems (<10 Wp) and solar system kits (10–350Wp). A database of over 190 quality verified products of this type can be viewed at https://data.verasol.org/. This new range of solar lighting products provide a cost competitive alternative to kerosene for lighting, while pre-designed solar system kits (sold with lights and other appliances i.e., phone chargers, radios, TVs, fans and fridges) address challenges related to appropriate sizing of systems and installation (historically responsible for high solar PV system failure rates and associated with the component-based approach to selling solar PV systems (Muchunku et al., 2018)).

In Eastern Africa, off-grid solar companies also leveraged the development and uptake of mobile money transfer systems to facilitate consumer finance models by bringing down the cost and complexity of debt recovery and making it possible to centrally manage a large pool of dispersed consumers. Mobile money makes it easier for consumers to make repayments for their systems wherever they can access a phone signal and make smaller payments more frequently. Furthermore, these electronic payments are linked to remote monitoring and control systems, enabling providers to monitor recovery rates in real time and remotely disable systems of defaulting or delinquent customers (Muchunku et al., 2018).

The most common business models employed by off-grid solar companies are (1) a retail model—cash sales for off-grid solar products up to 3Wp, in the US$ 3–30 price range, and (2) a Pay-As-You-Go (PAYGo) model—a consumer financing model for products in 3–100Wp range, with a cash price value of US$ 30–1000. The PAYGo model is based on a 13–19% down payment and periodic repayments (often daily) over a 12–36-month period (Lighting Global et al., 2020).

To a limited extent, a fee-for-service model has also been deployed for off-grid solar systems. The fee-for-service model is similar to the grid or mini grid model since customers only pay for the electricity services provided and ownership of the system is never transferred. In solar system fee-for-service models, electricity services are provided through standalone systems as opposed to an electricity distribution network. The fee-for-service model is typically based on a one-off joining fee and a monthly service fee for electricity services provided. For large off-grid solar systems this approach is significantly more affordable for customers than models where they have to pay for ownership as well as future maintenance and replacement costs. In its most basic form, it can be also applied as a rental model for solar lanterns or rechargeable batteries, where customers pay a recharging or usage fee. In 1999, the South African government introduced the fee-for-service is model for off-grid electrification i.e., to provide 50Wp solar systems to households more than 2 km from the distribution grid and in areas outside 3-year grid electrification plans (Energy Department: Republic of South Africa, 2012). Private companies who have implemented this model in Eastern Africa include Nuru Energy in Rwanda and FRES in Uganda.

IEA's Africa Energy Outlook forecasts that as income levels increase across sub-Saharan Africa, households will increasingly own appliances such as phones, televisions, refrigerators, washing machines and air conditioners. In rural areas the largest increases in appliance ownerships are expected to be for televisions and refrigerators. In the Africa Case policy scenario, television ownership is expected to increase from 0.2 units per household in 2018, to 0.8 units per household in 2040, while refrigerator ownership increases from 0.1 units per household to 0.7 units per household. Increases in ownership of air conditioners and washing machines are expected to be modest; in the range of 0.1 units per household in 2040 (International Energy Agency, 2019). Significant improvements in the energy efficiency of DC household appliances and the bundling of these with solar home system sales now enables off-grid customers to use appliances previously reserved for grid-connected AC customers (Lighting Global et al., 2020). Today's off-grid solar systems can technically provide the energy services that most rural households are expected to require by 2040.

Most of the off-grid TVs currently sold are DC powered and are sold via PAYGo as part of a solar system. They are mostly in the 15–32 inch size range and the US$ 53–300 price range (Verasol, 2021). In terms of global sales, the East African market represents the largest regional market for off-grid TV sales with 2020 sales figures as follows: Kenya—259,691, Uganda—15,684, Tanzania—30,709, Ethiopia—602, and Rwanda—10,414 (Global Off-Grid Lighting Association et al., 2020, 2021). Refrigeration units specifically designed for off-grid applications still have an extremely low penetration rate. In Eastern Africa, GOGLA's 2020 reports indicate sales of 2722 refrigeration units in Kenya, 1100 in Uganda, and 38 in Tanzania. Most refrigeration units are sold through PAYGo and bundled with a dedicated power system. These units, which range from 30–240 L in capacity, retail at US$ 160–1050 excluding the power system (Verasol, 2021). The most common units are medium sized refrigerators i.e., 51–100 L units with one or more fresh food compartments but no freezer compartment.

Taking into consideration only sales of quality verified off-grid solar products (Verasol, 2021), 2020 annual unit sales were estimated as follows: Kenya—1.9 million, Ethiopia—600,000, Tanzania—290,000, Uganda—280,000 and Rwanda—150,000 (Global Off-Grid Lighting Association et al., 2020, 2021). This widespread adoption of off-grid solar systems is indicative of a change in taste that is challenging an informal constraint i.e., that grid-based electricity is the only form of electricity acceptable to consumers, and that solar PV systems should provide a level of service identical to that provided by a grid connection.

4.2.2 Industry Mindset

We postulate that the following notions shape the mindset of the electrification industry:

1. *In addition to meeting the economic and socio-economic objectives of electrification, governments and national electricity utilities also need to meet the social objectives of electrification.*

   Using the South African experience, Gaunt demonstrates that electrification has been implemented to meet three very different objectives: initially economic (the first electricity utilities were the municipalities in the main towns and private companies supplying business, mining and related industries and for 80 years (from 1900) economics drove electrification), later socio-economic (spurred by political pressures in the 1970's and 80's, the electricity utility extended subsidized supplies to farms and rural service centres to keep farmers in business and support the development of rural areas), and recently social (i.e., due to religious obligations to help the needy, philosophical principles of giving equal consideration to the interests of all, and political or pragmatic reasons to help the poor). Although different solutions are needed to reach different objectives, the change was not immediately evident in many cases, because all the existing processes, networks, tariffs, and regulations had developed around concepts of electrification driven by economic objectives (Gaunt, 2005).

The viability assessments of economic electrification projects are based on financial analysis e.g., financial models of net present value or internal rate of return. Revenues based on realistic estimates of the customers' demand and consumption recover all costs. Only viable projects are implemented. If necessary, customers must pay connection charges or additional monthly rental to contribute to investment costs that cannot be recovered through standard tariffs. The viability of electrification for socio-economic reasons is based on economic analysis that attempts to quantify how electrification supports development by contributing to improved health, education, and other services that eventually bring customers into the formal economy. However, economic and financial analysis are inappropriate for assessing the benefits of social electrification because the development impacts are long term, because it is difficult to of express the benefits in economic values, and because of the tendency to understate welfare and multiplier benefits.

Social responsibilities have the potential to obscure or confuse the utilities' more obvious goals of delivering electricity efficiently and profitably. They also make more complex the role of the electricity regulators, who need to interpret conflicting aspects of government policy with regard to economic and social development.

2. *Electricity tariffs should be geographically uniform to promote perceptions of fair pricing.*

   Private sector mini grids are still considered experimental due the cost reflective nature of their tariffs; they charge significantly higher electricity tariffs (4–20 times more than national grid tariffs), while political preference is for a national uniform tariff. However, private mini grid developers argue that consumers are able and willing to pay these high tariffs because they get a better service at a lower price than the alternatives that are available to them (i.e., kerosene, diesel, and phone charging services) (Pedersen & Nygaard, 2018).

3. *Solar home systems are meant to be owned by the user.*
   This results from solar home system business models being historically and predominantly based on selling products (i.e., transferring ownership) rather than selling electricity services.
4. *The solar home system is not socio-politically considered as a complete or final electrification solution for households, and the same applies to mini grids that do not provide a level of service equivalent to the national grid.*
   This can be illustrated by the Multi-Tier Framework (MTF) for measuring access to electricity (Bhatia and Angelou, 2016), which uses five successive tiers categorized on the basis of their electricity supply attributes e.g., the ability to use certain appliances (or access certain energy service). Other supply attributes that are considered are the power/energy capacity, number of hours per day electricity is available and aspects such as reliability, quality, affordability, legality and health and safety, which mostly apply to higher electricity access tiers. A complete and final electrification solution is considered as one that allows a household to seamlessly graduate from the lowest to highest electricity access tiers when ready. While solar home systems can technically provide tier 0–5 levels of electricity access, affordability constraints restrict them to mostly providing tier 0–2 levels of access i.e., providing general lighting, phone charging, television, and air circulation (fan) if needed.

4.2.3 Values, Identity and Mission

Rural electrification agencies see themselves as responsible for facilitating equitable and universal provision of electricity for social and economic development in rural areas. Following changes in energy legislation in recent years, their mandate in some countries (e.g., Kenya and Tanzania) has been extended to include provision of other modern energy services and promoting the use of renewable energy technologies. However, provision of electricity in rural areas is still their focus.

Following the corporatization or commercialization of national electricity utilities, delivering shareholder value (where private investors have a stake), or delivering services commercially (where government is the main shareholder) is a key part of their mission. These utilities strive to deliver electricity services sustainably, while ensuring the quality and reliability of supply.

Both off-grid solar companies and private mini grid developers view themselves as social enterprises driven by a social mission to delivery electricity access in a financially sustainable way through advanced technological components and systems, and business models. The incentives of these companies are designed such that more impact directly correlates to more profit.

There was a strongly held belief amongst off-gird solar companies that the lower cost of energy access via off-grid solar products, and economies of scale were sufficient to enable access for all. Their position therefore was that public and donor funding should solely be directed towards activities that developed a sustainable and competitive open market e.g., subsidizing industry wide needs such as the development of quality standards, mass consumer education campaigns, and activities that provide consumers with opportunities to see the benefits of off-grid solar (Global Off-Grid Lighting Association, 2015). However, more recently, the prevailing view of these companies is that end-user subsidies will be needed to reach the poorest households with clean energy access. Nevertheless, they emphasize that due to the potential risk of negative market distortion, which could instead slow-down energy access, end-user subsidies need to be carefully designed and implemented to ensure there is no competition between the subsidized and commercial market (Global Off-Grid Lighting Association & Get.invest, 2021).

