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Journal of Urban Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjut20

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To cite this article: Emmanuelle Guillou & Bérénice Girard (2022): Mini-Grids at the Interface: The Deployment of Mini-Grids in Urbanizing Localities of the Global South, Journal of Urban Technology, DOI: 10.1080/10630732.2022.2087170

To link to this article: https://doi.org/10.1080/10630732.2022.2087170

Published online: 01 Aug 2022.

JOURNAL OF URBAN TECHNOLOGY
https://doi.org/10.1080/10630732.2022.2087170

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Mini-Grids at the Interface: The Deployment of Mini-Grids in Urbanizing Localities of the Global South

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ABSTRACT

Based on fieldwork conducted in Senegal, Tanzania, and India, this article argues for a territorialized approach to mini-grids. One of the most sought-after solutions to electrification and transition to renewable energies in the Global South, mini-grids can be defined as decentralized collective systems of electricity supply. Whereas the academic and grey literature has mostly focused on their presence in rural areas, this paper looks at their development in urbanizing localities. It documents access to electrical service in these spaces and shows that, behind the rather uniform vision associated with the mini-grid object, the service provided takes different forms depending on the environment in which it is deployed. The presence of mini-grids also raises issues of social and territorial equity of access to essential services. A territorialized approach to mini-grids, therefore, furthers our understanding of the complex energy changes at work in cities of the Global South.

KEYWORDS

Mini-grids; urbanization; essential services; Senegal; Tanzania; India

Mini-grids have become, in recent decades, one of the most sought-after solutions to electrification and transition to renewable energies in the global South. Due to the diversity of mini-grids in terms of technology, capacity, or business model, various definitions are available. In this article we define mini-grids as decentralized collective systems of electricity supply that can operate autonomously or can connect to the grid. They combine generation and distribution, while eliminating the "transmission" dimension present in the conventional grid. Mini-grids are indeed usually deployed locally, with a limited production capacity and a reduced number of users.

The literature on mini-grids in the Global South usually underlines their flexibility, local generation capacity, and use of renewable energies (Berthélémy, 2016; GVEP International, 2011). Mini-grids are also often compared positively to off-grid individual solutions, such as solar home systems, as they allow for productive uses (Peters et al., 2019). They are thus often seen as suitable solutions to combine electrification, economic development, and energy transition objectives (Odarno et al., 2017). The assumption that

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

mini-grids are first and foremost relevant options for the electrification of rural isolated and unelectrified areas of the Global South is rarely questioned by the academic and grey literature, which either focuses on these areas or overlooks the geographical dimension to focus on other aspects, such as financial viability, social acceptability, etc.

This paper calls for a territorialized approach to mini-grids and proposes an observation point for their deployment that has not been studied much so far: urbanizing localities. These localities have diverse administrative status, but share a common dynamic of rapid urbanization, with increasing population density and an expanding economy. They are at the interface between the rural and the urban and face a lack of access to essential services. Our fieldwork shows that mini-grids deploy rapidly in these localities.

We argue that this deployment is driven by the growing numbers of private actors involved in the off-grid electricity sector in the Global South. The literature on mini-grids has often underlined the lack of financial viability as one of the biggest challenges facing mini-grids (GVEP International, 2011; Payen et al., 2016: Bhattacharyya and Palit, 2016; Peters et al., 2019). It is especially a key issue for private operators who run mini-grids on a commercial basis. For these operators, urbanizing localities are particularly attractive, as they usually combine poor quality essential services, a dynamic economy, and a customer base whose practices are becoming more energy-intensive.

Second, following an emerging body of work on the everyday operations of mini-grids and on their impact on local political and social dynamics (Berthélémy, 2016; Balls and Fischer, 2019; Kumar, 2021), we argue that mini-grids contribute to the development of these transitional spaces and also reveal their specific evolutions at the intersection of the urban and the rural. We decipher how operators adapt their mini-grids to local contexts and discuss how the mini-grids contribute to redefine market and social relations.

Thus, a territorialized approach to mini-grids enables both a more fine-grained understanding of the deployment of mini-grids in countries of the Global South (spatial distribution, operation, impact on local social and economic dynamics) and a better understanding of the complex energy changes at work in the cities of the Global South.

Our analysis is based on several months of fieldwork carried out in three countries that are very diverse in terms of geography, demography, and electrification policy, as well as in terms of degree of extension of the conventional grid: India, Tanzania, and Senegal. However, we will see that a cross-analysis of the electrification of urbanizing localities by mini-grids in these three countries highlights many points of convergence.

This article comprises four sections. A first section examines and discusses the literature on mini-grids in the Global South and on urbanizing localities, while a second section presents our methodology. In a third section, we introduce the diversity of mini-grids and localities studied and analyze the drivers behind many private operators' preference for urbanizing localities. In a fourth section, we discuss how operators adapt their mini-grids to the specificities of these localities, but also how mini-grids can affect local social, economic, and political dynamics. In conclusion, we highlight some of the paradoxes that the deployment of mini-grids in these spaces brings to the fore.

Analytical Framework

The starting point of this article is to apprehend critically the mini-grid object as it is presented in the literature on the Global South. We will see that most works favor a rather

homogeneous (modern, high-tech, renewable energy-based) and a-territorialized vision of mini-grids. We believe that a more holistic and territorialized approach can help us better grasp their wide technical and managerial diversity and challenge the one-size-fits-all view often associated with the provision of electricity through these solutions. In the second part of this section, we will more specifically seek to territorialize the study of mini-grids by characterizing one of their preferred areas of deployment: we refer to them as "urbanizing localities."

