Enabling private sector investment in microgrid-based rural electrification in developing countries: A review

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ABSTRACT

Access to electricity is widely recognized as an important factor for economic and social development. Low rates of access, particularly in remote rural areas in regions such as sub-Saharan Africa, South Asia, and Southeast Asia, have led developing nations and international organizations to set ambitious goals to expand the reach of electricity. Decentralized solutions such as microgrids have been proposed as cost effective solutions to reaching communities located far from central grid infrastructure. Lack of capital from public and donor sources has severely impeded achieving access goals, leading to calls for greater private sector participation in electrification activities. However, due to the high level of risk associated with decentralized electrification projects in low-income areas, marginal expected returns on investment, and a lack of clear and effective public policy, the private sector has not shown significant interest in participating in such projects. The purpose of this paper is to review barriers to private sector participation in decentralized electrification projects and to identify solutions that have been implemented and proposed to overcome these barriers. The barriers discussed include unsecure revenue streams, inability to finance projects, and long-term project risks such as grid encroachment. The range of interventions and business models reviewed include methods to secure reliable demand, subsidy models, risk guarantees, and different revenue models. This paper does not include an analysis of the effectiveness of the different interventions described. Future research should evaluate the relative costs and benefits of these interventions in order to provide robust policy guidance to decision makers in developing countries.

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Contents

1. Introduction .......................................................................................................................... 1269
   1.1. Microgrids for electrification ...................................................................................... 1269
       1.1.1. Advantages of microgrid electrification ............................................................... 1269
       1.1.2. Advantages of private sector participation ......................................................... 1270
   2. Barriers to private sector investment in electrification via microgrids .............................. 1270
       2.1. Financial barriers .................................................................................................. 1271
       2.2. Institutional and policy challenges ........................................................................ 1271
       2.3. Technical challenges ............................................................................................ 1271
   3. Business models and policy support for private microgrids ........................................... 1272
       3.1. Financing and subsidy models ............................................................................... 1272
           3.1.1. Subsidy models ................................................................................................. 1272
           3.1.2. Tax incentives ................................................................................................ 1274
           3.1.3. Climate and carbon finance ........................................................................... 1274
           3.1.4. Preferential lending and risk guarantees ......................................................... 1275
           3.1.5. Public service concessions ............................................................................... 1275

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1. Introduction

Access to affordable and high quality electricity is essential for the development of modern economies. Low rates of electricity access in the developing world pose a significant barrier to sustainable economic and social development, particularly in rural areas. The International Energy Agency (IEA) estimates that about 1.3 billion people in the world, primarily in South Asia and Sub-Saharan Africa, still lack a connection to electricity [1].

Electricity access has been linked to many positive developmental and welfare benefits including greater economic opportunities and increased income, higher quality of life and access to information, improved health, and greater educational attainment [2-9]. Lack of electricity in rural communities has also been linked to disparities in regional development within countries and increased rural to urban migration, thus putting further stress on already strained urban infrastructure systems [10-12]. For this reason, access to electricity has taken greater prominence in recent years on the global development agenda.

State-owned utilities have traditionally carried out electrification projects driven by a mandate to expand social access to electricity services. Power sector reforms in the 1990s, advocated by organizations such as the World Bank, led to the commercialization and privatization of many state-owned utilities. This led to a shift in the treatment of electricity from a social service to a commodity [13]. Because rural electrification projects are rarely economically attractive, power sector reforms generally affected electrification activities negatively [14]. In some cases, countries have seen the number of people without access actually increase as population growth in unelectrified areas exceeded the number of new connections [15].

More recently, many countries have recognized that if electricity access is to be expanded into rural areas, resources need to be allocated for projects of a social rather than a commercial nature [14]. This has led to the establishment of dedicated rural electrification agencies whose mandates are to expand access to electricity for the purpose of long-term social and economic development [16]. Limited public and donor funds, however, have proven insufficient to meet the aggressive access goals that governments and international organizations have set. Increasing attention has now focused on how to encourage the private sector to invest in electricity access projects in developing countries. Because of the typically unattractive risk-return profiles of these investments, efforts to accelerate access by securing private capital have been largely unsuccessful [17]. As a result, several scholars have pointed out the need for greater academic work exploring barriers and solutions to unlocking private sector investment in electrification activities [18,19].

1.1. Microgrids for electrification

In the absence of legacy systems, many developing countries have the opportunity to leverage decades of technological advancement and experience in developed countries as they build innovative modern infrastructure systems. Microgrids, small electricity networks that have the ability to operate autonomously, can play a key role in developing an electricity infrastructure built around decentralized renewable energy technologies. At the same time, microgrids can accelerate electricity access to areas the central electricity grid cannot reach in the short to medium term. As these microgrids develop, they can be easily interconnected, creating a decentralized network that can aggregate loads and generation capacity, while maintaining the ability to operate as isolated systems should the need arise. Many developed nations are now devoting significant resources to retrofit existing infrastructure and permit the integration of decentralized technologies [20]. Countries with underdeveloped electricity systems are well positioned to leapfrog outdated centralized approaches.

This paper will examine the benefits of and the challenges faced by private sector participation in the deployment of microgrids for rural electrification in developing countries. It will further explore various solutions that have been proposed and tested to unlock the potential for private sector-driven microgrid-based electricity access projects. The paper is intended to provide a global perspective with an understanding that many solutions are very context-specific and must consider unique geographical and cultural conditions.

1.1.1. Advantages of microgrid electrification

The decentralized nature of microgrids is viewed as having several inherent advantages over traditional centralized infrastructure. These advantages include improved economics, technical performance, environmental sustainability, and regional equity in the context of rural electrification. In many countries, the reach of the electricity grid is extremely limited and almost exclusively serves urban areas. Sub-Saharan Africa is a prime example of electricity access disparity between rural and urban communities. The 2011 World Energy Outlook [21] reports the urban electrification rate in this region is 59.9% whereas the rural access rate is only 14.2%. Without a decentralized approach to expand access, many communities located far from existing grid infrastructure will be left in the dark for decades to come.

The proximity of load to generation in a microgrid is also an economic advantage. While it may be technically feasible to pursue an entirely grid-based electrification program, several studies have found that the cost of building distribution and transmission infrastructure to deliver power from centralized power stations often exceeds the cost of decentralized solutions. The low levels of rural electricity demand and the energy losses incurred en route do not justify the cost of building the long power lines to remote areas. Parshall et al. [22] found the average grid connection cost for a household in Kenya to be about US$1900, with more remote and sparsely populated communities having much higher connection costs. Decentralized solutions such as microgrids are therefore more cost effective solutions to delivering electricity to these areas [23,24]. Further, unlike other decentralized technologies such as solar home systems, microgrids can be more easily integrated into larger grids in the future when economic development takes hold, the central grid expands, and/or demand for electricity rises. Upon connection to the main grid, the microgrid then has the ability to feed excess electricity into the network or draw electricity to meet shortfalls. This aggregation of loads and generators on a larger scale unlocks greater economies of scale and more efficient management of the power system. By maintaining the ability to operate microgrids in...
an islanded mode once interconnected, the security of the power system is enhanced. The rolling blackouts often associated with centralized grid networks in developing countries could be avoided by distributing energy generation resources in semi-autonomous microgrids.

From a development perspective, the ability of microgrids to produce grid-quality power also presents benefits over other decentralized alternatives. While there are several companies operating in developing countries that offer energy services from solar home systems on a “fee for use” and “lease to own” basis, these systems are limited in the type of energy services they can provide. For example, M-KOPA, a company with over 100,000 customers in East Africa, offers small 8 W solar home systems (SHS) that power LED lights, a cell phone charger, and a radio. These systems are unable to provide electricity for productive use such as refrigeration, mills and food processing, sewing machines, and electric tools for carpentry and construction, which are key to stimulating rural economies and reducing poverty [7]. The service level limitations of SHS have also resulted in high levels of customer dissatisfaction where grid level service was expected [25].