Private mini grid developers also consider themselves as niche actors working to challenge the incumbent electrification regime to develop and grow the private mini grid niche. The electrification regime is currently based on grid extension and mini grids for large towns, which are operated by the national electricity utility. The work these niche actors are undertaking includes: (1) research to generate data from pilot projects to build a business case for mini grids to attract investment, (2) creating a normative and moral narrative about the private mini grid model (e.g., challenging the national uniform tariff norm by demonstrating that private mini grids provide better service at a lower price that the inferior alternatives available to those without access), and (3) improving the policy framework for private sector mini grids by establishing the parameters of future institutional structures and practices e.g., tariff models, grid codes, grid interconnection and cross-subsidy models for private mini grids (Pedersen & Nygaard, 2018).

4.2.4 Regulations, Laws, and Standards

Electricity Licensing Laws or Regulations

Licensing regulations specify the license and permit application processes, fees, requirements, obligations and conditions for license or permit revocation for the following: (1) generation licensees—entities authorized to operate a generating station and connect to a distribution or transmission network, (2) transmission licensees—entities authorized to operate a transmission network and connect its network to another transmission or distribution network, (3) distribution licensees—entities authorized to operate a distribution system, and (4) supply licensees—entities authorized to supply electricity to consumers through a series of commercial activities i.e., procuring the energy from other licensees, inspection of premises, metering, selling, billing and collecting revenue.

Rwanda's electricity law additionally provides for concession licenses—to be granted by the Minister in charge of electricity, and rural electrification licenses—a simplified license to expedite licensing for rural electrification projects for those operating in rural areas ("Law No.21/2011 Governing Electricity in Rwanda", 2011). Tanzania's legislation provides for licensing exemptions for generation, and off-grid distribution and supply activities in rural areas where the capacity is below 1 MW ("The Electricity Act of 2008, Tanzania", 2008).

Licenses contain particulars or conditions for e.g., provisions for bulk and retail tariffs or charges for electrical energy and capacity for different types of licensees and classes of consumers, provisions for the determination of charges for use of the transmission and distribution network services, the term of the licence, the maximum capacity of supply of the undertaking and the area of supply of the undertaking. Licensing regulations specify the factors considered in the granting of a license, which include: the economic and energy policies in place, the economic and financial benefits to the country or area of the undertaking, the proposed tariff offered, potential adverse effects to the contractual rights, and obligations of an existing licensee.

Electricity laws also require that all agreements relating to the sale of electrical energy and the provision of transmission and distribution network services between and among licensees, and between licensees and consumers, be approved by the electricity regulator before execution. The regulator also prescribes the principles for the tariff structure and the terms for the supply of electricity to consumers and is responsible for the review and approval of retail tariffs (which could be on a cyclical or need basis).

Licensing and tariff design principles have effectively legitimized and entrenched distribution utility monopolies and uniform national tariffs. Licensing regulations favour incumbent utilities since a distribution and supply license cannot be awarded for areas that have already been licensed out. Monopolies, however, make some regulations impossible to enforce e.g., revocation of licenses. In addition, since incumbent utilities have the widest network coverage nationally, the tariffs they charge become a national benchmark, which makes it politically inexpedient for regulators to approve higher tariffs for smaller distribution and supply licensees, even when they are justified.

Rural Electrification Fund

Rural electrification funds are typically established through primary legislation with the objective of accelerating the development of electricity infrastructure to provide electricity services to improve economic and social. development in rural areas. The legislation prescribes where the monies for the fund will be sourced e.g., electricity sales levy, and other monies appropriated by parliament, loans and grants from other governments and international finance institutions, and grants from non-governmental organizations. The fund is usually administered by the rural electrification agency.

Rwanda adopted a different approach to raising funds for electrification. The Ministers of Finance and Energy and senior development partners developed an energy sector-wide approach (SWAp) to help achieve its target of increasing electricity access. Under the SWAp approach, governments, donors, and other stakeholders join within a particular sector to coordinate sector specific policy, funding, and goals. Under government leadership, the approach involves movement over time toward common goals and coordination for funding and procurement. The SWAp is anchored in an investment prospectus for extending electricity access, which is used to raise co-finance from development partners to address the investment funding gap (Sanghvi and Gerritsen, 2012). In addition to this, the 2011 Law Governing Electricity in Rwanda provides for a Universal Access Fund to optimize access to electricity. It is based on contributions collected from dealers in electricity, as determined by Presidential Order ("Law No.21/2011 Governing Electricity in Rwanda", 2011).

Net Metering

Some electricity laws provide for net metering where a consumer who owns a renewable energy generator located in the area of supply of a distribution or supply licensee may enter into an agreement to operate a net metering system i.e., a system that measures the amount of electrical energy that is supplied by the distribution or supply licensee to the consumer who owns the renewable energy generator and vice versa ("The Energy Act No.1 of 2019, Kenya", 2019). In the countries considered for this study, Kenya and Tanzania have legislation that provides for this. Uganda, Rwanda, and Ethiopia do not currently have net metering legislation, but there are indications of government interest. Under its Decentralized Renewables Development Program (African Development Bank, 2017) Uganda has plans to pilot net metering systems on public buildings and draft legislation and standards to scale-up net metering. Rwanda has piloted net metering, while Ethiopia is considering it as regulatory environment improvement for mini grid development i.e., as a strategy for integration in mini grids are interconnected with the main grid (Ethiopian Ministry of Water, Irrigation and Energy, 2019).

Distribution Grid Code

The distribution code is defined as the requirements that users (i.e., persons or entities), connected to or making use of the electricity distribution system, must meet to ensure safe, secure, reliable and efficient of the system. Users include generation licensees, distribution licensees, and consumers—a person or entity obtaining end-use electricity supply from a licensee. Since the grid code applies to licensees, it is used in conjunction with the electricity licensing regulations.

The distribution code specifies: the technical and design criteria and procedures for the planning and development of the distribution system, the minimum standards for the methods of connection to the distribution system, operational components of the distribution system (e.g., demand management, interruptions, incident reporting), safety and system emergencies, the technical and operational criteria for providing metering services, and the technical and operational performance standards for supply quality, power quality and distribution energy losses, and the indicators used to measure these.

Unlike distribution systems supplying economic customers, the costs of under-design and under-capacity for electrification systems implemented for social objectives are low. This enables conservative load forecasting, which allows for leaner, more flexible design specifications and for the adoption of low-cost solutions e.g., (1) greater application of single-phase instead of the traditional three-phase distribution at medium and low voltage, (2) adoption of new technologies in line design and feeder conductor selection, (3) broad application of pre-payment metering, and (4) revised industry standards and implementation procedures (Bernard et al., 2008). Since low-cost electrification technologies and approaches are in line with the government's objectives of increasing electricity access, the distribution code, which is typically developed and enforced by the electricity regulator, has not been a significant barrier to adoption. In Tanzania, for example, electricity legislation allows the regulator to prescribe different technical quality of supply and reporting standards for licensee activities in rural areas, where such standards can reduce the cost and promote investment in rural electrification ("The Electricity Act of 2008, Tanzania", 2008).

Electricity Supply Reliability and Quality

Electricity supply reliability and quality are key attributes for defining and measuring energy access. Reliability is measured by the frequency and length of unscheduled outages/interruptions, while quality relates to voltage and frequency fluctuations. The distribution code specifies thresholds for the quality of supply that distribution utilities should comply with. With regard to reliability of supply, utilities are required to measure and report on their performance using a set of prescribed indicators. In Tanzania, distribution utilities are required to make public their targets for reliability of supply for the following year, disaggregated into targets for rural, urban and industrial consumers (Energy and Water Utilities Regulatory Authority, 2017). Requirements for reliability of supply are rarely specified in the distribution code or actively enforced. Kenya does prescribe performance standards for unscheduled interruptions and voltage level tolerance values. Its distribution code disaggregates consumers into urban and rural, with lower performance requirements prescribed for rural consumers (The Energy and Petroleum Regulatory Commission, 2017).

Two indicators commonly used to monitor grid reliability are, (1) System Average Interruption Frequency Index (SAIFI)—a measure of the average number of outages experienced by a customer on the grid, typically measured over a year, and provided for a city, region, or entire national grid in units of outages per year per customer, and (2) System Average Interruption Duration Index (SAIDI)—a measures of the average time of outages experienced by a customer on the grid, typically measured over a year, and provided in units of minutes or hours of outages per year per customer. The tolerances prescribed in Kenya for unscheduled interruptions for urban and rural customers respectively are SAIFI—3 and 6 outages per year, and SAIDI—2.5 and 7 h per year. Grid reliability data for Kenya collected as part of the World Bank's Doing Business (The World Bank, 2021a) and Enterprise surveys (2021b) gives SAIFI and SAIDI values of 6.9 outages and 12 h from the 2019 Doing Business surveys, and SAIFI and SAIDI values of 45.6 outages and 264.5 h from the 2018 Enterprise surveys.

By comparing reliability data across 109 low- and middle-income countries, Taneja demonstrated that utilities on average reported 15% of the outage durations that customers reported (Taneja, 2017). This conclusion was based on comparing data from the Doing Business surveys (which is reported by utilities) with information from the Enterprise surveys (which is reported by consumers). Before electricity reliability can be improved, it needs to be accurately measured. However, many utilities in low- and middle -income countries have limited instrumentation for measuring electricity reliability events. While there may be sensors for monitoring the condition of transmission lines, distribution lines often go unmonitored, and outages go unreported until unhappy customers contact the utility directly. While this can be addressed by smart meters capable of automatic notification of electricity outages, due to the technical capacity and excessive costs of meters, installation, and the analytic packages required, many utilities in the developing world have few, if any, plans to install such meters. In their absence measuring the reliability of electric grids is difficult (Taneja, 2017).