Towards a More Holistic and Territorialized Approach to Mini-Grids

The recent dynamics observed in the field of electrification in the Global South suggest that the contribution of mini-grids cannot be ignored. According to the International Energy Agency (2017, quoted in Balls and Fischer, 2019), more than a third of non-electrified households in countries of the South will be electrified thanks to these decentralized solutions. However, academic works on these off-grid solutions remain rather sparse,[1] while the grey literature, which is more extensive, tends to focus only on recently developed, renewable energy-based mini-grids, designed for non-electrified rural areas. We advocate for both a more holistic and a more territorialized approach.

First, mini-grids are often presented as recently implemented solutions that have, since the early 2000s, attracted the interest of governments and international investors (Berthélémy, 2016; GVEP International, 2011; Graber et al., 2018). This view focuses only on mini-grids developed by public action, often through international development programs, or by private entrepreneurs and start-ups, often from the Global North, who have recently invested in the sector. In this understanding, the use of the term "mini-grid" is generally limited to high-tech and renewable energy-based systems. It does not reflect the diversity we witness in the field. Be it in Tanzania or in India, we could indeed observe both recent and high-tech mini-grids and decades old ones, sometimes based on renewable energies such as small hydro, but also often fueled by diesel or other very polluting sources of energy.[2] The existence of this "first-generation of mini-grids" has sometimes been acknowledged by the literature, though only a few works include them in their general analysis of the role of decentralized energy access systems in the Global South (IRENA, 2016; PwC, 2016; Odarno et al., 2017; Kumar, 2021; Szakonyi and Urpelainen, 2015). We thus advocate for the need to take all forms of mini-grids into consideration to understand the nature, structure, and evolution of local electricity supply systems. Szakonyi and Urpelainen (2016) for instance show how the managers of diesel mini-grids in a market in Patna, Bihar, were able to prevent the development of a solar-based lighting solution for vendors that would have jeopardized their business.

Second, the literature tends to create a narrative in which mini-grids are first and foremost options for providing electricity to isolated communities that have been left out of the national electricity grid (Ulsrud et al., 2011) and neglected by national energy policies (PwC, 2016). While Payen, Bordeleau, and Young (2016) point out that mini-grids have a long history as solutions for electrifying rural and remote island communities out of the reach of the main grid, a FONDEM (2019) publication deliberately chooses to focus its study on rural electrification in sub-Saharan African countries, due to the low number of works on this subject. It considers mini-grids as "the most satisfactory solution" to

electrify all the members of a rural community simultaneously and cover their needs (FONDEM, 2019: 332). Two recent exceptions should however be noted. Sharma, Agrawal, and Urpelainen (2020) analyze the role of mini-grids in grid-electrified villages in India. As for Jacquemot and Reboulet (2017), they focus their analysis on mini-grids installed in towns of 2,000 to 5,000 inhabitants or more, in Mali and Madagascar. They describe how these mini-grids, with capacities ranging from 10kW to 10MW, sometimes connect several localities. Similarly, our observations show a concentration of mini-grids in areas that may be considered rural from an administrative point of view, but which in fact have the characteristics of territories undergoing urbanization (density, demography, built environment, nature and intensity of economic activities, etc.).

Third, the issue of the financial viability of mini-grids has garnered some scientific interest (Bhattacharyya, 2018). If we adopt Kariuki and Schwartz's (2005: 37) typology of small-scale service providers, we can distinguish four main types of mini-grids: (1) mini-grids established by private "individuals/entrepreneurs" which are run on a commercial basis, (2) mini-grids established by "user associations or self-help groups," which are "not always managed on a commercial basis," (3) mini-grids initiated by "government" and "managed on a commercial basis," and, finally (4) community-based schemes, "not managed on a commercial basis." This diversity of operators, associated with a plurality of technologies and service offers, implies the adoption of models mobilizing diverse resources, motivations, and objectives. The literature has underlined the growing number of private operators in the off-grid electricity sector (FONDEM, 2019). These actors, when running mini-grids on a commercial basis, require a financially viable model, which has consequences for the nature, location, and recipients of the services thus designed. This includes creating productive and income-generating activities around the mini-grids. The authors of the IRENA report (2016) also highlight the need to rely on innovative technologies and business models (see also Bhattacharyya and Palit, 2016). In this article, while we do not deny the existence of community or associative models of electricity supply through mini-grids, nor the existence of social entrepreneurs committed to electrify isolated rural areas, we argue that, for a growing number of private operators who run commercial mini-grids, the need to make mini-grids financially sustainable acts as an incentive to move closer to economically attractive areas, such as the ones on which we focus in this article (FONDEM, 2019).

Urbanizing Localities: Official Classifications and Their Impact on Essential Services

From India to Tanzania and Senegal, the areas under study are diverse in terms of physical and geographical characteristics, demographics, and density, but they all share specific socioeconomic and functional aspects, which make them attractive markets for mini-grid developers. We group them under the term "urbanizing localities."