From an environmental perspective, microgrids may have lower environmental impacts than traditional systems. Microgrids are well suited to use local renewable energy resources like wind, small hydro, and solar power. They may also be suitable for the application of advanced generation technologies like modular nuclear reactors, biomass-based systems, and combined heat and power. While most developing nations only contribute to a small fraction of global greenhouse gas emissions, the early adoption of renewable energy technologies presents an opportunity to pursue a cleaner and more environmentally-friendly development path than the developed economies of today. Should developing regions pursue fossil fuel-based solutions to meet their energy needs, the problem of climate change would only be exacerbated in the long term as economies grow and energy demand increases. Furthermore, it is developing nations that tend to face the greatest consequences of climate change while at the same time being the least prepared to adapt [7].

Besides providing environmental benefits, the use of renewable resources also enhances energy security. Many developing countries depend on imported diesel for a large portion of their electricity generation. This dependence on diesel and other imported fossil fuels exposes economies to price shocks resulting from the volatility of the price of oil and risks due to supply chain disruption. Renewable energy technologies rely primarily on freely available local resources and are, therefore, not vulnerable to the price of primary energy sources.

1.1.2. Advantages of private sector participation

Despite the apparent advantages microgrids and several public sector efforts encourage their deployment in rural areas, microgrid electrification has not yet contributed significantly to the alleviation of energy poverty in developing countries. There is growing interest in understanding how to encourage private sector participation in rural electrification efforts. One of the primary motivations for pursuing private sector investment in energy access projects is to tap into the large amounts of capital available in the private sector [19,26]. Electrification is a capital-intensive activity and one of the major constraints to rolling out electricity access projects is the limited availability of resources in the public sector and donor community. The private sector is therefore viewed as a source of capital to finance these infrastructure projects.

The advantages of private sector participation go beyond access to capital. Publicly-owned utility companies have also been known to suffer from inefficiency and poor technical performance [14]. Common reasons for failure in publicly-owned electrification projects are a lack of technical capability to properly maintain and operate the technology and poor service quality [27]. This has been found both in community-operated cooperatives and grid extension projects operated by public utilities. India has even experienced instances of de-electrification due to poor maintenance and vandalism [28]. Privately-operated microgrids, on the other hand, often benefit from technical skills, management capabilities, and efficiency that are lacking in community-run projects and even large, state-owned utilities [14]. Private sector participation in electrification projects could thus lead to both an increase in the availability of capital as well as improved technical and managerial performance. However, the private sector has not been quick to answer the call of governments in developing countries to invest in electrification projects. The next section will provide a broad summary of the barriers to private sector involvement in decentralized electrification.

2. Barriers to private sector investment in electrification via microgrids

Despite some clear advantages of private sector participation in electrification efforts, there are several challenges that must be overcome to make these projects attractive to potential investors and project developers. Expanding electricity access to rural areas in developing countries is often motivated by social concerns, but as with any investment opportunity, the private sector will measure the attractiveness of a project by its expected financial return and its associated risks. The security of revenue streams, long-term risks and policy certainty, regulatory transparency and complexity, as well as practical challenges relating to local organizational structures and technical implementation are issues of significant concern. This section examines various issues that must be overcome to create an enabling environment for private sector participation in microgrid electrification. Though many of these challenges are codependent, we divide them into three broad categories as represented in Fig. 1: financial barriers, institutional and policy obstacles, and technical challenges.

2.1. Financial barriers

Private sector investment decisions hinge primarily on the balance between risks and expected returns. In building a business case for microgrid electrification projects, concerns about both high levels of risk and low expected returns are likely to be raised. In the first place, a project must have a secure stream of revenue to fund operating costs, repay project debt, and provide a return to equity investors. Rural microgrids often serve poor populations with limited means to pay for electricity services. While it is well documented that poor unelectrified rural populations often pay more for the same energy services than their urban counterparts
Saharan Africa, late payment can be costly to project owners, and debt exceeding 10% and at times exceeding 20% in sub-Saharan Africa, late payment can be costly to project owners [32–36].

The level of electricity demand in rural communities is also typically very low. This results in a high unit cost to generate and distribute electricity, which in turn amplifies problems related to the ability of rural consumers to pay for energy services. The level of demand itself is highly uncertain [19]. It is not possible to directly measure the electricity demand in a community that has never had access. When assessing potential demand, it is therefore necessary to employ methods such as surveys of current energy use or to base assumptions on experiences in other villages [27]. Fabini et al. [37] have developed a technique to map predicted demand in unelectrified communities using demographic and socioeconomic data. Since the profitability of a project is highly dependent on the amount of electricity that is produced and sold, uncertainty regarding electricity demand in microgrids represents a significant risk to investors. Should demand fall short of expectations, the microgrid may turn out to be unprofitable. On the other hand, should demand exceed expectations, the installed generation capacity may fall short of demand, resulting in poor performance and customer satisfaction which could jeopardize the sustainability of the project [38].

Revenue security risks are amplified due to the capital-intensive nature of electrification, particularly if they include large amounts of renewable energy generation such as wind and photovoltaic systems, though the costs of these technologies are rapidly falling [39]. This means that several years may be required for the project to break even and start generating profits, which exposes project owners to long-term risks that could cause a project to fail before the recovery of initial capital investments [40]. Furthermore, such projects are often funded by project finance, which is based upon projected future cash flows rather than physical assets or collateral. Project developers will therefore need to demonstrate to debt providers that revenue streams are secure throughout the loan tenor.

Securing finance for rural electrification projects is often challenging. Electrification projects are seen as high risk by both debt and equity funders. These project-specific risks are often compounded by a generally poor local investment climate in developing countries resulting from perceived political risks and other country-specific challenges. This frequently results in projects being unable to secure the capital required for implementation. When they do, it is often on unfavorable terms with high interest rates and short debt tenors, which exacerbates the challenge of achieving sustainable, affordable tariffs [35,41]. Investors in microgrids will thus need assurances that their investments will be protected over the medium- to long-term [40].

Risks to overcome include grid encroachment, unregulated competition, loss of operating subsidies, changes in regulated tariffs, and other sources of policy and regulatory uncertainty. Addressing these risks requires a sound policy and regulatory environment that is often lacking in developing countries. The next section includes a discussion of these issues.

2.2. Institutional and policy challenges

Creating an enabling policy and regulatory environment is essential to stimulating private investment in infrastructure projects with low profitability and strong social welfare motivations. If private investment is to take place, the electricity sector must be open to the private sector and not subject to state-owned monopolies. Progress has been made in this regard in many countries under World Bank pressure for power sector reform. However, these reforms often lead to the treatment of electricity purely as a commodity and not as a public good. Such policies have been disastrous for rural electrification, where access to electricity should be motivated primarily by social rather than commercial motives [14]. Consequently, there must be a balance between the needs of the private sector and the goals of public policy in providing social services.