The foremost cause of electricity outages in Nairobi, Kenya is fuses. These faults occur when there is a local overload on a transformer, causing one phase to blow its fuse and lose power until the fuse is replaced. Proactive strategies to prevent such outages include replacing undersized transformers and rebalancing of phases i.e., moving customers from phases with heavier loads to phases with lighter loads. Though phases were likely initially balanced, unequal evolution in customer demand is likely to create imbalances over time. Faults with wider scope were found have a larger impact on the SAIFI and SAIDI indicators than those with the highest frequency. These are: (1) feeder faults—large scale outages resulting from maintenance activities (including scheduled outages) and other major events, and (2) phase across feeder faults—medium voltage conductor faults that can affect customers on the same phase of all transformers on the feeder. These can be addressed with better maintenance scheduling strategies and accelerating response to unexpected large faults. Beyond the customer service benefits of fewer and shorter outages, a key motivation for reducing outages is collecting revenue from additional electricity sales (Taneja, 2017).

A case study of a rural distribution grid in Unguja, Tanzania illustrates that when electricity is supplied by a capacity constrained grid to a resource constrained population, the quality of service can vary both spatially and temporally (Jacome et al., 2019). Using measurements from sensors at increasing distance from transformers revealed periods in which voltage measurements were well below the standard of 10% of the nominal voltage, which can lead to damaged appliances. Notably this was predominant for connections outside the 600 m recommended connection radius for the transformer. The study showed that voltage quality was more of a problem for respondents who owned high tier appliances (e.g., fridges, freezers, or blenders), than for those who only owned low-tier appliances (e.g., lights, television, or irons), which are common and less sensitive to voltage fluctuations.

The Multi-Tier Framework (MTF) for measuring access to household electricity supply sets thresholds for electricity reliability and quality. The thresholds for reliability are based on the SAIFI and SAIDI indicators and are more than 728 outages per year for tiers 0–3, 208–728 outages per year for tier 4, and less than 156 outages per year and a SAIDI of less than 312 h for tier 5. The quality requirement is that voltage is within the parameters specified by the distribution code and that voltage problems do not prevent the use of desired appliances.

The World Bank has implemented surveys on energy access using the MTF in Kenya, Rwanda and Ethiopia (The World Bank, 2020c). In Kenya 48.8% of grid-connected households experienced outages between 3–14 times a week (SAIFI of 156–728 outages), and 17.5% faced voltage issues that resulted in appliance damage (The World Bank, 2019). In Ethiopia 57.6% of grid-connected households experienced 4–14 outages a week (SAIFI of 208–728 outages), and 15.8% of households faced voltage issues that led to appliance damage (The World Bank, 2018a). In Rwanda 91.7% of grid-connected households experience more than 4 electricity disruptions a week (SAIFI of > 208 outages). Nationwide, 20.9% of grid-connected households face voltage issues such as low or fluctuating voltage (The World Bank, 2018b).

Mini Grid Regulations

Tanzania is considered a regional leader in mini grid development (Odarno et al., 2017). In 2008, Tanzania adopted a ground-breaking mini grid policy and regulatory framework to encourage investment in the sector, which has been reviewed and updated several times, most recently in 2020 (Energy and Water Utilities Regulatory Authority, 2020). A possible key success factor is the formal establishment, through the regulations, of a working group on small power development comprising of representatives of key public and private sector actors and stakeholders in the mini grid sector. The role of the working group includes advising the regulator on modifications or general improvement of the rules and guidelines related to small power development.

Tanzania's mini grid legislation defines a strategic area as an existing publicly owned distribution network operating at 33 kV or below with at least 10,000 customers. Small power projects, defined as electricity generating projects with a capacity of 100 kW–10 MW, can only be developed in strategic areas if: (1) they improve the voltage profile, (2) reduce the distribution network operator's system losses by at least 10%, or (3) they are being served using diesel or furnace oil engines. Small power projects can be developed through unsolicited proposals i.e., an application to a distribution network operator for a letter of intent—a statement of intent from a distribution network operator to connect and purchase power that a small power project developer offers to produce. A distribution network operator may also invite developers to submit bids to supply identified strategic areas. The regulations prescribe a 20-year standardized power purchase agreement based on technology specific tariffs pre-approved by the regulatory authority.

Very small power projects are defined as electricity generating projects with a capacity of < 15 kW at a single site selling power to at least 30 retail customers, or a with a capacity of 15–100 kW either selling power at wholesale to a public distribution network operator or retailing it to end customers. These types of projects shall only be developed in remote areas certified by the Ministry responsible for electricity.

Electricity generating, distribution or supply activities for projects with a capacity below 1 MW are exempt from licensing. However, developers of these projects are required to apply for and be issued with a certificate of registration from the regulatory authority before commencement of commercial operations. Mini grid operators are granted exclusive rights to distribute electricity in the area of service specified in the license or registration certificate issued by the regulator.

If a public distribution network operator or the rural electrification agency intends to connect a mini grid to the national grid, Tanzania's legislation makes provisions for the small power producer serving the mini grid, and the small power distributor retailing electricity to customers on the mini grid. The small power producer selling electricity to the mini grid may apply to the regulator for the right to sell electricity to the public distribution network operator, and the small power distributor may apply to purchase electricity from the national grid (i.e., through the public distribution network operator) under a bulk supply tariff, for resale to the customers on the mini grid. Alternatively, the small power producer and small power distributor may apply for asset compensation from the public distribution network operator or the rural electrification agency. The valuation of the distribution assets is dependent on their conformity to prescribed standards and the compatibility of the meters used with the public distribution network operator's billing and collection system.

Tanzania's legislation also prescribes specific tariff design principles for small power producers that retail the electricity they generate, and small power distributors, who purchase electricity in bulk for resale. The tariff design principles are based on full-cost recovery and a reasonable return on equity, and tariffs require approval by the regulator before the sale or offer of sale of electricity to customers. In addition, the community to be supplied should be informed about any tariff application due to be submitted to the regulator for approval. To calculate a reasonable return, the assets considered by the regulator exclude grants received from the rural electrification agency, government, or donors. Retail tariffs may include on-bill financing for e.g., connection charges, internal wiring, and end-use equipment for productive use.

Bilateral power purchase agreements for the sale of electricity to eligible customers are exempt from tariff approval. Eligible customers are entities authorized by the regulator to enter into contract for the purchase of electricity directly from an entity licensed to supply electricity.

Mini grid regulations in Kenya, which are under development, are more onerous, they propose a three-step process comprising of: (1) submission of an expression of interest (EOI) to the Ministry for exclusive site reservation and allocation, (2) an application for tariff approval from the regulator, and (3) an application to operate the generation and distribution infrastructure (Energy & Petroleum Regulatory Authority, 2021). These requirements are for all mini grids with a capacity of up to 1 MW i.e., there is no provision for exemptions or simpler requirements for low-capacity mini grids (e.g., <100 kW), as is the case in Tanzania.

To submit and EOI for site reservation private mini grid developers already have to had undertaken a feasibility study, engaged with the local community, received a letter of no objection from the local government and developed an indicative tariff. Subsequent to the EOI being approved, the developer then has to fulfil additional and more detailed requirements for tariff approval (e.g., full feasibility study, environmental authority approval, proof of land ownership or land lease agreement for the generating plant, way leave agreements for the distribution network and a community endorsement contract), and for licensing (e.g., local government planning approvals, evidence of a physical office or dedicated on-site staff, and publishing of a public notice of the license application to enable persons who may be affected to lodge an objection with the regulator). Kenya's proposed regulations also have provisions for the arrival of the national grid and its interconnection with the mini grid, which are intended to enable private developers to (1) continue generating income from the generation or distribution and supply or electricity, or (2) to sell off their assets to recover their investment.

In contrast, for the development of public mini grids for which the national uniform tariff shall apply, the implementing agency is only required to submit a notification to the regulator, which comprises of: (1) a feasibility study, (2) environmental authority approval, (3) an agreement between the implementing agency and the agency that will be responsible for operation and management of the mini grid where applicable (it is common practice for the rural electrification agency to develop mini grids and then transfer them to a distribution and supply licensee for operation and maintenance), and (4) evidence of dissemination of a public notice of the intention to develop the mini grid.

Uganda and Rwanda's mini grid regulations are similar to Kenya's, but they have simplified requirements i.e., requiring only application for registration for mini grids with a capacity below 500 kW and 50 kW in Uganda and Rwanda respectively (Electricity Regulatory Authority, 2020) (Rwanda Utilities Regulatory Authority, 2019). In Ethiopia, while developers or mini grids with a capacity of up to 50 kW also require a license, they are allowed to negotiate tariffs directly with the community and enter into a contractual agreement with customers, subject to endorsement from the local authority. They are exempted from a tariff application and review by the regulator (Ethiopia Energy Authority, 2020).

Rwanda and Kenya explicitly provide for DC mini grids, while Uganda and Ethiopia's power quality specifications only allows for AC mini grids. However, in all the countries considered, DC mini grid developers have no recourse when the main grid arrives.

There is information asymmetry between public actors (i.e., rural electrification agencies and national electricity utilities) and private mini grid developers with regard to which sites are not considered for grid extension or mini grids, in the short to medium term, in the national electrification plans. The result of this is that mini grid developers can, and do, spend a lot of resources in identification of potential sites and the preparatory work to develop these, only to be informed that the sites are already considered for electrification by the rural electrification agency or national electricity utility.

