Natural Resources Forum 43 (2019) 253–266 DOI: 10.1111/1477-8947.12181

Perceptions towards solar mini-grid systems in India: A multi-stakeholder analysis

Sachiko Graber, Tara Narayanan, Jose F. Alfaro and Debajit Palit

Abstract

This study identifies and assesses the perspectives of four key stakeholder groups towards solar minigrids in rural India. The stakeholders considered are policymakers, minigrid developers and operators, development organizations, and national grid representatives. Recent state and national policies in India have increased the focus on minigrids and their services. In this study, stakeholder interviews were employed to identify the attitudes towards the recent electricity policy, the underlying context for minigrid development, the role of minigrids in rural electrification, and the inclusion of minigrid systems within the larger framework of electricity sector policies by the recent government minigrid policies. Results indicate that stakeholders agree that minigrids, as a rural electricity service, are currently viable to complement the national grid due to their high reliability, performance in remote regions, and diminishing cost per unit. However, stakeholders disagree on the future outcomes, with diverging views on the priority of minigrids as an electrification tool in the face of the expanding central grid, the ideal implementation strategy for minigrids, and the potential for grid-minigrid interaction. Based on stakeholder feedback, the growth of minigrids in India is likely to be constrained by the confidence in recent policies, necessitating more frequent dialogue among decision makers and a solidified relationship to the national electricity grid.

Keywords: Rural electrification; stakeholder analysis; India; solar minigrids; energy access.

1. Introduction

This research assesses stakeholder perceptions of electricity from solar minigrids in the state of Uttar Pradesh (UP), India. UP has long featured one of the lowest household electrification rates in India (Registrar General of India, 2001, 2011; IIPS, 2016), though as of 30 November 2017, almost all the inhabited villages in the state have been connected to the grid infrastructure or the solar minigrids by the government (Rural Electrification Corporation, 2017). The state government has also recently developed policy and regulation for minigrids to promote sustainable rural electrification (UPNEDA, 2015; UPERC, 2016). The minigrid policy and regulation informed parallel national efforts intended to promote renewable based off-grid generation, drafts of which were released in the year preceding this study. This study focuses specifically on understanding the nuances of solar minigrids delivery and sustainability due to their prevalence, rapid penetration, significance indicated by the off-grid sector stakeholders, and co-benefits.

This study adds to the work done by Chaurey *et al*. (2004), which indicates that only 10–20 years ago, solar minigrids were considered to be a new and innovative electrification technology, whose merits were contested. The findings of that study indicate that rural inhabitants of one Indian state were deprived of satisfactory electricity supply from centralized sources (Chaurey *et al*., 2004). Ten years later, electrification through minigrids was observed to be lower than its full potential, despite some researchers opining its apparent cost competitiveness (Comello, 2017). The premise that solar minigrids are a viable method for electrification and their development in many parts of rural India directs this study. This study assumes that the distributed generation will promote development and contribute to the well-being in rural areas. It expands concerns about decentralized solar options by exploring the underlying tensions among electricity stakeholders that lead to this disparity.

This work also builds on the identification of Comello (2017) — using methods similar to those of this study — that the "gateway barrier" to minigrid deployment is the imminent threat of central grid expansion. It studies the minigrid policy,

Sachiko Graber, Tara Narayanan and Jose F. Alfaro, School for Environment and Sustainability, University of Michigan, Ann Arbor, Michigan, USA. E-mail: sgraber@umich.edu, tnarayan@umich.edu and jfalfaro@umich.edu
Debajit Palit, The Energy and Resources Institute, Darbari Seth Block, IHC Complex, New Delhi, India. E-mail: debajitp@teri.res.in

an effort to alleviate some of these concerns (UPNEDA, 2015). Considering that the previous work by Bhattacharyya (2013) recommended that regulation of off-grid electrification should be minimal, this study presents the opinions of involved stakeholders to provide valuable insight into sector responses to this new regulation. UP is an ideal setting for this study, since it has low electrification rates, significant experience with minigrid systems by private developers, and new policy formulation informing minigrid development.