We found that there is little to no literature on mini-grids in those spaces. Similarly, research in the field of urban studies is struggling to reach a consensual definition of these in-between areas (Bogaert and Halleux, 2015). In 1994, Mouafo (1994) hypothesized that this difficulty reflects the diversity of processes at work, which vary greatly depending on the context. For other authors (Pélissier, 2000; Tacoli, 1998; Simon et al., 2004, Halleux, 2015; Denis and Zérah, 2017), the explanation lies in the limited attention paid to these

interface territories (Pélissier, 2000), contrary to the abundance of publications on large cities, or on the dynamics specific to rural territories. The urban–rural dichotomy has, however, long ceased to have much meaning in the Global South (Simon et al., 2004) and, over the last few decades, the multiplication of so-called secondary urban centers (Pélissier, 2000), the phenomena of over-densification of the countryside (Harre et al., 2015), and the expansion of peripheral areas of large cities, have emphasized the need to pay attention to these mixed environments that are no longer rural and that, for some, will never become cities in the classical sense of the term (Halleux, 2015). Numerous works in urban studies have aimed at characterizing these particular spaces. In 2019, Steel et al. defined peri-urban areas as transition zones between urban and rural territories, presenting a strong heterogeneity in terms of land use and building forms, population densities, or pressure on land resources (Steel et al., 2019). For Mukhopadhyay, Zérah, and Denis (2020: 1), the process of urbanization does not only affect the outskirts of large cities, but also spaces "outside the metropolitan shadow," through a process they call "subaltern urbanization." The authors use the case of India to characterize the "autonomous growth" of these settlements, which develop independently of large agglomerations, planned cities, and industrial towns (Denis et al., 2012: 52). They underline how these settlements "provide potential access to jobs and resources" and are places where processes of "diversification of sources of income or occupational pluralism" can be observed (Mukhopadhyay et al., 2020: 8). As for Gururani and Kennedy (2021: para 1), they talk about "urban peripheries" to describe the diversity and heterogeneousness of "forms of extended urbanization" in India. They underline how these peripheries are "key sites of contestation, social exclusion, and speculation but . . . have also come to embody hope and aspirations for diverse social groups" (Gururani and Kennedy, 2021: para 1). These peripheries are often attractive to investors due to "their relatively cheaper land and under-regulated governance regimes" (Gururani and Kennedy, 2021: para 8). In their work on emerging urban centers in Tanzania, Lazaro et al. (2019) suggest that the villagization policy conducted in the 1960s and 1970s, followed by the liberalization of markets which became widespread from the 1990s, favored the development of many villages located away from major urban centers, which gradually became small urban centers, real hubs for employment, trade, and access to services.

Despite their crucial role in ongoing urbanization processes and their rapid demographic growth, these urbanizing areas are often still not recognized as such by censuses and, therefore, fall into a grey area of public action. In India, as in sub-Saharan Africa, the relevant administrative division remains that of the urban-rural dichotomy. Consequently, and depending on the context, emerging urban spaces fall artificially into one or another of these categories. While in Bihar, Jan van Duijne (2019) uses the term "hidden urbanization" to describe urban growth ignored by official statistics, in Sudan, Steel et al. (2019) report that many peri-urban areas are recorded as villages. In Tanzania, Muzzini and Lindeboom (2008) suggest that the urbanization rate would probably be higher if the urban-rural distinction was updated and rid of biased administrative definitions that pay little attention to density criteria. It is also interesting to note that the terms "urban," "peri-urban," and "urban fringe" are often not recognized by the majority of the inhabitants of these spaces, for whom the village remains the relevant category of belonging, even long after the locality has been absorbed by the city (Simon et al., 2004).

This gap between the rapid development of urbanizing localities and their recognition by official authorities has a strong impact on the development of essential services, as urban or rural classification often presides over modes of governance, capital flows, and regulations. In India for instance, Denis and Zérah (2017) show how a classification as "rural" signifies greater autonomy in land use and lower taxes, but also lower access to funding for networked services. More generally, Cailly (2011) argues that the vast majority of peri-urban municipalities have a rural status and do not have the means to meet the ever-increasing needs of their populations and provide them with the facilities made necessary by rapid urbanization. Even if these localities will eventually be granted urban status, Raman et al. (2015) point out that the revision process is long and tedious, pushing back the deadline for access to urban services.

Many researchers have thus highlighted the lack or even absence of urban facilities and access to basic services in emerging urban territories (see e.g., Fall et al., 2008; Botton and Blanc, 2014; Mpiana Tshitenge, 2015; Andreasen and Møller-Jensen, 2016). This situation creates opportunities for a diversity of more or less formal private providers offering a plurality of more or less efficient and more or less affordable services. Though several studies have focused on small-scale operators providing water, sanitation, or solid waste management in these localities (see for instance Botton and Blanc, 2014; Xess and Zerah, 2017), electricity access and services have largely been ignored, as they are usually considered the purview of regional or national governments. In this respect, this article contributes to a better understanding of the complex energy changes at work in these areas and their related social and economic dynamics.

Methodology

This article is the result of two separate research studies, one focusing on India, and more specifically on the state of Bihar, and the other on two sub-Saharan African countries, Senegal and Tanzania. In Bihar, the study looked at the dynamics of the local market for electricity in different urban and urbanizing localities. In Senegal and Tanzania, the study focused on mini-grids developed by small-scale private operators. It appeared that these were mostly present in urbanizing localities. Despite these two distinct approaches to the field, both studies share the same overall methodological approach and common analytical criteria. In March 2021, one more fieldwork was conducted in the state of Uttar Pradesh in India. (See Table 1.)