To a significant extent current mini grid regulations lean more toward being tokens to appease private mini grid developers rather than an acknowledgement of the value they can add and a deliberate attempt to fully integrate them into national electrification planning and implementation. The regulations require a significant level of effort required from private mini grid developers to identify and develop a site. In contrast, due to government support, rural electrification agencies and national electricity utilities do not have to put in anywhere near the same level of effort to identify and develop mini grid sites. Considering the remoteness, low population density and low economic activity in most of the available sites, this effort is not concomitant with the potential return on investment for mini grid developers.

Pedersen et al. point out that in Kenya, some private mini grid developers are deliberately avoiding the time-consuming and bureaucratic process of obtaining licences and negotiating tariffs with the regulator. Instead, they have established a verbal agreement that they can run their projects as pilots to avoid the bureaucratic process. They focus on, (1) improving operations and services to put themselves in a position to a first choice for potential investors, and (2) developing collaborative relationships with the national utility to position themselves to provide contractor services and supply technology. Other developers are adopting a more head on approach, initiating bilateral and multilateral meetings with the regulator, the national electricity utility and the rural electrification authority to agree on how the proposed policy and regulations can be implemented effectively in practice (Pedersen & Nygaard, 2018).

Off-grid Solar Quality Standards

In a review of solar home system projects supported by the World Bank and the Global Environmental Facility from 1993–2000, Martinot et al. state that the market for solar home systems has historically been plagued by challenges of poor quality products, poor installation and maintenance, and systems being oversold (i.e., through marketing claims that raise false expectations about what the systems can deliver) (Martinot et al., 2001). Funded projects can prescribe and enforce the standards within the scope of their project. However, after project completion, this task should transition to government by supporting the development and implementation of broader national compliance frameworks to enforce the standards.

The Lighting Africa program, developed by the International Finance Corporation and the World Bank and launched in 2009, adopted this approach (World Bank & IFC, 2021). Lighting Africa is a regional market development program with the objective of catalysing markets to deliver affordable, high-quality off-grid lighting and energy products. To protect consumers from poor-quality products and promote consumer confidence, Lighting Africa developed a series of quality standards and test methods for pico-PV lanterns and subsequently for solar home system kits with a peak solar PV capacity up to 350Wp. To meet the standards, products were tested against a baseline level of quality, durability, and truth-in-advertising. The market development program then exclusively worked with products that met the prescribed minimum standards, which resulted in a virtuous cycle of positive consumer experiences leading to increasing consumer confidence and increased adoption. These positive consumer experiences have also contributed to increasing government confidence in off-grid solar products and subsequently resulted in them ratifying the use of public funding to support the use of off-grid solar as an electrification approach.

As part of the transition to adoption and enforcement of these standards by governments, these program standards were adopted the International Electrotechnical Commission (IEC), which paved the way for their adoption by governments as national standards (Verasol, 2020). These standards have recently been adopted by Kenya, Tanzania, Uganda, Rwanda, and Ethiopia as mandatory national standards, which will be enforced by restricting the importation of off-grid solar products to only those that can demonstrate that they meet the adopted standards.

4.3 What Influences Firms in the Electrification Industry—External Environments

4.3.1 Socio-Political Environment

National Electrification Plans and Strategies

Largely driven by commitments to deliver on the sustainable development goals, most of the governments in the countries considered for this study have recently developed or updated their national electrification plans and strategies with a view to achieving universal electricity access by 2030. These strategies incorporate both on-grid and off-grid approaches, with private sector envisioned as having a key role in delivering electricity access through off-grid approaches.

Electrification planning typically uses geospatial data on e.g., electricity transmission and distribution infrastructure, population settlements (e.g., administrative cities, towns and villages, clustered housing structures, and trading centres), and social and administrative infrastructure (e.g., educational institutions, public water supply, health facilities and police stations), to determine which on-grid or off-grid electrification approach is most technically and economically suitable to deliver access. Using this geospatial information, integrated electrification planning defines the grid expansion boundary which demarcates where off-grid projects are developed, prescribing mini grids for settlements with sufficiently high housing density and off-grid solar for those without.

The foundation of an electrification plan is based on, (1) the existing medium voltage distribution network coverage, and how it is projected to grow over the planning period, and (2) the unit of electrification—the minimum size of the population settlement considered for grid extension or mini grid projects.

Countries with low medium voltage network coverage usually have unelectrified population settlements that are large in both size and number. These countries have a greater need for grid extension or mini grids to deliver electricity access to these large population settlements. In addition, where it will take time to increase the medium voltage network coverage, off-grid approaches are expected to have a long-term role i.e., the duration before mini grids are interconnected with the national grid and before households with off-grid solar systems get access to a grid connection. In Tanzania, development centres are considered as the unit for electrification, these are defined as settlements with at least 1500 inhabitants with existing social or administrative infrastructure (e.g., a school, dispensary, police station etc.), good access by road and some business activities. Tanzania's electrification plan leans heavily towards grid extension (i.e., 57% of the 3.8 million connection target) (Innovation Energie Développement, 2014), and is supplemented by a program to support the development of private mini grids (SIDA & DFID, 2016).

On the other end of the spectrum are countries with high medium voltage network coverage and unelectrified population settlements that are generally fewer and much smaller in size. These countries have less need for grid extension and mini grids and instead focus on grid densification—to connect unserved customers within reach of existing distribution transformers, and grid intensification—to connect housing clusters within 2.5 km of the existing medium voltage network. Off-grid solar is then considered for those who fall outside the reach of grid intensification. In Kenya grid intensification is considered for housing clusters, within 2 km of the medium voltage network, which can justify short medium voltage line extensions with distribution transformers. The justification is based on whether the grid intensification costs significantly exceed the average cost of grid extension projects. Where this is the case consideration is then given to off-grid solar systems. Kenya's electrification plan therefore leans heavily toward grid densification and intensification (i.e., 56% of the 5.65 million connection target), and to off-grid solar (i.e., 40% of the connection target) (NRECA International, The World Bank, & ESMAP, 2018).

On-grid electrification plans are implemented through a phased approach with different criteria being used for prioritization. Since it takes time to increase the medium voltage network coverage, and because governments often have a long-term vision of eventually electrifying the whole country with the grid, this sometimes influences whether off-grid approaches are considered interim (i.e., as pre-electrification) or final.

In Tanzania, settlements are connected as the medium voltage backbone is expanded, with development centres in proximity of expanded backbone (up to 40 km) being prioritized. In Ethiopia, the grid program will be expanded from the centre to the periphery, while off-grid technologies are distributed in parallel from the periphery (beyond 25 km). The strategy acknowledges that many consumers targeted for the grid program will have to wait a long time for a connection, it tries to address this through the provision of off-grid solutions as an interim solution. Grid connections are prioritized for areas within 2.5 km of the grid, off-grid solutions provided as a pre-electrification solution for areas 2.5–25 km of the grid, and as a long-term solution for areas beyond 25 km. After the arrival of the gird, it is expected that off-grid solutions will support the quality and reliability of electricity by providing backup services. In Kenya, the sequencing of grid and mini grid projects over the implementation duration is based on prioritizing 'low hanging fruits' i.e., areas with the lowest average cost per connection and the highest potential for new connections. Rwanda's rural electrification strategy aims to prioritize high consumption areas when rolling out the electricity grid network e.g., productive use centres, agro processing industries and mining areas, that will drive economic growth and households capable of paying for the connection costs (Rwanda Ministry of Infrastructure, 2016).

The table above (Table 1) provides an overview of the electrification approaches and targets of the five countries considered for the study as extracted from the national electrification plans of these countries. The investments costs are based on unit cost estimates for the different electrification approaches. The per connection costs across the five countries for the different approaches are as

Table 1 Overview of the electrification approaches and targets of the five countries considered for the study. Source: Authors' elaboration

Country	Date of Electrification Plan	Access level (Date)	Electrification Target (Date)	Number of TargetConnections	Electrification Approach (Target connections)	Total Investment Costs
Tanzania	Jul 2014	18% (2013)	75% (2035)	3.8 million	On-grid– 99% (*Grid densification – 42%, Grid extension – 57%*)Off-grid – 1%	$3.5 billion
Rwanda	Jun 2019	40.5% (2017)	100% (2024)	3.2 million	On-grid – 53%Off-grid – 47% (*Off-grid solar – 38%, Mini grids – 9%*)	
Uganda	Aug 2018	20.4% (2018)	60% (2027)	6.3 million	On-grid – 67% (*Grid densification – 48%*)Off-grid – 33% (*Mini grids – 2%, Off-grid solar – 31%*)	$0.56 billion **Grid densification only*
Kenya	Nov 2018	50% (2016)	100% (2022)	5.65 million	On-grid – 60% (*Grid expansion – 5%, Grid densification – 45%, Grid intensification – 11%*)Off-grid – 40% (*Mini grids – 1%, Off-grid solar – 39%*)	$2.75 billion
Ethiopia	Mar 2019	34% (2018)	100% (2025)	14.2 million	On-grid – 35% (*Grid densification – 32%, Grid intensification – 3%*)Off-grid (final) – 7% (*Mini grids – 2%, Off-grid solar – 5%*)Off-grid (interim) – 58% (*Combination of mini grids and off-grid solar*)	$4.1 billion

follows: grid densification US$ 160–747, grid intensification US$ 600–1057; grid extension US$ 732–1273; off-grid solar US$ 192–210; and mini grids US$ 630–1712. NB: The off-grid solar cost per connection does not reflect the cost of the system, but rather the government's contribution; it is expected that these systems will be delivered by the private sector with customers contributing to the cost.