In this study, qualitative research techniques were used to collect stakeholder perspectives. While less orthodox in the energy space, the qualitative techniques employed here allow the illumination of important opinions that usually cannot be captured through quantitative methods. Perspectives were collected from 18 individuals representing four main groups of stakeholders at both the national and state-level. The qualitative interviews were complemented with document analysis of recent scholarly research, different reports, and policy documents.

The interviews and document analysis described here were used to complement the analysis of a fifth stakeholder group: the consumers, whose perceptions of minigrid systems have been described in a previous work (Graber *et al*., 2018). The analysis of interviews and literature is used in this study to inform the minigrid landscape and improve electricity access in India — an important sector for ongoing national human development efforts.

The remainder of the paper is organized as follows. The rest of Section 1 describes the context and importance of electricity sector progress in India. Section 1.3 provides background information on the development and implementation of minigrids. Section 2 describes the methods used in this work. Section 3 includes a stakeholder analysis, presents the opportunities and barriers for the minigrid sector in India, and indicates the perspectives towards the recent minigrid policies. Section 4 presents the implications of the feedback received during this study. Finally, conclusions are presented in Section 5.

1.1. Minigrids and socioeconomic development in India

The importance of electricity drove the United Nations to set Sustainable Development Goal 7: the need to "ensure access to affordable, reliable, sustainable and modern energy for all" (UN, 2017). This goal reflects the focus of most developing countries on "electrification, [which] is virtually synonymous with modernization of the rural energy sector" (Kumar *et al*., 2009).

Several recent policy initiatives in India were meant to address continuing inequality among state-level transmission and distribution losses, power cuts, and overall electrification rates (Banerjee *et al*., 2015). Minigrids[1] in rural India complement the centralized grid to electrify remote rural areas. Remote rural areas have lower electricity demands than urban population centers, and often lack sufficient transmission and distribution infrastructure due to long distances and rough terrain. Even rural areas with access to the central electricity grid still suffer from low reliability and insufficient capacity (Global Data, 2012). Solar-based minigrid systems tend to be the least-cost option for reliably meeting rural electricity demands in many areas (Hazelton *et al*., 2014), while offering co-benefits such as climate change mitigation, job creation, and local economic flows (Thirumurthy *et al*., 2012; Dufo-Lopez *et al*., 2016). The current status of minigrids in India is discussed in more depth in Section 1.3.

Minigrids are usually promoted as a short-term measure required to provide the development benefits of electrification. However, many systems in rural India are intended to interconnect to the centralized grid once it expands sufficiently (Global Data, 2012). This eventual connection of minigrid and grid systems is intended to eliminate concerns about minigrid isolation and diminish the vulnerability of supply. Grid-connected minigrids are expected to exhibit better power quality, improved reliability, and lower peak cost (Yadoo and Cruickshank, 2012; Palit and Bandyopadhyay, 2016).

1.2. Policy in UP

This study focuses on the state of UP. UP is one of the states with the highest number of unelectrified homes (Rural Electrification Corporation of India, 2016) and a number of minigrid developers operate in the state to provide electricity access.

The first rural electrification efforts in India, after India attained independence, were primarily driven by state efforts. The involvement of private participants in this space began with the enactment of the Electricity Act in 2003 (Ministry of Law and Justice, 2003), which allowed independent operators to sell electricity through decentralized electricity solutions in designated rural areas without government licensing and regulation.

Thus, both the state and national governments have demonstrated ongoing efforts to electrify all villages and households[2] in UP over the past decades. In 2015, UP released a policy that sought to define the role of minigrids in context with the national electricity grid and outlined several scenarios with the interactions of both electricity service providers explicitly described. These interactions were financial and technical, and covered transactions involving assets, electricity as well as ownership and distribution rights (UPNEDA, 2015). In 2016, the

[1] A minigrid is a self-contained electricity grid with a generator and load. The term "minigrid" is used here to refer to any system with capacity under 1 MW, although technically there are subdivisions of microgrid, minigrid, picogrid, and nanogrid. The state and national policies in India use the term "minigrid".

[2] Village level electrification in India is defined through a number of criteria, including a minimum of 10% of households being electrified, all public places having electricity connections, and infrastructure such as a distribution transformer and 11 kV distribution lines being present. Therefore, an electrified village may have a significant number of unelectrified households.