In all cases, the fieldwork methodology made extensive use of the technique of—often repeated—qualitative interviews, with institutional actors at the local, regional, and central levels, elected officials, entrepreneurs, and international technical and financial partners, as well as with mini-grid operators. Most of these interviews were conducted face-to-face, some by phone, and depending on the context, a recording device was used or notes were taken. In addition, each researcher had numerous and diverse types of interactions with households and shopkeepers (informal discussions, semi-directed interviews). The objective of these interactions was to find out more about the customers of the mini-grids and their motivations (domestic uses, small businesses, productive uses). Finally, a substantial part of the fieldwork in Senegal and Tanzania consisted of following the mini-grid operators during their working days. This immersion made it possible to sweep quite a large number of villages, types of mini-grids, or

Table 1. Presentation of the empirical studies

	Senegal (Kaolack region)	Tanzania (Arusha region)	India (District of Bhagalpur, Bihar)	India (District of Kushinagar, Uttar Pradesh)
Period of fieldwork	One 2-week and one 2-month period of fieldwork conducted between December 2018 and November 2019	One 2-week and one 2-month period of fieldwork conducted between December 2018 and November 2019	Four 2-week periods of fieldwork conducted between December 2018 and September 2019	One 10-day period fieldwork conducted in March 2021
Number of interviews conducted with stakeholders	33	27	28	16
Number of households surveyed/ interviewed	19	15	45	17 (shopkeepers)

modes of service organization, but also encouraged informal discussions with the technicians and operators about their activities, and the observation of their various interactions with users (bill collection, repair of the power plant, repair of domestic equipment, installation of prepaid meters, etc.).

Mini-Grids in Practice: An *In-Situ* Analysis of the Emergence and Sustainability of Mini-Grids in Urbanizing Localities

A Diversity of Mini-Grids

In Senegal, the mini-grids observed are all located within a radius of 50km around the town of Kaolack (1,229,000 inhabitants according to the ANSD,[3] 2021), i.e., within the town's sphere of influence (geographical, functional, and cultural proximity). Thus, although the localities connected to a mini-grid are administratively considered rural, they are located in the peri-urban area surrounding Kaolack. They have strong links with the small urban centers of 10,000 to 20,000 inhabitants (2013 census) that are part of this peri-urban area and are connected to the conventional grid. The observed mini-grids all have the same technical characteristics: hybrid mini-grids (solar and diesel) of 5kWp installed between 2013 and 2017 and serving between 20 and 60 subscribers. These mini-grids are the result of public action, insofar as the Senegalese government decides upon the capacity of the mini-grid power plants and on the localities in which the equipment will be installed according to administrative (rural areas), morphological (high population density), geographical (distance of at least 5km from the grid), or socioeconomic (high demand, economic activities) criteria. The rural electrification agency then launches calls for tenders to small private operators for the operation of mini-grid "packages" already financed and installed. Electricity sales tariffs are set by the Electricity Sector Regulatory Commission and are binding on these operators. (See Figure 1.)

In Tanzania, mini-grids have been observed in more isolated localities that act as "service centers" for surrounding villages. A significant proportion of their inhabitants are migrants who have settled there to develop a business. Due to their distance from the city, these localities have a very large number of shops (restaurants, ice-cream

Figure 1. Mini-grid observed in Senegal (Keur Madiaye Fatim)
Source: Authors

vendors), social community structures and services (guesthouses, motorcycle repair centers, pharmacies, hairdressing salons). The observed solar or hybrid (solar and diesel) mini-grids are being developed by start-ups and private transnational companies that have designed the infrastructure according to the size of the population and to allow the electrification of productive uses, a *sine qua non* condition for the profitability of the service. These operators, therefore, favor big villages with economic potential located away from the main grid. The management of the service is a commercial one, and the tariffs of electricity are set by the operator in compliance with price caps set by the sector regulatory agency. (See Figure 2.)

Figure 2. Mini-grid observed in Tanzania (Kitumbeine)
Source: Authors

In Bihar, the study focused on two urban and urbanizing localities: Sultanganj, a small market town, which has a dynamic economic activity mostly based on a yearly Hindu pilgrimage, and Akbarnagar, a large village, whose economy is based both on agriculture and on local transit. Both localities are situated within 30km from Bhagalpur, a large city of more than 500,000 inhabitants. Grid supply in Bihar has infamously been very erratic since the 1980s, though it has improved drastically in the last couple of years. As grid supply was not trustworthy for decades and most households were not connected to it, an important market for alternative solutions to access electricity developed. In both localities, we could observe diesel-fueled mini-grids run by small local entrepreneurs. More recently, Indian or international start-ups and NGOs have developed renewable energy-based mini-grids. However, none of them were active in the localities of study during our fieldwork. Most mini-grids in Bihar run in a rather gray legal zone, as the state, contrary to some of its neighbors, has not adopted a clear mini-grid policy or created funding programs, except for isolated rural areas. Most mini-grid operators thus develop their businesses without any specific agreement or support from the State. (See Figures 3a and 3b.)