Electrification planning has identified electricity connection fees as a key barrier to the achievement of electrification targets. Connection subsidies and providing end users with payment plans for grid connection fees are common strategies for addressing this. Uganda has chosen to provide a subsidy of US$ 160 for all new household connections within the secondary distribution network; to be connected new customers are only required to pay a US$ 14 inspection fee after wiring their premises (Uganda Ministry of Energy & Mineral Development, 2018). Tanzania and Kenya combine a connection subsidy with a payment plan. In Tanzania, the fees (US$ 111–201) must be paid in three subsequent monthly instalments before the customer is connected. In Kenya, the connection fee (US$ 150) is paid over a 12-month period as part of the electricity bill. This approach enables a blanket electrification strategy to be deployed. In Ethiopia, the connection fee is based on electricity consumption and ranges from US$ 0–370$. Households in the first income quintile are exempted, while those in the second quintile pay US$ 50. The fee increases progressively for subsequent income quintiles (Ethiopian Ministry of Water, Irrigation and Energy, 2019).

Financing Plans for Electrification

The implementation of national electrification plans is a resource intensive undertaking and most of the plans considered for this study highlight, investment funding gaps, dependence on development partners, and the importance of private sector contribution and customer contributions from connection fees.

In Tanzania, the electrification plan is to be financed through levies (on electricity, pre-destination inspection and fuel) that contribute the rural energy fund (REF). Donors i.e., the governments of Sweden and Norway, also contribute to the REF. Private sector contribution is expected for off-grid projects; about 30% of the investment and preparatory costs. An annual funding gap of U$ 123 million is estimated, and to partially address this the electrification program prospectus proposes that the electricity connection subsidy also be recovered from customers through a monthly surcharge of US$ 5, which would represent a significant percentage of electrification costs for low consuming customers) (Innovation Energie Développement, 2014). In Uganda, the electrification plans are to be mainly funded through: (1) budgetary allocation from the Consolidated Fund (i.e., a fund consisting of all revenues generated by the central government, local governments, or other public agencies) and the transmission levy, (2) US$ 80 million committed for last mile connections from the World Bank, the UK Department for International Development (via the Energizing Development Program), the German Development Bank (KfW), the European Union (via the African Development Bank) and the French Development Agency, and (3) government commitment of 50% of its annual rural electrification budget to finance connections (Uganda Ministry of Energy & Mineral Development, 2018).

The Government of Kenya has made progress towards reaching universal electricity coverage through the Last Mile Connectivity Program which has been supported by donor-financed agreements. The levels of investment for grid expansion, densification, intensification, and mini grids over the first two years of the electrification plan, are roughly equivalent to the funding that has been pledged for the Last Mile program. Funding for Last Mile activities beyond year three has not yet been secured. The African Development Bank, the World Bank, the European Investment Bank, and the French Development Agency have jointly pledged approximately US$ 770 million, while years 1 through 3 requirements for densification and intensification are equivalent to approximately US$ 1082 million. Kenya's electrification strategy also recommends the establishment of a National Electrification Trust Fund that could be used to (1) manage all treasury allocations or (2) only manage the pool of repayments from customers connected through the last mile program. It is estimated that the latter could grow to US$ 280 million over the next 5 years (NRECA International, The World Bank, and ESMAP, 2018).

Ethiopia involved development partners in the design of its electrification program to facilitate buy-in and support. The grid component is to be funded through government contributions (15%), customer contributions (35%), and concessional finance and grants from development partners (50%). Customer contributions will be from connection fees charged; an average of US$ 150 per connection. For the off-grid component, the government's contribution is 40%, with the balance expected to be covered by contributions from development partners and private sector resources. Most of the funding from development partners is yet to be secured, aside from a US$ 375 million loan from the World Bank for the Ethiopia Electrification Program approved in 2018 (Ethiopian Ministry of Water, Irrigation and Energy, 2019).

Influence of Development Agencies

Bhamidipati et al. demonstrates that transnational agencies (e.g., development agencies) tend to play a leading role in mobilizing resources, exert varying degrees of influence through financing projects and providing expertise, and enjoy a superior position in global networks. This allows them higher bargaining power, with the opportunity to advocate and support their preferred solutions. They gain legitimacy due to their embeddedness and siting within the wider global network instead of specific actor characteristics as such (Bhamidipati et al., 2019).

A review of the history of World Bank policies toward aid to the electric utility sector over the last three decades of the twentieth century, shows a shift in policy from supporting large infrastructure projects of vertically integrated, government-owned utilities, to support for liberalization, privatization, and restructuring of the electric utility industry in potential recipient countries, with aid often hinging on reforms of this nature (Hausman et al., 2014). This demonstrates the bargaining power that transnational agency such as the World Bank have, and how they use it to influence electricity policy (including electrification approaches).

Recent World Bank electrification project designs suggest a shift towards results-based financing mechanisms (e.g., output-based aid). The Global Partnership on Output-Based Aid (GPOBA) is a global partnership program administered by the World Bank. It was established in 2003 to develop output-based aid (OBA) approaches across a variety of sectors—among them water, energy, health, and education. As of September 2015, through a portfolio of 44 projects with US$ 228 million in commitments for subsidy funding and ongoing technical assistance activities, GPOBA is demonstrating that OBA can deliver a diverse range of services and lasting results for the poor (Khalayim, 2016). OBA has been used as a model to finance on-grid electrification activities in Ethiopia, Uganda, and Kenya. Ongoing World Bank electrification projects in Kenya, Rwanda and Burundi are now incorporating the use of results-based financing mechanisms to deliver electrification through solar home systems (Kenya (The World Bank, 2017b), Rwanda (The World Bank, 2020b) and Burundi (The World Bank, 2020a)).

The Role of Civil Society

Broadly speaking some civil society organizations have been contributing to electricity access by implementing or supporting projects that pilot or demonstrate new or different approaches to delivering electricity access. These organizations use funds that they source from development partners and donors. Their approach ranges from developing and implementing projects or programs that provide demand side or supply side subsidies (e.g., results-based financing programs targeting underserved areas and low-income households (EnDev, 2021)) to programs supporting innovative technologies and business/delivery models that demonstrate alternative electrification approaches and drive systemic change. Some of the alternative approaches nurtured by civil society have been subsequently adopted by governments. EnDev, for instance, has served as an incubator and source of innovation in the development of new types of results-based financing instruments in the energy access sector, some of which have subsequently been adopted for wider implementation by the governments of Kenya, Rwanda and Burundi for off-grid solar electrification, using funding from the World Bank (i.e., the projects mentioned in the section above).

Public-Private Partnership Models for Electrification

If structured properly and offering appropriate incentives, Public-Private Partnerships (PPPs) can enlist private resources to supplement public resources, thereby increasing the pool of capital available to meet the electrification challenge. Some PPP strategies considered in the electrification plans reviewed include: (1) demand side subsidies -proposed in Rwanda, Kenya and Ethiopia to address off-grid solar affordability challenges for low-income households by directly reducing the retail cost, (2) supply side support—proposed in Kenya and Ethiopia in recognition of higher working capital costs and extra capital and operational expenditure costs associated with marketing off-grid solar in areas beyond the grid. This support is to avoid these costs being borne by the end-customer, either in terms of a higher system price or the absence of the service altogether, (3) market support services—proposed in Ethiopia in the form of collection of customer and market information, and customer aggregation for businesses, and (4) reducing costs, de-risking investment and providing credit lines for prospective mini grid developers in Tanzania and Ethiopia.

Governments also acknowledge that the ability of private sector to provide off-grid solar products or mini grid services affordably depends in part on exemptions from tax and import duties. Until 2014, most governments in East Africa offered tax and duty exemptions for equipment for the generation of solar and wind energy, including accessories, spare parts and batteries that use or store solar energy (which allowed appliances solar with solar PV systems to also benefit from tax and duty exemptions). However, the scope of these exemptions was subsequently limited to equipment used for generation and storage of energy, thereby excluding appliances, spare parts, and other accessories (Coffey International Development Ltd, 2019).

Electricity Concessions

Electricity concessions represent one approach to increase the flow of private sector resources and expertise to electrification. Under concession arrangements, the state delegates to the private sector the right to provide a service yet retains some control over the sector by incorporating in a concession contract or license the terms and conditions that will govern the infrastructure project or company. Concessions may be better understood when located along the continuum of PPP arrangements in the provision of infrastructure services. Options along that continuum vary based on the allocation of risks and responsibilities—from pure public to pure private ownership and operation (Guislain and Kerf, 1995).

Leasing represents a type of concession in which the public sector retains ownership of the assets as well as responsibility for making new investments and expanding the asset base. The private partner assumes responsibility for operating and maintaining the assets, providing the public service, and collecting payments for it. In exchange for the right to collect payments, the concessionaire makes regular lease payments to the asset owner. Strict concessions, as opposed to leases, require the private lessor to operate, maintain, and expand the asset in accordance with negotiated and specified terms. The lessor must return the asset, with all improvements, to the owner at the end of the concession period.