UP electricity regulator followed the minigrid policy with the release of minigrid regulations for the state (UPERC, 2016).

Despite the ongoing government efforts to expand electricity access and quality, researchers opine that rural inhabitants remain dissatisfied due to the unreliability of the electricity grid and the brown- and black-outs (Sandwell, 2016; Urpelainen 2016).

1.3. Minigrid development in India: Current status

Minigrid prevalence in India has expanded significantly over the last decade or so due to increased involvement of private players, local banks, and the government through the Ministry of New and Renewable Energy (MNRE)'s Remote Village Electrification Programme and the Village Energy Security Programme (Palit, 2013; Palit and Chaurey, 2011).

Minigrids have been significant in rural electrification efforts, and studied in detail (Palit, 2017), but currently face several challenges unique to their evolution. Commercial minigrid development also faces challenges that hinge on the willingness and ability of potential customers to pay, which in turn depend on additional factors, such as assets, education levels, or location; these factors affect a service provider's willingness to operate in a village (Chaurey, 2004).

Long-term system sustainability is a final concern of minigrid projects. Solar minigrid systems face risks including uncertain demand, unproven business models, low power availability (compared to the grid), and limited ability of consumers to pay cost-reflective tariffs. Although the levelized cost of solar electricity is low compared to many other sources, the upfront capital needed for renewable generation projects increases the risk to investors. The transaction cost for maintenance and customer service in remote areas is another challenge hindering minigrids.

Rural consumers often mistrust electricity from the centralized utility due to the increased costs from factors such as remoteness and grid expansion (Chaurey, 2004; Sharma, 2014). Studies show that a simple connection to the grid provides limited returns to household income due to low quality of grid-provided energy (Chakravorty *et al*., 2014). Central electricity providers are criticized for their "neglect of the consumer" and lacking sensitivity to consumer expectations (Sharma, 2014), contributing to consumer demand for alternative electrification options. While all census villages in India have been electrified as of April 2018, household-level electrification varies widely across states (Rural Electrification Corporation of India, 2017). Furthermore, there are many remote hamlets of census villages, locally called majras, tolas, paras, etc., which are yet to be electrified, and can often be most affordably and efficiently electrified through minigrids.

Today, minigrids pose both opportunities and challenges to rural consumers. They are easily differentiated from the centralized grid due to the profile of the power they can provide, which are nearly opposite for the two sources of electricity (Graber *et al*., 2018). Table 1 provides a brief overview of the attributes of each power source as described by parties involved in this study. Further descriptions and observations of typical systems that were studied are detailed in other literature (Palit, 2011; Urpelainen, 2016; Yadoo and Cruickshank, 2012).

Table 1. Grid and minigrid attributes (Graber *et al*., 2018)

Attribute	Minigrid	Grid
Power	Low	High
Reliability	High	Low
Hours availability	High during peak demand; otherwise may be limited	Low during peak demand; unreliable

Minigrid systems and the centralized grid present opposite strengths that would be valued by the customer. Therefore, the trade-offs rural consumers are required to make in choosing service from one versus the other are very relevant to understanding the utility of minigrid systems in rural developing environments.

2. Methods

To better understand the context of policy mechanisms for minigrid development, this study relies on one-on-one interviews using semi-structured questionnaires and a review of existing policies and research (both scholarly work and grey literature) in the field. This process is in line with other studies using qualitative methods of data collection (Malhotra *et al*., 2017). Following a thorough review of literature available on minigrid implementation in rural India, five groups of stakeholders were identified as holding unique perspectives on, and roles in, the minigrid space. These groups are: (1) NGO/advisory groups; (2) renewable energy policy representatives; (3) national grid representatives; (4) minigrid developers; and (5) consumers.

The uniqueness of each group was ascertained through their role within the recent development of state and national minigrid policies, as well as through their position in the broader landscape. The fifth stakeholder group, mini-grid electricity consumers, was covered via conducting a structured perception survey (the results of which were published as part of another study by Graber *et al*., 2018) and not interviewed due to the inappropriateness of using a small sample size to collect the views of such a large and diverse population. The outcomes of that study are included here to allow a broader picture of the sector and relevant viewpoints. These are not analyzed again, but results are referenced in Sections 3 and 4.