In order to ensure financial sustainability for private investors, tariff regulations must permit cost recovery and subsidies may be necessary to promote affordability to consumers. These policies must balance the need to protect and attract investment and the obligation to promote social and economic development among the rural poor. A lack of regulatory independence has often led to unsustainably low electricity tariffs due to political pressure to maintain affordability. Unfortunately, these low tariffs have made the electricity sector in many countries unprofitable and unattractive to the private sector [42]. It is also important to minimize regulatory and licensing complexity. Bureaucratic red tape increases transaction costs, unnecessarily extends timelines, and deters investment [17]. Clear policy and regulatory frameworks and long-term policy certainty permit the development of bankable business plans and financial models. Policies and regulations that are frequently changing or are poorly defined lead to a breakdown in investor confidence that the policies on which they are building their business case will be respected. Well-developed policies and regulations, however, are only one of the prerequisites. Effective administration of policy and regulation relies on clear institutional structures with well-defined allocation of roles and responsibilities. All too often, institutional structures and regulatory processes are complex and difficult to navigate, acting as a barrier to potential project developers and investors [19]. Furthermore, where state-owned utilities exist, it is essential to have clearly defined relationships between private and public actors in the sector. For example, the creation of the Agence Sénégalaise d’Électrification Rurale (ASER), which was meant in part to relieve the Senegalese utility SENELEC of its electrification mandate and attract private sector participation, was initially a source of conflict and resentment as the utility viewed the new arrangement as a threat [43].

Beyond the state institutions, it is important that any electrification project involves the local community in the project from an early stage. Poor coordination and consultation with target customers has frequently resulted in projects that do not meet community needs and do not achieve local acceptance or participation. The consequences of this have been low uptake of energy services, poor payment morality, low collection rates, and high incidence of electricity theft [19]. Creating effective local organization and stakeholder consultation is a challenge in remote areas where there is often a cultural gap between project sponsors and project beneficiaries. Bridging this gap is essential to creating a sustainable project that meets the needs of beneficiary communities.

2.3. Technical challenges

This review does not focus on the technical design of microgrids. However, there are several technical issues that affect the feasibility of microgrids for rural electrification that should be noted. For any grided system, population distribution patterns are an important determinant of the technical design specifications and capital investments required to build physical infrastructure. Low density and highly dispersed settlement patterns result in higher distribution infrastructure costs per customer when compared to more densely populated areas. Population...
density and settlement patterns are therefore an important factor to consider when evaluating the appropriateness of a microgrid as a technical solution for electrification [44].

Microgrids are also more sensitive to local energy consumption patterns than interconnected grid systems. Because loads are aggregated over smaller geographical areas, the variability of demand is more pronounced than in large national and regional grids. Combined with potentially high proportions of variable and intermittent renewable energy sources, grid management becomes a greater challenge. This complicates the generation system design process, which must maximize service quality while minimizing cost. Uncertain load profiles add to this problem, making it difficult to size the generators required to meet the demand.

Once the project has been built, a lack of local technical skills creates challenges in maintaining and operating the system [19,45]. The remoteness of some sites can make maintenance and repairs challenging, with high costs and long lead times for the delivery of replacement parts, which may not be available in local markets. Tefera [34] notes that in some cases in Ethiopia, utilities have stepped in as a supplier due to the difficulty of sourcing materials for construction. Local skills and supply chains are important to the long-term sustainability of microgrids. Even when these skills have been developed, experience has shown that newly trained technicians may be tempted to take their new found skills to urban areas with higher salaries [46]. Meeting the technical challenges of rural microgrids thus requires the preparation and retention of local technicians and operators.

3. Business models and policy support for private microgrids

Despite the aforementioned challenges, many strategies have been put forward to overcome these barriers to private sector participation in electrification generally, and microgrids specifically. This section examines various models that have been proposed or tested in the field, including various subsidy and finance models, strategies to secure and stimulate electricity demand, and innovative revenue models. It also highlights important considerations relating to organizational and institutional approaches, as well as technical and skills development solutions. Fig. 2 provides an overview of public policy interventions and

![Fig. 2. Policy interventions in support of private sector microgrid electrification.](image)

Table 2 links the barriers from Section 2 to the interventions described in Section 3.

3.1. Financing and subsidy models

While subsidization is often not a preferred intervention due to concerns about economic sustainability and market distortion, the need for subsidies to make electricity affordable to the rural poor is most often a reality. Subsidies for microgrids can take a number of different forms, but they typically support either capital or operating expenditures. A number of non-subsidy financial supports, such as loan and partial risk guarantees and concessional debt to overcome failures in capital markets, exist as well [47]. The implications of these financial supports are diverse and must be carefully considered when designing programs to encourage private sector investment in electrification. Table 1 summarizes the various policies reviewed in this paper.

3.1.1. Subsidy models

Capital subsidies, which reduce the initial investment cost for project implementers, are frequently cited as preferred to operating subsidies for reasons of long-term sustainability. Capital subsidization corresponds well to the cost structure of microgrids, which require large investments in electricity distribution and generation equipment. Capital subsidies also tend to promote the use of capital-intensive generation technologies such as wind, solar, and hydropower. Compared to fossil-based generating technologies, these renewable energy technologies have lower exposure to fuel price volatility and operating cost uncertainty. The reduction of capital requirements and the fuel price certainty of renewables leads to affordable electricity tariffs without the need for continued subsidization throughout the life of the project [48]. Greater uptake of renewable energy technologies has the positive side effect of improved environmental performance as well. The use of low carbon technologies also has the potential to attract carbon emissions reduction credits, which can be an additional source of revenue for the microgrid.

One of the primary motivations for attracting private sector participation is to overcome a lack of capital in the public and donor spheres. This shortage of public capital for electrification projects is therefore also a limitation on capital subsidies. However, using public funds to provide capital subsidies may permit the limited amount of public capital available for electrification to be stretched farther by coupling it with private sector investment. The level of capital subsidization offered should seek to deliver affordable electricity to consumers with a reasonable return to investors, while at the same time maximizing the number of projects that public funding can support.

Experience has shown that full subsidization of capital costs of privately owned systems is a disincentive to fiscal discipline. For example, a program in Peru that offered fully subsidized solar home systems found that many of the systems provided to the poor were later sold [49]. While the technology is different, the principle is still applicable to microgrids, where a developer may be tempted to, for example, install more generation capacity than is necessary to meet demand. Capital subsidies have also received criticism, primarily in the context of community ownership. There is evidence that indicates that projects fully financed by the owners and beneficiaries are more likely to be well taken care of [50]. Such examples have also led to the implementation of output-based subsidies.

Output-based, or performance-based, subsidies are only paid out if a project reaches certain goals or milestones. They allow governments to align subsidies with specific policy goals such as expanding access [47]. For example, subsidies can be linked to the
Table 1
Summary of public microgrid support interventions.