The rural electrification concessions that have been attempted in sub-Saharan Africa are:

1. Mini grid concessions—Mostly for isolated mini grids generating and distributing power. However, some serve as local distributors of power acquired from the national grid e.g., concession of small grid extensions—distribution-only networks that sell power generated by a national utility to local areas previously unconnected to the grid. Some mini grid concessions have been established through competitive selection (e.g., the WENRECo mini grid in the West Nile region of Uganda), while others have been selected and negotiated on a case-by-case basis. In Uganda, in the concessions for distribution only networks, the rural electrification agency finances, designs and constructs grid extensions and then leases the lines to private entities. The agency also covers major maintenance costs e.g., repair and replacement of transformers. However, electricity tariffs are designed to be cost reflective; the lease allows concessionaires to apply for tariff reviews. Uganda has 5 concessionaires operating under this model, who as of 2015, were together serving 40,000 customers (Castalia, 2015).
2. Solar Home System concessions—Contracting of private firms to install and maintain solar home systems in defined geographic areas (typically sparsely populated areas far from the grid). Solar companies compete to have an exclusive right to supply solar home systems or electricity from solar home systems to the area. The expectation is that in return for these exclusive rights, the concessionaire will invest in establishing supply and maintenance networks in the

target region. This was implemented in South Africa where the concessionaire was expected to assume the risks of capital investment, operations, collection, system losses, inflation, and fluctuating rates of interest and foreign exchange. The only shared risk was that of fluctuating demand, which was split between the participating municipalities and consumers. The latter were charged a minimum monthly service charge and the former were meant to provide a monthly operating subsidy to reduce the demand risks assumed by the concessionaire. Cost-recovery remained a significant operational challenge to the continued operation and expansion of these companies (Hosier et al., 2017).

3. Rural zonal concessions—enable governments to concede the rights to electrify a large area or zone. The terms of the contract may be technology-neutral, leaving the concessionaire free to deploy whatever technology they consider most advantageous to service the area. The area of a rural zonal concessions should be large enough to permit economies of scale. Concessionaires charge cost-recovery tariffs subject to regulatory oversight, but the rural electrification agency may help keep costs low by providing initial capital subsidies as part of its contribution to the partnership. In Senegal, which hosts the one case of a rural zonal concession in Sub-Saharan Africa, the risk associated with the prices of purchased power and fuel is shared between the concessionaire, the government (which provides subsidies to the utility that are passed through to concessionaires in pricing), and consumers (fuel-price pass-throughs). Owing to the complexity of risk-sharing formulations; the rules and standards governing multiple electrification technologies in the same contract; and the need for negotiation of capital cost subsidies, rural zonal concessions require strong institutional capacity both to establish and to regulate (Hosier et al., 2017).

The characteristics of the rural electricity market in developing countries limit the scope of concession arrangements and the potential of private sector participation. Because rural electrification has usually been inconsistent with the investment requirements of private investors, many concessionaires demand public grants or cost-sharing to meet the financing gap associated with rural electrification projects (Hosier et al., 2017).

Sufficient Electricity Access and Energy Mobility

Monyei et al. argues that electrification policies in the global south are ambiguous and inconsistent with regard to (1) what constitutes sufficient electricity access and (2) how electrification projects can guarantee energy mobility for connected households (Chukwuka G. Monyei et al., 2019). Energy mobility is defined as the ability of households to increase their energy demand (which may result from an increase in the number of electrical appliances they own or extending the usage of already owned electrical appliances) (C. G. Monyei et al., 2018).

Monyei et al. uses the South African example to illustrate the disparity and injustice in the distribution of resources between poor households that are grid connected and those that are off grid. Under the 2014 Free Basic Electricity (FBE) policy, poor households that are grid connected are guaranteed electricity supply of up to 50 kWh/month and peak electricity demand of up to 20A. In contrast, the 2018 Non-Grid Electrification Policy Guidelines identify solar home systems as a suitable temporary alternative to grid electricity and specify a 95Wp capacity solar home system with the capacity to supply 475 Wh/day (14.25 kWh/month). The system limits the appliances the household can use and the number of hours they can be used i.e., allows for the use of a DC colour television for four hours; four hours of lighting using high efficiency lights; the use of a portable radio for ten hours; and charging of mobile phones (NB: This is an upgrade from the 2012 policy guidelines which specified a 50Wp solar home system) (Energy Department: Republic of South Africa, 2018). Monyei et al. argues that advocating for implementation of solar home systems in poor off-grid households boosts rural peripheralization and caps electrical appliance ownership by households. Since most of these households cannot afford the systems (which are subsidized by government and implemented via a fee-for-service model), it follows that they will not be able to afford a system upgrade on their own.

The electrification plans of Kenya, Ethiopia, and Rwanda, prescribe off-grid solar systems capable of at least delivering Tier 1 level of electricity service to a household i.e., an entry level solar home system kits with a capacity of 11–21Wp. Ethiopia tries to address energy mobility through its pre-electrification strategy and the expectation that they will electrify the whole country with grid equivalent service in the long term. Off-grid solar and mini grids will be used to offer mid-term pre-electrification to 5 million households between 2.5–25 km from the existing grid. These households are expected to be connected to the grid between 2025 and 2030. An additional 3.3 million households are expected to get a grid connection by 2025, but since the rollout will take up to seven years, short-term pre-electrification through off-grid approaches will be used to provide them with access. Finally, about 1 million households located > 25 km from the existing grid, and not expected to be connected at least-cost by the grid by 2030, are considered for long term pre-electrification (Ethiopian Ministry of Water, Irrigation and Energy, 2019).

Electrification planning therefore tries to guarantee households access to a minimum quantity of electricity (i.e., a Tier 1 level of service), and tries to address energy mobility through the expectation that all households will eventually be connected to the grid. However, while commendable, the ambition to connect all households to the national grid it is unlikely to be realized in practice. As a starting point, electrification planning should therefore consider how households who are initially connected through an entry level solar home system (delivering Tier 1 level of service), can at least graduate to an off-grid solar system delivering Tier 2 level of service—more specifically along the trajectory of entry-level systems (11–21Wp) to basic systems (21–50Wp) to medium systems (50–100Wp) to high-capacity systems (>100Wp) as defined by the Lighting Global program (Lighting Global et al., 2020).

4.3.2 Economic Environment—What selection pressures, exerted by markets, are faced by different firms?

Rural Electrification Agency

The International Energy Agency estimates that to reach full access by 2030 and maintain it to 2040 in Africa, would require multiplying current investment levels by five. The cumulative investment would reach more than $2 trillion between 2019 and 2040 (or over $100 billion per year). Half of the investment needs would be spent on grid expansion, reinforcement, and maintenance. Most of the rest would be for low carbon power capacity, where solar PV takes an important role, reaching almost $25 billion per year on average (International Energy Agency, 2019). With electrification agencies heavily dependent on international funds from development agencies and banks, these agencies are effectively competing against each other for the same limited pool of funds for electrification. In addition, with pressure to achieve universal electrification by 2030, electrification agencies must stretch the funds they have at their disposal to deliver increasingly more connections per dollar spent.

National Electricity Utility

While most of the capital costs for electrification are not borne by national electricity utilities, experience has shown that electrification programs (especially large-scale blanket electrification programs) have resulted in increased operation and maintenance costs for utilities without a concomitant increase in revenue from newly connected customers.

The unviability of South Africa's electrification program was found to be a direct consequence of the household energy consumption being substantially lower than expected during the planning stages. Average energy consumption during the first 5 years after connection was reported as 83, 95, 106, 121 and 138 kWh/month, while a consumption per household of 400 kWh/month is needed to break even. Thus demonstrating that the electrification programme was uneconomic and unsustainable without cross-subsidisation (National Electricity Regulator, 1998). Rwanda's Ministry of Infrastructure arrived at a similar conclusion, their Energy Sector Strategic Plan estimated that a consumer would need to use approximately 130 kWh per month to fund the cost of their own connection. However, results from their Electricity Access Roll-out Programme (which increased electricity access for households from 364,000 in 2012 to 590,000 in 2016) showed that almost half of the consumers connected were using less than 20 kWh per month (Rwanda Ministry of Infrastructure, 2016). Kenya's aggressive electrification program led to an increase in domestic consumers from 1.5 million in 2010, to 4.5 million in 2015. However, newly electrified consumers are lower consuming, and they brought down the average electricity consumption of domestic consumers in 2016 to 30% of 2009 levels. A deeper look into how consumption develops for newer customers showed that their consumption peaked at a lower level; between 20–25 kWh per month for rural consumers and 25–40 kWh per month for urban and peri-urban consumers (Taneja, 2018).

With most of the electricity revenue for national electricity utilities coming from a small number of large industrial and commercial consumers, electrification activities that focus on domestic consumers in rural areas are of no financial benefit to these utilities. With rural domestic consumers frequently falling within the subsidized segment of the tariff structure (the lifeline tariff), utilities struggle to cover the costs of supplying electricity in rural areas. While this could be addressed by reviewing the tariffs, the tension resulting from these utilities being government owned and/or government regulated, and the government being keen for electricity to remain affordable for all, prevents this from happening.

It is reasonable to suspect that the increased operation and maintenance burden resulting from grid extension projects, will subsequently result in a reduction in the responsiveness of the utility to electricity outages, and that this will be More so the further away that customers are from urban and peri-urban areas (i.e., as one approaches the external boundaries of the national grid). However, without accurate, disaggregated, and representative grid reliability measurements, this theory is difficult to prove.

Where national electricity utilities are already in a weak financial position (e.g., TANESCO in Tanzania), the approach of handing over grid extension projects financed and implemented by the electrification agency to the national electricity to operate and maintain is being reconsidered. In Tanzania, a consequence of the significant increase in grid extension projects will be an increase in operation and maintenance activities for TANSECO e.g., maintenance of the lines and substations, connection of customers (only a first wave of customers is connected under the grid extension projects), extensions of the distribution network, installation of the logistics for pre-paid meters, and control of pre-paid meters. The implication is that TANESCO will need more personnel to cope with the high increase in the workload, as well as organizational or even institutional changes. The alternatives considered in Tanzania's National Electrification Program Prospectus include: (1) the creation of a rural electrification business entity in TANESCO with separate accounts, (2) the creation of private distribution companies which buy in bulk from TANESCO and assume all functions of a distribution company, (3) the outsourcing of the distribution activities to private companies under a management contract, and (4) the creation of a separate rural utility (Innovation Energie Développement, 2014).