In Uttar Pradesh, the study focused on localities in the district of Kushinagar, where the company Husk Power Systems installed solar or hybrid mini-grids. In most localities, we were also able either to observe diesel mini-grids run by local entrepreneurs or to interview local entrepreneurs who previously ran such mini-grids. These localities

Table 2. Presentation of the mini-grids

	Senegal (Kaolack Region)	Tanzania (Arusha Region)	India (District of Bhagalpur, Bihar)	India (District of Kushinagar, Uttar Pradesh)
Number of localities studied*	5	2	2	6
Number of inhabitants per locality	Between 700 and 2,000 inhabitants	Between 7,000 and 12,000 inhabitants	Between 30,000 and 60,000 inhabitants	Between 10,000 and 30,000 inhabitants
Number of mini-grids studied	6	5	5	7
Sources of energy used	Hybrid (solar + diesel)	Solar / Hybrid (solar + diesel) / Hydro	Diesel / Kerosene	Solar / Hybrid (Solar + biomass, solar + diesel)
Mode of financing	Mini-grid infrastructure financed by public action, mini-grid and service then managed by private operators on a commercial basis	For-profit mini-grids run by a private company	For-profit mini-grids run by small local private operators	For-profit mini-grids run by a private company
Regulatory framework	Geographical location, technical standards, management standards and tariffs regulated by the rural electrification agency and the sector regulatory agency	Technical standards, management standards and tariffs regulated by the rural electrification agency and the sector regulatory agency	No	Mini-grid policy offering exit options for operators of RE-based mini-grids. No price regulation unless subsidized by the government.

*This includes both mini-grids that were observed and mini-grids about which interviews were conducted with the company or the entrepreneur who runs/ran them.

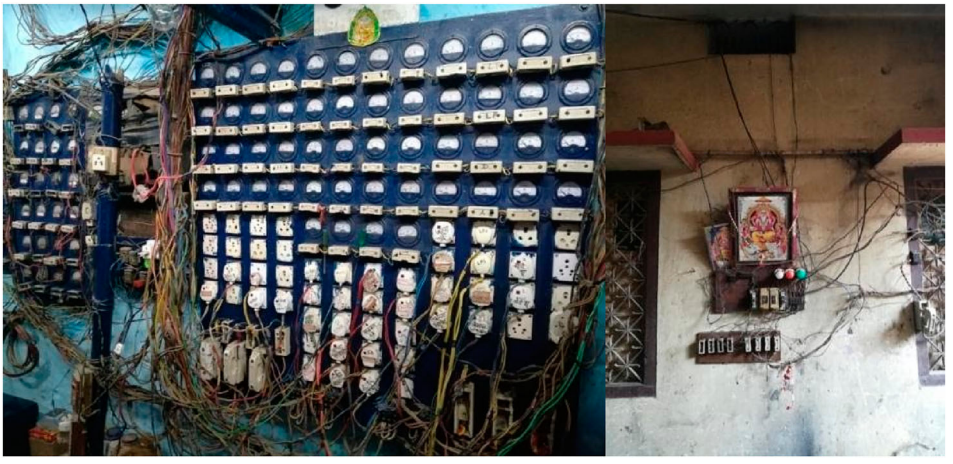

Figure 3a and 3b. Electrical installations of *Generator Wallahs* in Bihar

were either clusters of contiguous villages, large villages or small towns. We estimate that their populations vary from around 10,000 to 30,000. Most had a rural status, but some were in transition from rural to urban (Nagar Panchayat). They all had dynamic market areas, with numerous and diverse shops. In some localities, we were also able to observe small manufacturing units (carpentry, etc.). The continuing existence of agricultural activities was also often visible, especially outside the market area, through the presence of agricultural equipment, cow dung cakes, etc. The State of Uttar Pradesh introduced a mini-grid policy in 2016 that offers exit options for renewable-energy-based mini-grids. Privately-run mini-grids, which do not benefit from government subsidies, are free to set their own tariffs and choose where they install their mini-grids.

Urbanizing Localities, a Prime Location for Mini-Grids Operated by Private Operators

As mentioned before, urbanizing localities in the Global South are often places where networked utilities are either absent or (highly) defective. At the same time, these are places where people start adopting an urban lifestyle, where economic activity is diversifying, thus leading people to have more energy-intensive practices and higher expectations as regards the quality of public service they benefit from. This discrepancy between the expectations of residents and the reality of services is often being filled, in the electricity sector, by mini-grids.

Indeed, though most private companies installing commercial mini-grids advertise their role in rural electrification, their presence on the territory often tells a slightly different story. As our interviews with operators, managers, and developers show, many actually tend to favor large villages and places that, though officially rural, have economic and social dynamics which bring them closer to urban areas. These places have sometimes been selected from the outset by the operators (through an agreement with public authorities, for instance) or chosen after several attempts to set up in more isolated rural areas. Here, the example of the company Husk Power Systems,

which is active in Uttar Pradesh and Bihar, is telling. Its founders started by electrifying a few villages with biomass plants as a charitable activity, but as they moved to transform their activity into a business, they started to also target larger villages and small towns, which proved to be more viable markets for their service. Interestingly, the academic and gray literature on mini-grids has often hinted at this spatial distribution of mini-grids without really addressing it (Ulsrud et al., 2011; Sharma et al., 2020; Bhattacharyya, 2018). A notable exception can be found in the FONDEM's 2019 report on rural electrification in Africa, which mentions that mini-grid operators "logically target dynamic rural hubs and users who are likely to pay a tariff that reflects the profitability expected by investors" (FONDEM, 2019: 27). Thanks to our interviews, we were able to identify a number of usual selection criteria taken into account by the different mini-grid operators and managers we met.