<table>
<thead>
<tr>
<th>Subsidies</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital subsidies</td>
<td>Subsidization of capital costs for project realization.</td>
<td>Reduces capital burden and time to capital recovery.</td>
<td>Lack of public sector capital is a motivation for private sector subsidization but also a limitation on funding subsidies. Reduced incentive for fiscal discipline.</td>
</tr>
<tr>
<td>Operating subsidies</td>
<td>Subsidization of operating costs during operations. Includes fuel subsidies.</td>
<td>Promotes affordable tariffs to end-users.</td>
<td>Exposes project to risk of subsidy discontinuation. Viewed as unsustainable and a continuous burden on public funds.</td>
</tr>
<tr>
<td>Output-based subsidies</td>
<td>Subsidization of capital and/or operating costs after project realization based on fulfillment performance of criteria.</td>
<td>Ties subsidies to specific policy objectives such as connection rates.</td>
<td>Exposes developers to high cost at risk as subsidies are not paid until after project realization.</td>
</tr>
<tr>
<td>Direct tariff subsidies</td>
<td>Direct subsidization of consumers through instruments such as electricity vouchers or via sale of power to a subsidized 3rd party retailer.</td>
<td>Can be targeted to specific customer classes in the case of vouchers. Expands access to grid subsidies if sold to state owned retailer. Long-term PPA with third party reduces revenue insecurity.</td>
<td>Essentially an operating subsidy with similar associated risks.</td>
</tr>
<tr>
<td>Guarantees and preferential lending</td>
<td>Loan guarantees: Assists project in securing debt by assuming the debt obligation in event of default.</td>
<td>Enables microgrid to secure debt finance or secure debt finance on more favorable terms. No upfront cost.</td>
<td>Transfers risk of project failure to guarantor. Cost is difficult to quantify.</td>
</tr>
<tr>
<td></td>
<td>Partial risk guarantees: Guarantee to private lenders by third party to fulfill contractual obligations of government in case of nonperformance.</td>
<td>Enables projects to secure debt by reducing risk related to government nonperformance on subsidies and other obligations.</td>
<td>Government incurs additional cost in securing partial risk guarantee.</td>
</tr>
<tr>
<td></td>
<td>Preferential lending: Direct lending on concessory terms to projects.</td>
<td>Provides access to debt finance at reduced interest rates and/or longer tenors.</td>
<td>Transfers risk of project failure to debtor.</td>
</tr>
<tr>
<td>Tax incentives</td>
<td>Customs/duties exemptions: Reduction or exemption of microgrid equipment from customs and import duties.</td>
<td>Reduces capital costs. No reduction in public revenue if project would not otherwise be realized.</td>
<td>Reduces public tax revenue if the project would have been realized without incentive. Vulnerable to abuse if exempted equipment is multiple applications.</td>
</tr>
<tr>
<td></td>
<td>VAT/sales tax exemptions on equipment: Reduction or exemption of microgrid equipment from VAT/sales tax.</td>
<td>Reduces capital costs. No reduction in public revenue if project would not otherwise be realized.</td>
<td>Reduces public tax revenue if the project would have been realized without incentive.</td>
</tr>
<tr>
<td></td>
<td>Income tax exemption/reduction: Reduction of operating expenses through reduction in tax burden.</td>
<td>Reduces operating costs. No reduction in public revenue if project would not otherwise be realized.</td>
<td>Reduces public tax revenue if the project would have been realized without incentive.</td>
</tr>
<tr>
<td></td>
<td>VAT/Sales tax exemptions on electricity sales: Reduction or exemption of electricity sales from VAT/sales tax.</td>
<td>Reduces electricity prices for consumers.</td>
<td>Reduces public tax revenue from taxes on substituted, unsubsidized forms of energy.</td>
</tr>
<tr>
<td>Concessions</td>
<td>Award of exclusive rights to service a geographic area for a fixed term with minimum service level obligation.</td>
<td>Protects microgrid investments from competition in medium to long-term. Often accompanied by subsidies.</td>
<td>Provides monopoly status to a single private sector operator. Proper regulation necessary to protect consumers.</td>
</tr>
</tbody>
</table>

Table 2
Summary of barriers and interventions.

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to finance</td>
<td>Loan guarantees, Climate finance, Partial risk guarantees, Preferential lending</td>
</tr>
<tr>
<td>Affordability</td>
<td>Public subsidization, Tax exemptions/reductions, Financing of connection fees</td>
</tr>
<tr>
<td>Grid encroachment</td>
<td>Public service concessions</td>
</tr>
<tr>
<td>Revenue security</td>
<td>Long-term PPAs, Anchor customers, Fixed service based tariffs, Financing of appliances</td>
</tr>
<tr>
<td>Revenue collection</td>
<td>Prepayment meters, Mobile phone payments</td>
</tr>
</tbody>
</table>

number of customers connected to the microgrid; therefore incentivizing microgrid operators to connect as many customers as possible rather than focusing on a small group of more profitable high-consumption users [51]. The German development organization Gesellschaft für Internationale Zusammenarbeit (GIZ) is currently developing such a subsidy scheme for microgrid development in rural Rwanda [52]. To the developer and investor, output-based subsidies involve more risk than upfront capital subsidies. Projects must be financed, built, and operating before the subsidies can be accessed. Output-based subsidies must therefore be based on clear and transparent criteria and policies to mitigate these risks.

Subsidization of operating costs can take several forms. The subsidization of fuel is a commonly used subsidy, which is primarily used to reduce the cost of diesel. Diesel subsidies are often applied nationally and are not necessarily specific to electricity generation. Such subsidies reduce the cost of diesel-based electricity generation, which is then reflected in lower tariffs to
customers. The use of subsidized diesel, however, comes with an environmental cost and can create a long-term burden on national budgets [19]. Several studies have shown the levelized cost of electricity from renewable energy is frequently lower than the cost of diesel-generated electricity [24,53,54]. While conventional generation technologies such as diesel have many technical advantages over variable and intermittent renewable energy technologies such as wind and solar, subsidization of diesel has the potential to increase the total economic and environmental cost of electricity generation by making lower cost clean technologies less attractive.

Another form of operational subsidy is direct subsidization of tariffs. This typically takes the form of a power purchase agreement whereby the owner of the power generation sells the electricity generated to a third party, often a state subsidized utility, which then sells this electricity at a lower rate. Grid-based electricity in developing countries is often supported by public subsidies so that electricity can be sold at rates below the cost of production. Subsidizing privately owned and operated microgrids in this way ensures that all electricity consumers have access to public subsidies and equal tariffs. The power purchase agreements (PPAs) that typically accompany this arrangement are designed to ensure long-term revenue security to independent power producers (IPPs). PPAs will be discussed in greater detail in Section 3.3 on revenue models.

An alternative form of direct tariff subsidization is through the use of “energy coupons” provided by the government. These “coupons” can be redeemed for the purchase of electricity from a microgrid. This form of subsidy is given directly to consumers and can be targeted to people with the least ability to pay [55]. Such a model grants policy makers a greater ability to create subsidies that target the most vulnerable while requiring those with greater means to make greater financial contributions to the microgrid. For the microgrid operator, these subsidies serve to broaden their customer base and increase revenue.

### 3.1.3. Climate and carbon finance

With the high level of interest in integrating renewable energy technologies into rural microgrids, it is natural to consider carbon finance as a means of subsidizing the use of clean technologies for rural electrification. Carbon finance is based on the value of avoided carbon emissions that can be traded on carbon markets, giving the holder the ability to offset emissions in developed countries where such emissions are capped or regulated. Credit for emissions reductions is measured by establishing a baseline level of emissions. In the context of an isolated microgrid, the baseline could be built around the assumption that the default alternative would be to use diesel-based generation [23]. The difference between the diesel baseline emissions factor, measured in carbon equivalents per kWh, and the emissions factor for the clean technology would then be credited to the project owner based on the amount of electricity generated by the system. The goal of carbon finance programs such as the Clean Development Mechanism (CDM) is to offset carbon emissions in the developed world while supporting cleaner development paths in the developing world [58].

The literature has given mixed reviews on the potential of carbon finance to fund energy access. As it stands, high transaction costs make carbon finance unattractive to small scale energy generation projects [26] with a large majority of registered CDM projects to date being large-scale projects in middle income countries such as China [7]. While the bundling of projects under Programmes of Activities (PoAs) and standardized baselines can reduce these transaction costs [26,59], price volatility in carbon markets makes it difficult to build a business case reliant on carbon finance [60]. It is therefore unlikely that a private investor would make an investment decision on the basis of the availability of carbon-based revenue.