Small Private Electricity Generation and Distribution Companies

Mini grids are expected to have a key role in delivering electricity access in rural areas sub-Saharan Africa. IEA estimates that mini grids are the least cost option for 160 million people (about 28% of the full access target for rural areas) (International Energy Agency, 2019). However, jury is still out on whether purely private mini grids, which generate their own electricity and whose revenue is solely or primarily from retail electricity sales, will play a significant role. The indication currently is that purely private mini grids are still in the experimental phase, and that commercial investors will not invest until the business models for private mini grids are documented, and credible and robust evidence provided for investors to base decisions on. To address this, some mini grid developers are working to collect data from their installed mini grids to generate key success indicators for mini grids, which can be used to advise new investors in the field (Pedersen & Nygaard, 2018).

The main challenges faced by private mini grids include: (1) lower average revenue per user than the threshold required to make private mini grids viable, which is due to small, inconsistent or dormant users (inconsistent electricity use is linked to the seasonality of income), and (2) the difficulty in identifying and consolidating large numbers of commercially viable sites to sustainably cover their overhead costs (Muchunku et al., 2018).

Since most private mini grids do not currently generate enough revenue for private companies to depend on them exclusively, some mini grid developers double up as contractors, technology suppliers and/or service providers for other mini grid developers (including governments and donors) (Pedersen & Nygaard, 2018). Where private mini grids are interconnected with the national grid and can sell power to the grid (e.g., in Tanzania), these companies combine retail electricity sales with independent power production and sale to the national utility under a long-term power purchase agreement.

Uganda has experience with public private partnerships through mini grid and grid extension concessions. Mini grid concessions were designed to encourage entrepreneurs to electrify regions on the principle of commercial viability, through delineating concession areas and providing a 20-year concession to generate, distribute and sell electricity within the concession area. However, this approach did not work as envisioned. The reasons for this included: (1) tariff caps, which meant the concessionaire was unable to cover operational costs, and (2) lack of capital or delays in accessing capital, which translated into significant delays in developing new generating capacity and expanding the distribution network to increase the customer base. The lessons learnt from piloting this approach were that (1) there was a significant commercial risk in rural electrification, and (2) there was a lack of commercial interest in financing electrification projects.

In response to these experiences, the concession model was restructured so that the government would finance and construct grid extension projects (through the rural electrification agency) and the lease these lines to private entities. The rationale was that simple operating agreements allocated less risk to the private sector. By creating concessions that are less focused on capital improvement, grid extension concessionaires would be able to focus more resources on customer relation and service quality. Uganda's experience with these grid extension concessions has shown some promise, with concessionaries able to consolidate large numbers of customers, and most of them being cash flow positive (or demonstrating the potential to be) (Castalia, 2015).

The profitability of grid extension concessionaires is ultimately dependent on revenue from electricity sales i.e., the number of customers, the quantity of electricity they consume, and the margin between the tariff that concessionaries charge and the bulk supply tariff they pay. The rural electrification agency is responsible for the design, extension, and upgrade of the distribution systems (i.e., to connect new customers), and major maintenance (e.g., the repair and replacement of transformers). Since the electrification agency's objectives are non-commercial, this translates into how they design and plan the distribution grids; they tend to focus on the quantity of connections rather than the quality (i.e., larger consumers). In addition, since concessionaires are dependent on the electrification agency for major maintenance, upgrades and extensions, implementation delays significantly affect revenue generation and growth. Concessionaires lack the capital to implement these themselves (as and when required), and then apply for reimbursement from the rural electrification agency (Castalia, 2015). Operational challenges and timely access to capital are the main barriers to the success of small grid extension concessionaires. However, these challenges do not appear to be insurmountable.

Off-grid Solar Companies

The predominant business model for systems that can at least deliver Tier 1 level of electricity service (the minimum requirement for most national electrification plans) is the PAYGo model. The PAYGo value chain consists of the following segments: Product manufacturing, product design, software development (for sales and customer management), marketing and distribution, consumer financing and after-sales support. The PAYG model requires a responsive customer service system to register customers, address technical challenges, coordinate, and deploy technicians and follow up on defaulters (customers tend not to make repayments when their system is not working). First generation PAYGo companies are typically vertically integrated, dealing with all segments of the value chain, excluding manufacturing. However, the sector now has a diverse array of companies who only focus on specific segments of the value chain (Lighting Global et al., 2020).

The vertically integrated PAYGo business model inherently necessitates rapid growth and scale. Companies that implement this model require finance to develop new products, set up software platforms and distribution networks, expand into new markets and extend consumer loans. PAYGo companies do not accept deposits like a commercial bank, and are therefore dependent on funding from investors, lenders, and internal cash reserves to finance the consumer loans. The larger the value of a consumer loan and the lengthier its term, the more the working capital needed to fill the negative cash flow gap that is generated during the normal course of business. For example, a PAYGo company selling 1500 units per month (with a system cost of US$ 200 and an 18-month repayment period), can create a loan book of approximately US$ 1 million after five months (Lighting Global et al., 2020). As a result, working capital is necessary for a PAYGo business to scale up, and the lack of it will restrict growth. Financing needs for receivables are closely tied to the rate of revenue growth, and thus PAYGo companies will not remain reliant on external capital indefinitely. They will be able to finance most of their operations from internal cash flows once they reach scale and their growth rates slow (conversely, the more aggressive the company's growth, the greater the need for external funds). It is therefore estimated that they may need to rely on external sources of funding for 8–15 years (Bardouille et al., 2017).

Market experience has shown that aggressive growth can affect long-term sustainability, creating a tension between maintaining both fast growth rate and high portfolio quality. Fast growth can be generated by e.g., lowering the amount of customer down payment to make sales easier, extending repayment periods to increase addressable market, simplifying customer vetting processes, using part time contractors to maximize deployment speed, and using commissions that focus on rewarding acquisition (without putting sufficient emphasis on portfolio quality). However, while these approaches generate fast initial growth, they subsequently lead to low earnings and plateauing growth due to higher default rates and sales force churn. This not only leads to increased direct costs but also translates into negative word-of-mouth and lower penetration (Hybrid Strategies Consulting, 2017).

In response to both investor pressure and the challenges of building a sustainable off-grid solar business, PAYGo companies are shifting from growth at all costs to focus on unit economics, profitability, and sustainable scale. A key business model shifts is optimizing the customer relationship established and the knowledge generated from initial PAYGo sales (e.g., the creditworthiness of the customer) to offer other energy products and services (e.g., clean cooking solutions) and new products e.g., insurance, cash loans and other durable goods. Essentially increasing the value generated from each PAYGo customer secured.

The off-grid solar industry is also seeing the disintegration of the vertically integrated business model as companies find and focus on their niches and increase efficiency along the value chain. The industry is seeing more specialization, including from previously vertically integrated companies, as companies focus on financial sustainability and the off-grid solar industry grows large enough to support a wider array of specialist firms. Examples of this include, (1) emergence of third-party service providers offering PAYGo software to off-grid solar companies in different parts of the value chain, (2) large international companies are partnering with better positioned local distributors to reach unserved markets, rather than trying to establish large-scale last mile distribution themselves, and (3) several PAYGo companies have expressed interest in and the intent to outsource consumer finance to both microfinance institutions and larger finance institutions so that they can focus on their core capabilities (e.g., product or software) (Lighting Global et al., 2020).

Notably, off-grid solar software providers have developed an application programming interface that allows mini- or micro-grid developers to integrate off-grid solar PAYGo software into their platforms. This enables the integrated management of both mini grid and off-grid solar revenue streams (Lighting

Global et al., 2020). One implication of this is that companies no longer need to fit into either the mini grid or off-grid solar category, they can provide either or both depending on the context.

Customer repayments for PAYGo systems are dependent on the cost of the system and repayment duration; for more expensive systems, the repayment duration would need to be longer for the repayment fee to be lower. The effectiveness of the PAYGo model in delivering affordable electricity access is therefore dependent on the amount of daily/weekly/monthly repayment fee charged i.e., the extent to which this fee can be covered by the discretionary income of the target market segment (the lower the fee, the larger the potential market). The 2014 Africa Energy Outlook estimates that Kenyan households spend 3–5% of their income on electricity, with poor households spending the larger percentage (Global Energy Economics Directorate, International Energy Agency, 2014). This would indicate that the PAYGo model is primarily serving households in the US$ 6–40 $/day income range, who would not typically be considered as low income.

The 2020 Off-Grid Solar Market Trends Report provides estimates for the addressable market in sub-Saharan Africa for different off-grid solar products based on theoretical affordability. The addressable market is the population of households without electricity access, a product is considered affordable if the monthly cost is < 5% of total monthly expenditure, and theoretical affordability assumes the payment of equal monthly instalments of the product cost throughout its lifecycle. Based on these assumptions the percentage of households in sub-Saharan Africa able to afford the different sizes of PAYGo solar home systems is as follows: entry-level systems (11–21Wp)—83%, basic systems (21–50Wp)—35%, medium systems (50–100Wp)—32%, and high-capacity systems (>100Wp)—10% (Lighting Global et al., 2020).

5 Discussion

5.1 Representing the Electrification Industry using the TEF—A Summary of the Findings

Geels illustrates the triple embeddedness framework using a diagram that highlights the relation between firms and the industry regime and their interactions in economic and socio-political environments. Figure 1 below uses the TEF diagram to summarize the findings from the sections above.