A first criterion concerns the existence of a demand for the service. This includes the lack of access to grid electricity, as well as the "economic potential" of the area. On the one hand, lack of access means either the absence of the conventional grid, its failure or its unaffordability. For example, the mini-grid operators in Senegal and Tanzania explained that their feasibility studies factor in the distance of the village from the grid (the minimum acceptable distance varies between 4 and 10 km). On the other hand, economic potential refers to the presence of a potential customer base, in terms of willingness and ability to pay for the service and electricity consumption. As we have seen, these spaces act both as places where residents from rural areas can access services and shops and as "places of adjustment" for those moving away from the primary sector (Denis and Zérah, 2017: 14). They offer a concentration of diverse commercial activities (grocery stores, clothing shops, mobile phones stores, pharmacies, etc.), and often small to medium-sized manufacturing and industrial units. All these activities require reliable access to electricity. Interviews conducted with shopkeepers in Bihar and Uttar Pradesh confirmed the importance they attached to steady electricity supply. Shopkeepers were thus often ready to pay several hundred rupees per month in addition to their electricity bill from the public distribution company for a back-up service from the local mini-grid. More generally, small towns and urbanizing villages are places where people "slowly embrac[e] the habits and lifestyles of urban consumption" (Denis and Zerah, 2017: 5), including investing in electrical appliances such as refrigerators, washing machines, etc. These new habits lead to higher electricity consumption and needs. These elements are especially well apparent in this quote from the website of Husk Power Systems, which promises "reliable, low-cost AC power that matches the aspirational needs of [thei]r customers; for households, community services, small businesses and factories." Similarly, the mini-grid operators we met in Senegal and Tanzania pointed out the importance of such "economic potential" in the villages served, which was measured through different indicators such as willingness-to-pay studies or number of businesses in the village.

Interviews with mini-grid developers also revealed an important technical issue to be considered when assessing the viability of a mini-grid: density. Depending on the technology used to produce electricity, its capacity and technical specificities, a mini-grid will be able to offer good-quality service only up to a certain distance. For instance, several operators of diesel mini-grids in Bihar mentioned that beyond 500 meters, their service was not trustworthy or of quality. They thus limited their development to a

radius of 500 meters from their diesel generator to prevent complaints from customers. Mini-grid operators consequently tend to prefer high-density places, where they can find in a limited space an important number of potential customers.

A third criterion relates to accessibility and road connectivity. Rapid urbanizing spaces are often hubs for local commerce and transport. Denis and Zérah (2017) thus mention the role of government programs of road building in the development of small towns in India, as good-quality roads allowed for increased regional connectivity and renewed forms of urban–rural linkages. As such, small towns and urbanizing villages are often easier places to access for out-of-town technicians, who might have to intervene in case of a technical failure or for regular maintenance. In Senegal for instance, one of the observed mini-grids operates with batteries that require frequent refilling of distilled water by technicians based in town. In some cases, connectivity is also sought in telecommunications. A business developer in Senegal testified that one of the selection criteria was the coverage of the area by the telecommunication network to be able to use mobile money.

It is worth noting that these criteria are used not only by private operators, but also, in some countries, by electrification programs endorsed by public authorities. Thus, a program manager with a donor-funded national program in Senegal explained that the dynamism of the economic activity is key for the selection of villages. Even in cases where mini-grids are the results of local initiatives, one has to factor in the importance of being able to mobilize economic capital and of rapidly finding a suitable customer base to start and sustain the operation. Though such conditions might not be readily available in isolated rural areas, rapidly urbanizing localities and small towns are places where people might be able to mobilize capital more easily through kinship or the sale of agricultural land (Xess and Zérah, 2017; Denis and Zérah, 2017).

In conclusion, rapidly urbanizing areas tend to combine a number of socioeconomic and spatial criteria that make them particularly advantageous to private operators running mini-grids on a commercial basis. Smaller and more isolated villages tend to be excluded by such selection criteria. Mini-grids in these areas may thus often not be managed on a purely commercial basis (i.e., community-based schemes, mini-grids partly or fully-funded by international development programs or public electrification schemes, sometimes run by social enterprises, etc.). In Tanzania, for instance, community or faith-based organizations operate mini-grids without taking into account these criteria. Their objective is not to develop a commercial activity but simply to electrify the village or parish. Moreover, in the case of faith-based organizations, the service is often largely subsidized by donations, which cover maintenance and investment costs.

Discussion: Adaptation of Mini-Grids in Tense Spaces: Dynamics of Mutual Adjustment

Pursuing our objective of territorializing mini-grids and the service they provide, we now turn to how operators adapt their products and services to the socioeconomic specificities of these urbanizing localities and especially to their rapid pace of change. In return, we will also see various ways in which the presence of a mini-grid can affect urbanizing localities. Through some particularly relevant—albeit not exhaustive—examples of

mutual adaptation, our objective is to analyze how mini-grids and spatial dynamics interact.

Service Providers: Adapting Service to Changing Heterogeneous Areas

Offering a Flexible Service. We were first able to observe diverse forms of managerial and technical arrangements, and even sometimes ad-hoc bricolage, by the mini-grid operators (Bhattacharyya and Palit, 2016). By this, we mean various forms of flexibility in tariffs' definition, collection of dues, etc. Their objective is to respond to the needs of a diverse customer base, which might have an increasing energy consumption, but also fluctuating incomes, and face various challenges to access the grid.

These arrangements can be facilitated by relying on local employees, as the case of PowerGen, in Tanzania, shows. The company had initially designed its service to rely solely on mobile prepayment, in order to adapt the service to isolated areas, and to subscribers with fluctuating incomes, but it finally reintroduced in parallel the possibility for subscribers to purchase electricity credits directly from the local operator. This decision was motivated by the reluctance or lack of capacity of some subscribers to use mobile technology. The possibility of dealing directly with the local operator also made it possible for users to negotiate payment terms. Similarly, operators of diesel mini-grids in Bihar often mentioned in interviews the importance of remaining flexible when defining tariffs and collecting dues in a local economy that remains highly informal and where underemployment is widespread.