Multilateral funds such as the Global Environmental Facility (GEF) provide other forms of climate finance. The objective of the GEF is to finance the incremental cost (the additional cost of using clean alternatives over traditional technologies) of using environmentally friendly technologies instead of more conventional solutions through grant funding. Because renewable energy technologies are often the lowest cost solution in remote rural areas [23,24,54], the incremental cost may in fact be negative which would render the project ineligible for GEF funding. Furthermore, Zerriffi et al. [58] found that GEF funding for energy access projects did not cover the entire incremental cost in roughly half of all cases analyzed. From a purely financial perspective, a private investor would have no incentive to pursue clean technologies if incremental costs are not met. Even in the case where incremental costs are exactly covered by GEF funding, the investor would be neutral between technologies from an economic standpoint. Zerriffi et al. [58], however, did find that in some cases incremental costs were exceeded, providing a net benefit to the project sponsors. Furthermore, the level of GEF funding is not dependent on variable market prices and in this way gives microgrid developers greater certainty for decision making than carbon credits. Other multilateral funds for clean energy development that provide support for energy access projects include the Climate Investment Fund, the Global Energy Efficiency and Renewable Energy Fund, Seed Capital Assistance Facility, and the Renewable Energy Enterprise Development program operated by the United Nations Environment Programme [59].

Climate-based financing of electrification projects has not been significant historically and is only relevant to projects implementing clean energy solutions. Newer mechanisms such as PoAs and other interventions that reduce transaction costs have the potential to increase carbon financing for electrification projects [26]. Despite this progress, building a business case dependent on carbon finance remains challenging. Uncertain long-term carbon prices add further risk to projects that are already considered high risk.
3.1.4. Preferential lending and risk guarantees

Even with a favorable cost structure, microgrid projects can be difficult to finance. Governments and development finance institutions (DFIs) have also explored interventions to facilitate the ability of electrification projects to secure finance. This can be done by providing debt facilities directly or through risk and loan guarantees. To overcome difficulties in securing debt funding from commercial banks on acceptable terms, some governments and DFIs have offered investors debt funding at preferential rates [7, 59]. These arrangements typically offer lower interest rates and longer debt tenors than those available commercially. Additionally, they may offer debt finance for projects that would not be able to secure commercial debt under any terms. China has been providing low-interest loans for rural energy projects since 1987 [57]. These loans, provided at around half the commercial interest rate, have supported a variety of renewable energy projects for electricity access in rural areas [61].

Preferential lending, the provision of debt on concessionary terms, may be appropriate when projects are financially viable but perceived to be too risky by commercial lenders. By offering debt to projects at concessionary rates, the lender is assuming default risks at a reduced risk premium. Preferential lending is only effective when the project has a strong business case and attractive return expectation [26]. Concessionary loans can overcome barriers to obtaining debt and enhance returns on strong projects. However, leveraging an unprofitable project with debt will only serve to amplify losses on equity. Gunning [51] also notes that there exists some controversy over interventions that “distort market conditions” such as offering financial services under conditions not available on the market.

As an alternative to direct lending to projects, governments and DFIs have also offered loan or partial risk guarantees to assist projects in securing debt funding from commercial institutions. Under a loan guarantee, the guarantor agrees to become liable for all or a portion of debt to the funding institutions in the case of default. Partial risk guarantees are provided by organizations such as the World Bank and provide private lenders with assurance that the guarantor will fulfill government obligations towards the private sector project in the case of nonperformance [62]. Such guarantees may permit projects unable to obtain debt finance to secure the required funds or, for risky projects, to secure debt on more favorable terms. Loan guarantees transfer risk from project owners or financiers to the guaranteeing government or organization. The expected cost of loan guarantees is much more difficult to gauge than other financial support mechanisms because the probability of default is unknown. Loan guarantees require no initial cost to the guarantor but risk becoming a heavy financial burden should project risks turn into defaults on debt [47]. Partial risk guarantees must be purchased by the government or entity securing the guarantee on behalf of private sector actors therefore increasing the cost of the intervention, be it subsidies or concession contracts [62].

One reason that lenders are averse to providing debt to microgrid electrification projects is that they are unfamiliar with such projects and do not know how to properly assess the project risks [33]. Loan guarantees can help generate the experience and track record necessary for commercial lenders to begin lending to future projects without such strict terms. A unique lending approach was taken by commercial banks in Rwanda to obtain security on debt provided for microhydro power projects developed by public–private partnerships. Because of the unfamiliarity of the banks with hydropower investments and the associated risks, they were unwilling to provide debt on the basis of projected cash flows from electricity sales. The agreed-upon solution was that the banks would purchase the turbines used in the projects and lease them back to the project owners as a form of collateral.

The assets of the project owner and shareholders were additionally required as loan guarantees. Such extreme conditions such as the inclusion of shareholders’ private assets as security are certain to deter many potential investors. However, it is likely that such conditions would be relaxed as lenders gain more experience and comfort with the technology and business model [33].

It is also possible to support access through the provision of microfinance to rural electricity consumers [59]. Part of the capital cost required to establish microgrid connections is shared with customers through the payment of connection fees. Connection fees are meant to cover the cost of physically linking customers to the grid. These costs can be a significant barrier for low-income consumers who may otherwise be able to pay for electricity service. Removing this barrier promotes wider access to electricity service, permitting government to achieve social and equity objectives and providing microgrid operators with more customers. Micro-finance for connection costs can be provided by third parties or directly by microgrid operators, who can collect loan payments over time along with service payments. As will be discussed in Section 3.2, common electrical appliances can be bundled into this cost to provide greater benefit to users while stimulating increased electricity demand on the microgrid.

3.1.5. Public service concessions

While not strictly a financial support intervention, the awarding of concessions to private companies for electrification of geographic areas is a means by which governments can mitigate long-term project risks by isolating investors from competition. The concession model awards private companies monopoly rights to distribute and retail electricity in a geographic area. These concessions typically include an obligation on the concessionaire to maintain a specified level of service and to connect all or some minimum number of customers within their concession. At times it has been difficult to attract private sector interest for concessions in rural areas, which are viewed as challenging, risky, or potentially unprofitable. Some countries have therefore elected to bundle concessions. Through this approach, concessions to distribute electricity in dense urban areas are bundled with less attractive rural concessions [16, 25]. For example, in the 1990s, Argentina launched a program to expand rural electricity access by offering concessions to private companies, which would then receive subsidies from the local provincial government. Concessionaires were selected based on predefined criteria, which included the amount of subsidy that they would require to implement the project. The concessions provided for a 15-year monopoly under regulated tariffs. Under the terms of the contract, the concessionaire was required to provide service to all households and public facilities within their concession, provided their accounts were in good standing [25].

Due to the long term and regulated nature of private concessions, a transparent tariff and subsidy setting process is essential to providing certainty to concessionaires while ensuring that public money is spent in a responsible manner and consumer interests are protected. Subsidies can include initial connection costs and ongoing tariff and operating expense support. Concession contracts must clearly define the terms of the agreement. Important terms include the way in which risk is shared, incentive schemes, as previously described, and performance standards with associated penalties when these standards are not met [63].

Mostert [16] distinguishes between decentralized and centralized electrification approaches. In the context of concessions, this reflects the size of concessions offered. Large concessions, which divide territories into a small number of large areas, are more likely to attract large foreign utilities that can leverage greater economies of scale. However, in regions that are viewed as particularly high risk, such as sub-Saharan Africa, such public tenders may fail to attract viable bids.
Concessions in a decentralized approach may include a mix of small-to-medium and large concession areas and encourage the participation of multiple players including local companies and investors. These smaller projects may suffer from higher relative transaction costs and less favorable economies of scale. This could act as a deterrent to larger international investors, allowing room for domestic businesses to participate. The decentralized approach tends to attract a larger number of participants resulting in a more competitive market at the cost of economies of scale [16].