Within the above mentioned four stakeholder groups, individual organizations were identified as having significant interest in, and influence on, minigrid development in rural India. These were identified through the literature review process and snowball method. Less than 20 organizations were noted as having a significant role in the sector, and an attempt was made to interview a representative from each of these key organizations (noting that this approach would yield at least 3 organizations in each stakeholder group).

Table 2. Stakeholders interviewed

Group	Role in minigrid development	Stakeholders
NGO/advisory groups*	Collect and disseminate data; represent consumers; advise government on policy; provide funding	TERI, GIZ, Clean Energy Access Network, Shakti Foundation
Renewable energy policy representatives	Design and implement minigrid policies; oversee renewables development	National level - MNRE; State level - Uttar Pradesh New and Renewable Energy Development Authority (UPNEDA)
National grid representatives	Promote expansion of national grid; responsible to ensure countrywide electrification	Central Electricity Authority; Uttar Pradesh Power Corporation, Ltd.; Uttar Pradesh State Load Dispatch Centre
Minigrid developers	Develop, implement and operate minigrid systems on local scale	OMC Power; Mera Gao Power; TERI; Grassroots and Rural Innovative Development Private Limited

Experts interviewed for this study are disaggregated by stakeholder identification because of their differing roles and goals in minigrid development.
*The organizations TERI and CLEAN include both advisory and implementation arms. However, since only the advisory component of CLEAN was interviewed, it is included as an NGO/advisory group. Several representatives from TERI were interviewed, so their feedback has been categorized in both stakeholder groups.

Stakeholder interviews were conducted by the authors from May to June 2016 in the cities of Delhi and Lucknow — the national and UP capitals — and followed the responsive interview method. A sample interview guide used to frame a stakeholder interview is included in the Appendix. The stakeholders targeted represented policymakers, minigrid developers, development organizations, and the national grid. Interviews of 30–90 minutes were recorded to ensure accuracy and focused on the role of minigrids in village-level electrification, especially in small rural habitations. Due to the opportune timing of this study, interviews also addressed issues surrounding the new minigrid policies and regulations at the state and national levels. In total, 18 experts representing 12 organizations and categorized into four stakeholder groups (detailed in Table 2) were interviewed. Though a few potential interviewees were not included in this study due to logistical constraints completing the interviews, the 18 interviewees form the majority of well-recognized players in the small Indian minigrid sector and represent a fair cross-section of the relevant stakeholder landscape.

The interviews were analyzed through aggregation of responses within stakeholder type, especially through role-ordered matrix comparisons, which allowed multiple comparisons across stakeholder type. This aggregation of responses was necessary due to the sensitive nature of topics discussed and the hesitancy of the authors to attribute any response to an individual or particular organization.

This study focuses on the context of UP, although several of the stakeholders interviewed also shared their national electricity outlook.

3. Results and analysis

3.1. Context: factors affecting minigrid success

Based on the feedback received from all interviewees, Figure 1 uses a whole-systems analysis approach to reflect the general relationship of the main stakeholder groups to minigrid development. Minigrid developers are responsible for on-the-ground implementation, and both minigrids and the centralized grid are perceived to have a direct influence on the electricity market. Minigrids exist within the environment defined by both rural electrification and minigrid policies, which specify technical and financial constraints of operation. Renewable energy agencies, NGOs and advisory agencies have significant influence on the development of those policies. As indicated by the hashed line, although consumers interact with electricity systems, there is a disconnect between consumers and other stakeholder groups (who are responsible for higher-level decision-making).

Regardless of stakeholder affiliation, the 18 experts interviewed in Delhi and Lucknow revealed three themes relevant to the development of the grid-minigrid electricity nexus. Interviewees believed these themes were significant enough to discuss at length, thus indicating their importance to the minigrid field and its developments. As most of the key stakeholders have been covered in the interviews, the responses are believed to represent the broader field of minigrid development in India, as noted in Section 2.