Flexibility can also be built into the mini-grid itself. For instance, in Uttar Pradesh, Husk Power Systems installs the meters of its customers on its poles. It makes it possible to bypass the landlords' permission to install a meter and also to supply electricity to street vendors. As such, Husk is able to differentiate itself from the grid by making its service offer more flexible and adapted to the socioeconomic diversity of the customer base.

Diversifying the Service Offer Around Equipment Sales. Another form of adaptation can be found in the sale on credit of electrical equipment for productive and domestic use. This reflects the adaptation of operators to rapidly changing energy practices and needs in urbanizing localities. Villagers can often buy fans, welding machines, air compressors, or milling machines. These electrical appliances are energy-efficient and solar-adapted. The sale of this type of equipment on credit accompanies the development of new industrial and commercial activities in these areas, taking into account the customers' limited ability to pay. At the same time, in contexts where the grid might arrive soon or where customers might be able to choose between different electricity-supply services, the acquisition of such equipment makes them more captive to the mini-grid, insofar as these devices are not necessarily transposable to other modes of electricity supply.

The development of electrical services is also initiating in these urbanizing areas a new concept of access to electricity, which no longer involves only the supply of energy, but also the satisfaction by the operator of a certain number of needs for energy-related services. Although this trend is not specific to the areas studied (similar dynamics can also be observed in rural areas), what is notable here is the development of a service offer

adapted to the specific needs of areas undergoing urbanization. While a mini-grid operator in Tanzania has installed Wi-Fi zones near the mini-plant, the sale on credit of equipment for industrial use (welding machines, air compressors, etc.) or commercial use (blenders, printers, etc.) reflects the operator's desire to accompany a demand that is increasingly similar to urban demand. In the locality of Kitumbeine, for example, a resident met during the survey took advantage of this opportunity to acquire a printer and a photocopier on credit, which enabled him to diversify his activity, which had previously been limited to the sale of school supplies (notebooks, pens, etc.). He explained that he had quickly attracted a local customer base that previously had to travel to the nearest administrative center to print and photocopy.

Adapting to an Increasingly Competitive Environment. Certain adjustments also aim to ensure the sustainability of the business in a competitive environment. The arrival of the conventional grid or the improvement of its supply is indeed often expected in the near future, if it hasn't already happened. Whether or not they are protected by regulatory frameworks, mini-grid operators usually integrate this predicted evolution into their business models. They implement different strategies that can either target the mini-grid itself or the service provided.

In Senegal, one strategy is to redefine the activity itself around infrastructure mobility. With this in mind, a mini-grid operator has begun examining the possibility of containerized mini-grids. Another example of such technical adaptation can be found in India where Husk Power Systems changed the energy source of its plants (from biomass to solar or hybrid plants) to improve the stability and quality of its supply. The company also changed its business model from an objective of first electrification to a service that can either replace or supplement the conventional grid by offering back-up.

Local Operators: Between Economic Opportunities and Renewed Social Relations

We now turn to how the presence of the mini-grid can affect localities. Recent works have underlined how mini-grids carry the risk of reproducing, on a local scale, pre-existing power relations and inequalities of access (Balls and Fischer, 2019; Kumar, 2021). We bring here a complementary perspective on how mini-grids can bring economic opportunities, but also contribute to reshaping social and power relations at the local level, by looking at the experiences and trajectories of local operators.

Bringing Economic Opportunities. First, mini-grids create diverse opportunities for local populations, and especially, economic opportunities favoring social mobility trajectories for local operators and technicians, who often develop strategies of income diversification (Zérah, 2020). In Tanzania for instance, two local operators interviewed said they had applied for the position because they saw it as an opportunity to further develop their business. Thanks to their position, they benefited from free commercial premises within the mini-power station which allowed them, in parallel to their activity as local operators, to run their businesses. In both cases, the position of local operator was only one activity among others, combined with the management of a hairdressing salon or a school supplies shop (See Figure 4).The socioeconomic trajectories of most

Figure 4. Local operator selling school supplies in Tanzania (Komolo)

managers of diesel mini-grids in Bihar similarly show how these businesses can be a source of economic opportunity for their owners. Indeed, while the launch of most of these informal mini-grids was often financed by familial capital or loans from relatives, the money earned from the business has often been reinvested in other commercial activities at the local level such as clothing stores, grocery stores, etc.

Reshaping Social Relations. But local operators are not only gaining economic opportunities. Their role as operators can also turn them into powerful actors at the local level. In Senegal for instance, some local operators we have met are responsible for the management of the power plant, and are the sole decision-makers with respect to its hours of operation. This role gives them significant power over the social and economic life of the village and a position of authority over other villagers. They also benefit from free access to the highest level of service provided by the mini-grid. Recently, all subscribers have had smart meters installed, except for local operators who have refused to have such devices installed. The managers of the companies concerned tolerate these exceptions to the rule, as they are aware of the importance of the role played by local operators in the smooth running of the service in the villages. Thanks to their access to the highest level of electrical service, these operators have been able to develop new commercial activities (sale of ice and cold drinks, for example), which would be beyond reach for most other shopkeepers.