3.2. Securing and stimulating demand

One of the key challenges to building a sustainable microgrid model while maintaining an affordable tariff structure is generating sufficient demand for electricity, which will produce enough revenue to cover operating costs, repay debt, and provide returns for investors. Approaches to overcome this challenge have included simply selecting sites with more energy-intensive customers, taking measures to stimulate demand by enabling customers to use more electricity, and establishing commercial and light industrial facilities that require electricity and generate local income.

The first step in securing sufficient electricity demand is to target communities that are likely to require more energy. Not only does this increase the economic sustainability of the microgrid, it is also likely to result in greater developmental benefits to the electrified community. Communities with higher potential electricity demand have higher levels of commercial and industrial activity, access to markets through transportation infrastructure, and potential to exploit nearby tourist sites or high agricultural potential. Proper site selection may include the identification of one or more anchor customers that have high, reliable electricity demand, and the ability to pay for electricity at an attractive tariff. These anchor customers range from rural industries, to public buildings, to infrastructure systems such as base transceiver stations (BTS) for mobile phone networks [16,64].

BTSs for mobile networks are particularly promising anchor customers. These facilities are widespread in off-grid areas across developing countries, about 639,000 at the end of 2012. In an off-grid situation, they are typically powered by diesel generators or, increasingly, stand-alone hybrid renewable energy systems [65]. Electricity provision to BTSs is estimated to make up around 40% of mobile network operators’ (MNOs) operating costs [66]. MNOs are therefore eager to reduce the cost of electricity provision and have been selling their BTS sites at a rapid rate to independent tower operators, who then lease capacity on the sites back to the operators. This trend has also encouraged tower sharing, resulting in larger loads at BTS sites. BTSs have several desirable qualities as anchor customers for microgrids. They provide a high level of certainty regarding electricity demand and have a very predictable and flat load profile for which it is easy to design a power supply [67]. They do require a high level of reliability, but considering their current energy costs, would likely be willing to pay a premium for it. They are expected to have a high payment morality and new off-grid BTS sites are being installed everyday.

Given the rapid rate at which new BTS sites are being established [65], it is likely that they will be reliable longer-term customers.

Rural industries such as mineral extraction and agro-processing facilities are also potential anchor customers. These customers typically have substantial electricity demand and, provided they are operating at a profit and rely on electricity for their operations, should exhibit good payment morality. However, they are also more likely to have challenging load profiles with significant variability and intermittency. This may result in higher cost power supply systems. Furthermore, relying on temporary anchors customers like mines, may create a risk to the microgrid, as they are designed around the energy needs of the anchor. Failure of the anchor typically leads to failure of the microgrid. The use of multiple anchors can mitigate this risk.

Public service buildings can also serve as anchors but they typically do not require large amounts of power. Typical loads at schools, for example, may include lighting, a few computers, and perhaps some audio-visual equipment. While loads from schools, health clinics, and administrative offices consume more energy than households and generate daytime demand that complements residential morning and evening peaks, they are not likely to be substantial anchors. Heating and air conditioning loads, while not common in many rural developing country contexts, could represent a significant load. In any case, the existence of such infrastructure is a positive attribute for a potential microgrid site.

Regardless of the presence of an anchor customer, the largest proportion of customers in a microgrid is likely to be households. Households are generally low-demand customers. Particularly after first connection, households do not possess many electrical appliances and the upfront investment required to obtain them is a barrier to increased electricity demand. Many companies offering solar home systems in off-grid areas on a fee-for-service or microfinance basis have bundled the most desired appliances with their systems. This enables customers to obtain greater utility from their systems and also allows companies to upsell clients to larger systems that can power telecommunications and sound systems. Microgrid operators could stimulate demand on a microgrid in a similar manner [26]. As discussed in Section 3.1, the offer of microfinance to fund connection costs can help overcome barriers related to upfront costs. Providing microfinance for both connection costs and appliances simultaneously has the potential to stimulate greater electricity demand in the residential and small enterprise sector.

Providing assistance to community members to invest in and benefit from the productive use of electricity can also generate demand and increase the affordability of electricity to customers [26]. This requires strong integration with the community and a good understanding of community needs. Potential projects include electric mills, water pumping, workshops, and irrigation. Income-generating activities are particularly appropriate as they increase the ability of customers to pay for electricity.

3.3. Microgrid revenue models

Securing predictable long-term revenue streams is a key determinant of microgrid success. The previous section described different strategies employed to establish demand for electricity. The importance of securing demand stems from the assumption that revenue and electricity demand are closely tied, as is the case in the metered business models used by traditional utilities. The coupling of revenue and demand however, depends on the revenue model microgrid operators adopt. Several private microgrid operators have implemented tariffs based on access to services such as lighting and charging rather than consumption of kWhs. This section reviews several microgrid revenue models followed by a brief overview of revenue collection systems and

![Revenue Models](image)

**Fig. 3.** Overview of tariff and revenue collection models.
technologies. Fig. 3 summarizes the tariff and revenue collection models that are discussed.

Perhaps the lowest risk model for microgrid operators is the sale of electricity to a reliable third party under a long-term PPA. This third party, most often a state subsidized utility, will then retain the power to end-users. PPAs have traditionally been used to encourage private electricity generation in a grid-connected setting. IPPs are privately owned and operated electricity generators who sell power under a PPA to either an electricity trader, an electricity distributor, or directly to an end user. When a public entity is offering the PPA, the payment received by the IPP for each unit of energy delivered is called a feed-in tariff (FIT).

Several countries have attempted to attract IPPs to generate electricity under a PPA to feed into existing utility-owned microgrids. These grids are typically powered at great expense by diesel generators. Current prices for renewable energy such as wind and photovoltaic power can be significantly lower than the cost of diesel generation depending on local energy resources. Although the generation capacities required for these microgrids are much lower than those required for systems connected to the main grid, a price premium is often offered for generators on microgrids. Kenya, for example, offers $0.12/kWh of electricity generated using solar PV technology for a system connected to the main grid but $0.20/kWh for systems connecting to microgrids [68]. Tanzania also offers significantly higher rates for IPPs feeding into microgrids [69].

However, it is not just the FIT that is important in attracting private sector investors. The counterparty to these agreements must be ‘bankable’ and there must be long-term certainty regarding tariffs to ensure that the project will produce a reasonable return on investment. As an example, Tanzania offers PPAs to IPPs on different terms for generators linked to the main grid and isolated microgrids. A major shortcoming of the Tanzanian standardized PPA is that, in the event that isolated microgrids are connected to the main grid, PPAs for IPPs feeding into microgrids will be terminated and given the option to sign a new PPA under the terms and tariffs for grid-connected systems [62,70]. The low tariff for grid-connected systems is not viable for most renewable energy projects. The risk that the main grid may arrive before the project is fully amortized is likely to prevent would-be project developers from securing debt finance.

Another important attribute of the PPA is the duration of the agreement, which should be at least as long as the debt tenor. In the case of renewable energy projects, such as wind and solar photovoltaic power, this is typically 15 years or more due to the capital-intensive nature of these technologies. Having standardized documents setting out the terms and conditions for IPPs and clearly defined processes for the development, approval, and interconnection of these generators can greatly reduce the transaction cost of these projects as well. Transaction costs can be a major barrier for small projects where these costs may represent a significant portion of the total project development and capital cost.