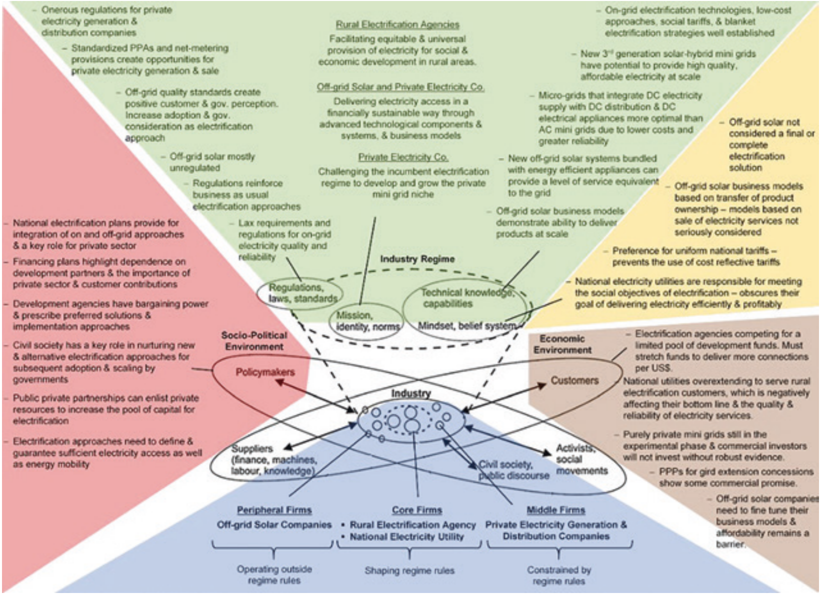

Fig. 1 An illustration of the electrification industry using the triple embeddedness framework. (Source Authors' elaboration)

5.2 Postulating the Reorientation and Recreation Required to Make Progress Towards the Universal Electricity Access Goal

Acknowledging electrification funding constraints, the capacity limitations of national electricity utilities (in terms of their ability to provide a similar level of service to both urban and deep rural customers), and that new rural household connections are eating into the revenue margins of national electricity utilities, two challenges that should be addressed are, (1) increasing the flow of private sector resources and expertise to electrification, and (2) reducing the burden that on-grid (and mini grid) electrification activities are creating on national electrification utilities.

Grid densification and intensification should remain the preserve of national electrification utilities, especially in urban and peri urban areas. However, for grid intensification additional criteria should be used to determine which settlements or housing clusters qualify i.e., intensification should be done for economic or socio-economic reasons, but not solely for social reasons. Thresholds based on standardized financial and economic analysis that applies realistic estimates of customer demand should be used to determine the settlements or housing clusters that qualify for grid intensification. For settlements or housing clusters that do not qualify for grid intensification, a combination of DC micro-grids and off grid solar systems should be considered.

Due to the industry lock-in created by the long-held perception that AC electricity is superior to DC electricity, the potential of DC micro-grids is not fully appreciated. ESMAP's projection that the development costs for third-generation AC mini grids will reduce, and their LCOE as a result, could be further extrapolated when considering DC micro-grids. Furthermore, because these systems are based on low voltage DC, they represent a low safety risk, which justifies the deregulation of these types of grids. Deregulation would allow DC micro-grid developers to completely bypass the onerous regulatory requirements applicable to the development of private AC mini grids and enable them to identify and serve household clusters in the same way that off-grid solar companies identify and serve individual households.

While deregulation implies that the question, 'what happens when the national grid arrives,' remain ambiguous, it is also reasonable to assume that if a household on a DC micro-grid has affordable and reliable access to all the electricity services they need and want, then the arrival of the national grid will be of no interest to them. When the grid arrives, customers with high power and energy demands can be specifically targeted. In addition, with AC-DC converters readily available in the market, it would be straightforward to supplement the capacity of the DC grid with electricity from the national AC grid, if required.

The availability and affordability of high efficiency DC appliances is invaluable for off-grid electrification efforts since they are suited to both off-grid solar systems and DC micro-grids. The demand for these appliances is still low (relative to AC appliances), making it difficult for manufacturers to achieve economies of scale and drive down costs. Government policy should therefore be targeted at addressing this by bringing down the cost and increasing demand. However, the opposite is happening, with import duty and taxes currently being levied on appliances used in off-grid solar systems.

The key challenges that need to be addressed to effectively use off-grid solar to meet national electrification targets are energy mobility and market distortion. The off-grid solar fee-for-service model has characteristics that suggest potential to address these challenges. The fee-for-service model provides a low entry requirement for the customer (in form of a connection fee) and lower ongoing payments since the customer is only paying utility bills for the electricity service, rather than making payments to own the system. The model also provides for energy mobility; when customers are ready and willing to make larger utility payments, the off-grid solar provider can upgrade their system by e.g., increasing the generation and battery storage capacity to enable them to use their existing appliances for longer and/or use additional appliances. If an upgrade requires replacement of the existing system with a new system, then the off-grid solar provider can remove and refurbish the old system for reuse (i.e., to provide electricity services to a new customer), or sell it at its residual value on a cash or PAYGo basis.

The fee-for-service model for off-grid solar is well suited for the application of both a demand side and supply subsidy because it contributes to making electricity services more affordable for the consumer. In addition, as it is provided as a capital subsidy to the off-grid solar provider, it reduces the company's capital requirements and reduces the long payback period associated with the fee-for-service model. The model is also compatible with the application of results-based financing instruments.

Targeted subsidies would be the most effective way of addressing market distortion i.e., when using subsidies to deliver connections through off-grid solar. However, targeting low-income groups works best in countries with the institutional capacity to collect accurate income data, or where there is a comprehensive classification system in place e.g., the Ubudehe program in Rwanda, which classifies the Rwandan population into four categories based on income levels. Other countries implement more generic social protection programs with databases of beneficiary households. While these provide a good start for identifying who should benefit from an off-grid solar system subsidy, they are not exhaustive.

The fee-for-service model can mitigate against market distortion because of the following: (1) there is little overlap between the two models, which means they don't directly compete—one sells electricity as a service and the other sells off-grid solar products, (2) to date there has been limited use of the fee-for-service model in Eastern Africa, which means the playing field will be levelled for everyone—the subsidy won't provide one PAYGo company a unique advantage over another, (3) it will possible to clearly communicate the distinction to customers i.e., PAYGo being used to provide an off-grid solar system on a commercial basis and fee-for-service being used to provide an off-grid solar electricity connection under the public electrification program, and (4) this distinction will facilitate the continuous monitoring, evaluation and review of the eligibility criteria being used to provide the subsidy and the effectiveness of how it is being applied.

A notable advantage of using PAYGo companies to provide off-grid solar connections is the potential to leverage their interest in also providing offer other energy products and services (e.g., clean cooking solutions) and new products e.g., insurance, cash loans and other durable goods. With SGD 7.1 also setting out targets for universal access to clean cooking solutions and governments keen to address this as well, the interest that PAYGo companies have in also delivering clean cooking solutions provides an opportunity for governments to combine electricity access programs with access to clean cooking programs and use the same companies to deliver on their targets.

The capacity of national electrification utilities to operate and manage existing grid extension and mini grid projects (i.e., those that have been or will be financed and developed through the rural electrification agency) should be evaluated. For existing projects (mini-grid and grid extension distribution networks) comprehensive electricity quality and reliability measurement protocols should be established and minimum performance requirements set. If, as determined by the regulator, the national electricity utility repeatedly fails to meet these performance requirements, then these projects should be withdrawn from the national electricity utility and leased out private electricity distribution and supply companies. These companies would purchase electricity in bulk from the national electricity utility for resale to end consumers, be allowed to develop their own renewable energy generating capacity to supply the distribution network and have the option to enter into a net metering arrangement with the national electricity utility. To optimize logistics and facilitate economies of scale for private companies, the rural electrification agency would have to develop suitable clusters of these projects when inviting private companies to bid for them.

Rural electrification agencies should also re-evaluate the current approach of unconditionally handing over grid extension and mini grid projects developed with rural electrification funds to national electricity utilities. Because most national electricity utilities are owned by the government, it is likely that they take up these projects out of obligation as opposed to commercial interest. Rural electrification agencies should instead invite both private companies and national electricity utilities to bid for the operation and management of newly established distribution networks.

The current practice of developing mini grids or grid extension projects is based on engineering, procurement, and construction (EPC) contracts i.e., turnkey projects procured by the rural electrification agency. A key flaw with this approach is that the EPC contractors have no long-term responsibility for the operation and maintenance of the distribution network. A procurement process that combines the EPC contract with a lease to operate and maintain the distribution network could in theory result in a better-quality distribution network, because it would be in the interest of the EPC contractor to design and construct the grid in a way that makes it cost effective to operate and maintain. It also creates a larger financial opportunity for private companies, who would generate revenue from the EPC contract in the short term, and from electricity sales in the long term.

6 Concluding Remarks

When the triple embeddedness framework was developed, it had in mind industries associated with societal problems (e.g., decarbonisation and air pollution control) and large incumbent firms (mostly private) with bargaining power. While the societal problems could be addressed through sustainability transitions, the firms in these industries are reluctant to address them. The TEF postulates that the reorientation of incumbent industries towards radical innovations that address grand challenges will require pressure from consumers, policymakers, civil society, and social movements. The accumulation of such pressures may stimulate incumbent firms to overcome lock-in mechanisms and reorient towards more radical innovations.

This paper sought to apply the TEF to a different kind of societal problem i.e., universal access to affordable, reliable, and modern energy services (SDG 7), where the incumbents are public companies and government agencies (i.e., national electricity utility companies and rural electrification agencies) and the private firms in the industry are small and have little or no bargaining power. The application of the TEF to this problem was then used to identify (1) how to facilitate the foundational rethink (unlearning of existing beliefs) required, and (2) where and how external pressure could be exerted to achieve electricity access targets. The TEF provides a structured way of laying out the key aspects associated with electrification to create a picture that enables one to 'see the forest for the trees' and identify where and how to achieve more effective complementarity between on and off-grid approaches, and public and private firms.

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