Beyond the case of local operators, the presence of a mini-grid can reshape social relations between the villagers who are "connected" and those who are not. Thus, many examples of market relationships created around the mini-grid were observed during field surveys—the possibility for an unconnected individual to recharge their phone, free or not, at a connected neighbor's home; the informal extension of the mini-grid from a subscriber's meter to their neighbor's in exchange for sharing the electricity bill; or the pooling of domestic appliances such as refrigerators, are all examples that demonstrate the appropriation by users of the mini-grid and its functions. We make the hypothesis that these uses and these new interdependencies tend to strengthen the position of the mini-grids in these spaces, and to foster their maintenance.

Conclusion: Mini-Grids, Innovation, and Inequitable Access

In many urbanizing localities of the Global South, the conventional grid is not—and for probably a long time will not be—hegemonic. Consequently, a series of actors, more or less supported and regulated by the public authorities, intervene daily in the supply of electricity to the populations of these areas. As we have seen, they renew the notion of access to electricity through a range of service offers, create new economic opportunities, and also play a role in the structuring of social relations. Zérah (2020: 219) speaks of mini-grids as "legitimate forms of building urban services" and not only as temporary or marginal solutions. She invites us to move away from a "dominant vision of innovation" (Zérah, 2020: 199) and to consider urbanizing spaces not as recipients of the dynamics of urban centers, nor as an extension of rural lifestyles, but as spaces from where new ways of thinking about access to electricity can emerge.

Mini-grids could be a source of inspiration for conventional operators, towards more flexible and tailor-made forms of electricity provision (Kumar, 2019). The flexibility of the technical components and of the business models of mini-grid operators indeed enables them to serve areas and populations that are not—technically and economically—easily reachable for the main grid and to adapt their system to the spaces in which they deploy. However, in the absence of well-established regulations, equitable access to the resource is not assured. On the one hand, line losses are a strong technical constraint that leads operators to favor connections within a restricted perimeter around the power plant rather than to extend their service, leading to the exclusion of peripheral dwellings and less dense neighborhoods. On the other, the populations' ability to pay in urbanizing areas is also a barrier. Thus, in most study areas, the high tariffs charged by mini-grid operators in the absence of state subsidies exclude the poorest households. Some diesel mini-grid operators in Bihar have in the past dealt with this issue by giving households the possibility to pay for the mini-grid service with the kerosene they received monthly from the government. Equitable access is here enabled by a form of "misappropriation" of public subsidies. Finally, mini-grids can also bring to the fore the question of equitable access to the conventional grid: in Senegal, for instance, the under-capacity of the observed mini-power plants makes it impossible to provide continuous access to electricity, fueling the dissatisfaction of subscribers who pay more than neighboring localities connected to the grid, for a lower level of service.

Several authors have thus called for a more precise analysis of the moral economies on which mini-grids are based (Zérah, 2020). For Cholez and Trompette (2019: 353), the micro-capitalist logic that governs the operation of these systems is at the origin of a number of paradoxes that are echoed in the empirical insights presented in this paper: "empowering the poor but sustaining profitable activities and solvent customers, bringing a collective solution but reasoning the economic balance at a very small scale, and fostering economic development but reducing power energy supply and time slots." This balance is in practice difficult to find and implies an exclusion of the most isolated and poorest, and a reproduction of inequalities between urban and urbanizing areas, but also within urbanizing areas. In addition to the socioeconomic and spatial dimension of access to electricity, Balls and Fisher (2019: 2) have described, in the case of Northern India, how mini-grids are not able to completely isolate from local politics and further

"risk foreclosing possibilities for poor households to make demands of their local political representatives for access to electricity and inclusive development."

All these elements raise the question of social and territorial equity (Bousquet, 2006) of access to essential services in urbanizing localities, and of the role of the State in the development of these places and call for a move away from a technical and managerial vision of mini-grids to question the regulations governing the deployment of these alternative offers in third spaces.

This article thus highlights the paradox of mini-grids, which are often presented as bearers of a socially progressive transformative vision, and of their development in heterogeneous spaces where, far from ironing out inequalities, they can (re)produce them. In other words, while we have explored in this article the many ways in which mini-grids adapt to and accompany the social and economic transition of urbanizing areas, the model currently dominant in the localities of study—i.e., mini-grids managed on a commercial basis by a private operator, within regulatory frameworks that are either undeveloped or non-existent—does not allow for the establishment of a genuine essential electricity service based on equity criteria.

Notes

1. We refer here only to studies on mini-grids. Other off-grid solutions (solar home systems, solar lanterns, etc.) have been the object of several studies. See for instance Aklin et al. (2017), Akrich (1989), Balls (2016), Bensch et al. (2018), Cross (2019), Grimm and Peters (2016), Jacquemot and Reboulet (2017), Urpelainen and Yoon (2015).
2. In Tanzania, some of our interlocutors mentioned the existence of decades-old hydropower mini-grids run by religious communities or by large industrialists and farmers who installed a mini-hydro plant to electrify their activity and subsequently connected neighboring villages to it. In India, we were able to observe diesel mini-grids that have been running since the late 1980s.
3. ANSD: Agence nationale de la statistique et de la démographie.

Acknowledgments

The authors would like to thank É. Verdeil, S. Jaglin, M.-H. Zérah and the anonymous reviewers for their helpful comments on different versions of this paper. They would also like to thank the ANR Hybridelec, the LATTS, the PRODIG Laboratory, the Centre for Policy Research and the Centre de Sciences Humaines for their material and financial support.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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