The limited size of microgrid loads also creates the possibility that at times the full power being produced by an embedded renewable energy IPP might not be required or would cause conventional generators to operate below minimum load factors. In this case, these renewable energy generators might be required to curtail their output. Project investors and financiers will therefore likely insist that the IPP be compensated even for energy that is curtailed to de-risk the project from uncertainties related to electricity demand. This risk is particularly important to mitigate in microgrids that are fully owned and operated by private companies. In such instances, risks related to electricity demand on the system fall entirely on the owner of the microgrid. To eliminate this risk and encourage investment in microgrids that are entirely owned and operated by the private sector, Rwanda has embarked on an innovative pilot project that offers privately operated projects compensation based on the availability of power on the microgrid. The detailed terms of the arrangement have not yet been made public, but based on pre-qualification documents released by Rwanda’s public utility Rwanda Energy Group (REG), the microgrids will be owned and operated privately but the power will be purchased and retailed to consumers by REG [71]. This relieves the microgrid operator of risks related to demand and the complexity of setting up revenue collection systems. Furthermore, REG will retail the electricity to consumers at the regulated tariff, thereby providing microgrid customers access to subsidies afforded to grid-connected consumers. Public subsidies of electricity are significant in Rwanda where the costs of generating and delivering a kWh of electricity are currently 200 Rwf (US$0.29) and the current retail tariff is 134 Rwf (US$0.20) [72]. While this system increases the cost of public subsidization of electricity, it does provide equal access to such subsidies to the so-called “geographically disadvantaged” [28].

Most often, long-term PPAs with a third-party retailer have not been available to privately owned and operated microgrids. For microgrids that retail electricity directly to end users, there are various revenue models that have been explored to meet the needs of both consumers and microgrid operators. Tariff models typically fall into two categories: tariffs based on energy consumption and tariffs based on maximum power consumption. There are arguments for the appropriateness of both revenue models. Energy-based tariffs could be seen as more equitable. Those who consume the most electricity pay the most. Others have observed that the predictability of a fixed monthly rate for a connection limited by the amount of power that can be drawn makes it easier for consumers to budget their limited incomes. Furthermore, it has been argued that fixed tariffs are more appropriate for microgrids because the cost structure of microgrids is largely composed of fixed costs [48].

Fixed monthly payments can be based on the demand from a certain number of appliances, most often light bulbs, or on a maximum allowable power draw from the microgrid. Microgrids with tariffs based on maximum power consumption often enforce this policy by installing load limiting devices that disconnect the customer when their demand exceeds the limit to which they have subscribed [38,73]. In the absence of a physical limitation on power consumption, some microgrid operators have instituted strict penalties for those found to have installed unauthorized appliances that exceed their allotted power [38]. With such an arrangement, customers are limited in how they can use the microgrid, but are not limited in how long they can use it. This revenue model may be less appropriate for microgrids powered by operating expense-intensive generation technologies, such as diesel generators, for which operating cost is closely tied to the amount of electricity generated. Higher than anticipated electricity consumption in a diesel powered microgrid using fixed tariffs could result in revenues that are insufficient to meet operating costs. However, with a capital-intensive generator such as a solar array, the operating cost is not related to the electricity produced but rather the installed generation capacity.

The more traditional tariff structure is based on the number of kWh consumed by the customer. This system requires the installation of electricity meters, which increases the cost of connections. Energy consumption-based tariffs can use either prepaid or postpaid revenue collection systems. The literature emphasizes the need for tariffs that can at least recover the cost of operation while remaining as affordable as possible [48]. Keeping tariffs at affordable but sustainable levels permits broader access to energy services within communities. Having more customers spreads fixed costs among a larger pool. Microgrid operators seeking to
maximize their return must strike a balance between higher tariffs and a larger customer base.

Lessons can also be learned from fee-for-service solar home system companies. Most of these companies charge a flat rate for their services because their cost structure consists almost entirely of fixed costs associated with financing hardware, providing maintenance, and customer services. Microgrids, particularly those relying on renewable energy, also have high fixed costs. The potential for demand falling short of expectations presents a significant risk for microgrids with high fixed costs. A revenue model similar to that of solar home systems may be appropriate while still permitting user access to electricity services without consumption limitations.

A hybrid revenue model where customers pay a fixed monthly charge that permits the use of a fixed amount of kWhs per month, with excess consumption charged at an energy based tariff, would ensure that fixed costs are met. At the same time, it would ensure that those who consume less do not subsidize more energy-intensive customers. As previously discussed, basic electrical appliances can be financed and bundled into this monthly charge to ensure that consumers have the equipment needed to benefit from the basic electricity allowance.

Regardless of the revenue model employed, revenue collection can be a financial, technical, and logistical challenge in remote rural areas. Prepaid meters have become increasingly popular even in grid-connected settings [74,75]. In such a system, revenues are collected prior to consumption and customers are disconnected automatically when their credit is exhausted. These meters reduce the cost and complexity of billing and revenue collection and allow customers to avoid consuming more electricity than they can afford [76]. Experience from Peru has shown about a 66% reduction in revenue collection costs using prepayment meters over traditional revenue collection methods. While prepaid meters are more expensive than traditional meters, the operational cost savings were found to pay for the increased cost of meters in 5 years [77].

Community participation has also been found to be crucial to maintaining high collection rates and good payment morality. Cooperatives and projects involving local community committees have shown significantly higher payment rates and lower incidences of electricity theft. In some cases, community management has provided a reduction in electricity theft from as high as 35% down to 15% and settlement of accounts in arrears for up to 5 years [7].

Regardless of the payment method, seasonal income patterns will inevitably create problems for consumers in some regions. The World Bank’s Energy Sector Management Assistance Program (ESMAP) advises that flexible payment options be adopted for those who do not receive regular incomes. This can take several forms, including large prepayments when seasonal incomes are received or less frequent collection of payment designed to correspond with influxes of income such as after harvests [38]. Some energy service companies in East Africa that operate solar home system services allow systems to be paid off over a number of years and permit users a fixed grace period during a year to accommodate customers with cash flow problems. Customers who are in a grace period have their services disconnected remotely through the mobile phone network. If the grace period becomes exhausted, the system is repossessed. This is an undesirable result for both the service provider and the customer because collection of systems located in rural areas represents a significant cost.

The remote disconnection of service described in the previous example is possible through the integration of mobile communication chips into the solar home system hardware, which permits communication with the device via the mobile phone network. Such technology could also be integrated into microgrids so that users that have not paid for their service can be disconnected without the need for a technician to go to the premises and manually disconnect service. Furthermore, mobile money systems, which began in Kenya and are now growing in popularity around the world, can be used to collect payments through mobile money transfers [77–79]. A portion of each transaction will go to mobile network operators as a service fee. This service fee not-withstanding, acceptance and uptake of the technology can simplify revenue collection by leveraging existing mobile network payment infrastructure. Mobile payment paired with remote disconnection through the mobile network can vastly reduce the complexity of revenue collection. Mobisol, for example, provides electricity services through solar home systems ranging in size from 15 W to 200 W [77]. Using a mobile connection, Mobisol can monitor customer use of electricity and system performance, and remotely unlock systems for use after payment. Remote monitoring of system performance permits remote diagnosis of technical issues and fast response for maintenance and repairs [79]. Such a system, of course, necessitates the existence of a mobile network that offers mobile money services at the microgrid site.

### 3.4. Institutional models

The effective design and implementation of any rural electrification program depends on the existence of effective institutions. According to Irwin [47], institutions are “the set of rules governing decision making” and includes “who is involved in making which decisions, who has the right to be consulted and make recommendations to the decision makers, what justifications must the decision makers provide about the decision, what monitoring of the results of the decision must be undertaken.” Institutional structures for rural electrification will typically include government ministries for finance and energy, regulators, private sector actors (including developers, investors, technology providers, and lenders), multilateral institutions, non-governmental organizations, donors, and community representatives. Effective institutional structures must ensure that decision makers have positive incentives to make good decisions. This means establishing accountability, avoiding conflicts of interest, and ensuring that decision makers have access to the information required to make good decisions [47].