3.1.1. The grid is currently absent from and unreliable in remote rural areas

The national grid in India is still striving to reach all parts of the country, and remote villages are disadvantaged due to the distance and irregular terrain that separate them from major electricity supply lines. In addition, a significant number of unelectrified households are located in officially "electrified" villages or in hamlets of electrified villages. The development potential of such areas, deemed electrified by the government, is significantly threatened by such barriers to the procurement of household electricity connections. While the government's Saubhagya scheme seeks

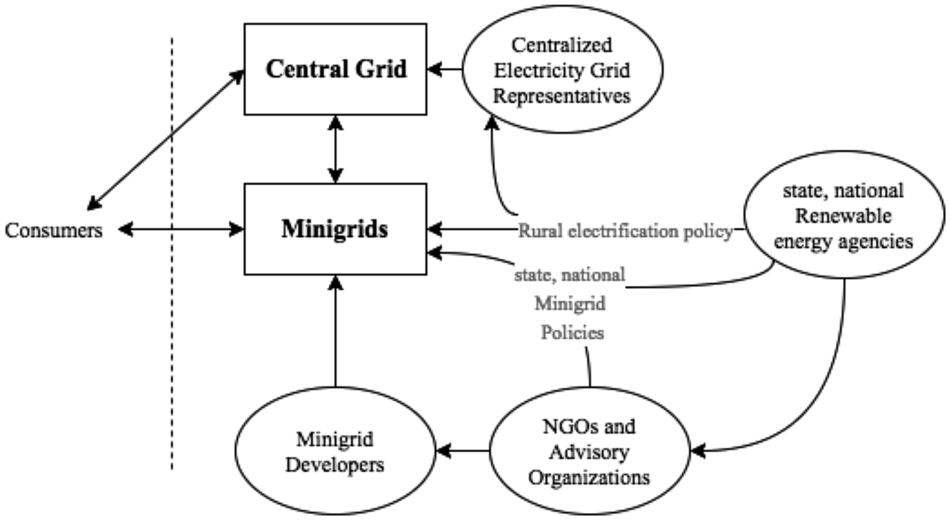

Figure 1. Stakeholder relationships and influence. While the grid and minigrid are often considered to be separate systems, they each have a significant effect on the other due to the involvement of other actors and the impressions they each make on consumers. Circles represent the stakeholder group, while boxes reflect physical infrastructure. Arrows represent the interactions between entities.

to electrify every household by March 2019 and the Power for All programme aims to provide 24 × 7 electricity to all by 2022, stakeholders expressed limited faith in the ability of the government to meet these deadlines. The main grid's limited rural access, difficulty in providing connections in a timely fashion, repair and maintenance issues in remote areas, and general unreliability are perceived as main opportunities for minigrids, since the smaller local systems with decentralized management are better suited to the provision of reliable power to remote areas. Minigrids performance in rural areas currently exceeds that of the grid in the realms of reliability and decentralized performance. This is also corroborated from the consumer perception study by Graber *et al*. (2018), which reveals that satisfaction level of consumers towards mini-grids are twice that of the centralized grids.

3.1.2. Minigrid development comes with a higher risk than more traditional power

Minigrids do not follow the standard conventional power plant economic model because of the high risks associated with the electricity demand and payback from isolated systems. The payback period for minigrids, especially DC systems, is much shorter (most providers of DC systems claimed to recover their investment in 2–3 years for systems with a 20-year lifetime), but investors are still difficult to attract. Most minigrids receive aid from external agencies such as philanthropic funding, which provide the necessary financing as well as "de-risking" individual investments by providing, for example, loan guarantees. The need for external assistance and the perception that consumers may be unwilling or unable to pay for electricity creates concern about whether minigrid operations can become self-sufficient in the long run.