Overly complex, opaque, or poorly defined institutional structures can be a significant barrier to private sector participation. Overlapping and conflicting institutional functions and poor inter-agency coordination can make the institutional landscape difficult and expensive to navigate for project developers [19]. The results are higher transaction costs, more red tape, and often the deterrence of any private sector investment. This has led to many countries developing dedicated rural electrification agencies that are tasked to be a central point of contact for electrification activities and to enforce regulations.

Gridded electricity distribution is a natural monopoly [14]. Given that the purpose of electrification is often to enhance livelihoods and social welfare at the bottom of the pyramid, public support is generally required to make electricity services affordable to the poor in developing countries. As such, effective regulation of the electricity industry, and rural electrification activities in particular, is essential. The role of the regulator is to create an environment that both promotes investment and protects the public interest. This is a delicate balance that is prone to political interference. Common regulatory functions are tariff setting, granting licenses, guaranteeing service quality through enforcement of standards, and providing a forum for complaints [80].

Tariff setting is one of the most crucial roles that regulators play because the tariffs that microgrid operators are permitted to charge their customers lies at the heart of project profitability. In many jurisdictions, small generators, including microgrids, are exempt from tariff regulation and are permitted to fix their own tariffs.
tariffs or to do so in consultation with the local community [80]. Where exemptions do not exist, microgrids are sometimes subject to blanket tariff regulations that apply to all electricity distributors. These tariffs are generally designed for large utilities that are often state-owned and benefit from public subsidies. While such tariffs promote equitable energy costs nationally, they are not well adapted to microgrid cost structures that are often much higher than grid-based electricity on a per unit basis. Without some sort of subsidization, these tariffs will most often render microgrid projects unviable.

Other regulators make tariff decisions on a case-by-case basis. A “cost plus” model is frequently employed to ensure that investors are able to cover their costs plus a reasonable return [51]. The definition of a reasonable return is left to the regulator but should balance affordability, recognition of the opportunity costs incurred and risks carried by the microgrid investor. Cost plus models can also be tied to subsidies where tariffs are fixed below cost for social reasons. In such a case, the regulator will determine subsidies based on a fixed target return for the microgrid owner. Such a model comes with an administrative burden due to requirements for project operators to furnish detailed financial information that regulators must assess in determining subsidies. It also reduces operator incentive to control cost because a fixed return is guaranteed [51].

Regulators are also commonly tasked with adjudicating applications for electricity generation and distribution licenses. Licensing requirements are meant to ensure that service companies provide a minimum level of service quality and consumer protection. Overly stringent licensing requirements can create large administrative burdens on private operators and increase transaction costs that operators will attempt to pass on to customers. The role of the regulator is to strike a balance between protecting the interests of investors and consumers [80]. These requirements are typically very context-specific and no general prescriptions can be offered.

The creation and enforcement of standards also often falls to regulatory agencies. These standards are meant to ensure service quality and safety. The World Bank advises against over-regulation of microgrids and advocates the use of different standards on the basis of system size, with the smallest systems being required only to register and file annual reports [10]. The regulator must find a balance between ensuring quality service and minimizing costs. If it is envisioned that in the future microgrids will be integrated with a larger grid, standards should ensure compatibility to avoid costs related to infrastructure that must be replaced or upgraded.

Finally, policy makers also have a role in creating an environment conducive to the development of business and industry that supports electrification activities. In many developing countries, the equipment and skills required to implement rural electrification projects are not available locally in sufficient quantity or quality [59,81]. Importation of equipment and hiring of foreign consultants adds cost and complexity to electrification projects, including microgrid-based projects [16]. Steady and predictable investment in electrification activities stimulates the development of local supply chains and skilled labor, which in turn reduces prices and transaction costs. However, supply chains and pools of labor take time to develop and will only take hold when steady investment takes place. This requires a steady flow of funds to projects. Further, institutions of vocational and higher education tied to programs that prevent “brain drain” can also support electricity access and should be a priority for governments.

4. Discussion and future work

Active participation and investment from private sector actors are essential if ambitious goals to expand access to electricity in the developing world are to be achieved. Decentralized microgrid-based projects will play an important role in ensuring that people who are far from the grid are not left waiting in the dark for decades to come. As it stands, microgrid electrification projects are not attractive opportunities for the private sector due to high levels of risk and potentially low returns. Unlocking this investment will require innovation on the part of businesses, carefully designed policies as well as incentive programs from the public sector and donor community.

Innovative entrepreneurs will need to find ways to secure reliable revenue streams while minimizing costs. Several opportunities exist including the leveraging of anchor clients such as off-grid cell phone towers, decoupling revenue and demand with service based models, and providing microfinance to households and small businesses to purchase electrical appliances.

The objectives of electrification are often social in nature, providing a strong justification for public sector intervention and subsidization. Many subsidy models have been proposed and implemented. Capital subsidies have traditionally been viewed as more sustainable than subsidies on operating costs. Output-based subsidies acting as both capital and operating subsidies have the ability to tie subsidies to performance and specific policy objectives. Long-term power purchase agreements between private operators and public utilities also have the potential to mitigate risks and extend public grid-based subsidies to rural electricity consumers. As has been proposed in Rwanda, private operators can own and operate decentralized grids while selling the power to the state-owned utility that retails the electricity using existing prepaid electricity systems and distribution channels.

Even with a strong subsidy program that improves the profitability of decentralized electrification projects, developers are often unable to secure the required financing to realize the project. Risk averse lenders that are often unfamiliar with and unable to assess the merits of such projects may require guarantees from a third party. This may come in the form of a loan guarantee from a government or a partial risk guarantee from an organization such as the World Bank. Direct lending from governments and development finance institutions at concessionary rates can address this problem as well.

The allocation of rural electrification concessions has had success in South America in encouraging private sector-based electrification, although not necessarily through microgrids. Concessions provide private operators with protection from competition in the medium to long-term. These have often been accompanied by subsidies or have been attached to more attractive urban concessions.

Strong and effective institutions and policy must support all of these public interventions. Ineffective institutions unnecessarily increase transaction costs and lead times, which could deter investment entirely. A common policy barrier that must be overcome is a blanket electricity tariff cap that renders private projects unviable without access to the same subsidies received by distributors on the central grid.

There is still a lot of work that can be done to reduce uncertainties in microgrid business models and better understand ways that government and the donor community can support sustainable private sector electrification projects. More work needs to be done to understand the way that rural populations use electricity after first receiving access and how this behavior evolves over time. Uncertainty about electricity demand remains a major challenge in building strong business cases for privately operated microgrids. A greater understanding of factors influencing rural electricity demand and how rural consumers respond to price and different tariff schemes would greatly improve the ability of potential project developers to meet the needs of rural consumers and create sustainable and bankable projects.
Additionally, very little quantitative work has been completed to date to understand the comparative costs and benefits of the public interventions described in this paper and how these interventions affect the risks and returns faced by private sector investors in microgrid electrification projects. In order to ensure that limited public and donor funds are allocated in the most cost effective manner, more work is needed to quantify the risks and benefits of the various support measures that could be pursued. All of the above mentioned challenges have to be addressed in a collective manner. Only after that will it be possible to use the untapped energy resources in developing countries. Large masses will be energized with microgrids that rely on the distributed energy resources and operate in a sustainable and reliable manner.

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