3.1.3. Centralized electrification is likely to expand rapidly

Of the nearly 18,700 rural villages (as of August 2015) targeted for electrification by the Ministry of Power, around 17% (3,200 villages) were assigned to be electrified using renewable minigrids under the decentralized distributed generation scheme due to their extreme remoteness. All other villages were to be connected to the national grid, representing the expansion of the centralized system that is expected to threaten existing minigrids. Although minigrids development exhibits a diminishing cost per unit of energy, the centralized grid still boasts cheaper electricity (as the sector is under economic regulation and rural consumers are cross-subsidised by charging higher tariffs for industrial and urban consumers) and greater power delivery. Concern about grid expansion has prompted minigrid developers to protect themselves by preemptively promoting the strengths of their services (reliability of power) to consumers and investors, and the government to issue policies to protect minigrid players in the event of overlap and competition by the grid.

3.2. Stakeholder perspectives on minigrids — opportunities and barriers

Table 3 summarizes the individual stakeholder responses on the minigrid opportunities, barriers, and threats to minigrid development by stakeholder group. Stakeholders more closely tied to the minigrid or grid differed in their perception of the problems facing the minigrid, but all respondents supported the minigrid as an electrification and development tool.

One of the most common ideas reflected in the discussions of prospects for minigrid sustainability and

Table 3. Stakeholder perspectives on minigrid development

	Stakeholder perspectives of:	
	Minigrid benefits and opportunities	**Minigrid threats and barriers**
NGO/advisory groups	• Alternative to grid's unreliability • Needed for generation, since grid has insufficient transmission capacity in rural areas. • Simple solution for rural households who are willing to pay for electricity • Meet consumer's basic needs (lighting and mobile phone charging) • Quick impact solution to rural electrification	• More expensive than the grid per kWh of energy. • Technical limits to power provision • Restrained by limited external funding, and requires sustainable local investment • Need to regulate consumption (e.g., via meters) to combat increasing demand • Different government leadership promotes different paths to electrification • Large systems are too expensive with long paybacks; cannot compete with grid for cost recovery • Need continuing impact evaluation • Not all consumers value electricity enough to pay
Government - renewable energy agencies	• Grid unreliability creates space for minigrid development • Local generation and consumption is best • Decreasing cost of electricity • Increasing demand due to increasing awareness of minigrid systems • Possible solution to national electricity shortages • Provide economic co-benefits	• Limited impact where the grid exists • Need to pay back infrastructure costs if/when threatened by grid (exit clause of Minigrid Policy may not be enough)
Government - national grid representatives	• Minigrids can provide better service than the grid in some cases; grid expansion is limited • Electricity problems in UP create demand for quality electricity • Growing consumer base and demand • Benefit public (co-benefits) • Consumers value reliability • Consumers in remote villages are willing to pay for electricity • Decentralized generation decreases transmission losses to remote villages	• No need for minigrids, grid will reach everywhere in 5 years • Not valuable due to niche market • Developers are too worried about profit, do not prioritize consumers • Technical improvements to grid transmission and distribution systems expected to eliminate need for minigrids
Minigrid developers	• Increasing aspirational need of consumers allows minigrid growth (e.g., more power to run televisions) • Minigrids currently have a strong business case that is anticipated to continue	• Limited use to small appliances • Stopgap solution until grid comes • Different than grids

Due to their differing roles in the minigrid sector, each stakeholder type tended to have a unique view on the opportunities for and threats to minigrid development in rural India. The main points made by each stakeholder group are listed below to provide clarity on the differences and similarities in their perspectives.

expansion was the competition for resources and marketability of the minigrid and grid. This concern has been discussed in the development context but does not seem to have been elaborated in literature. The different influences between the two electricity systems are reflected in Figure 2, which was developed as a whole system thinking diagram as indicated by Meadows (2008). The figure shows that investment in the grid can improve power provision, while the minigrid already displays consistent power and reliability levels. Although an important factor, grid reliability, is not noted here, it is not a significant attribute, as the grid was found to consistently lack reliability in all contexts considered in this study. A detailed analysis of the relationships indicated in Figure 2 can direct the identification of highest-impact intervention points for future studies or project implementation.

3.2.1. Opportunities

Minigrids were supported across the board for their ability to immediately provide development benefits to remote areas based on three main premises: basic electrification is a need, grid expansion progress is difficult to predict, and minigrids are a solution. These benefits were construed as a "social policy" benefiting the greater public in addition to individual households.

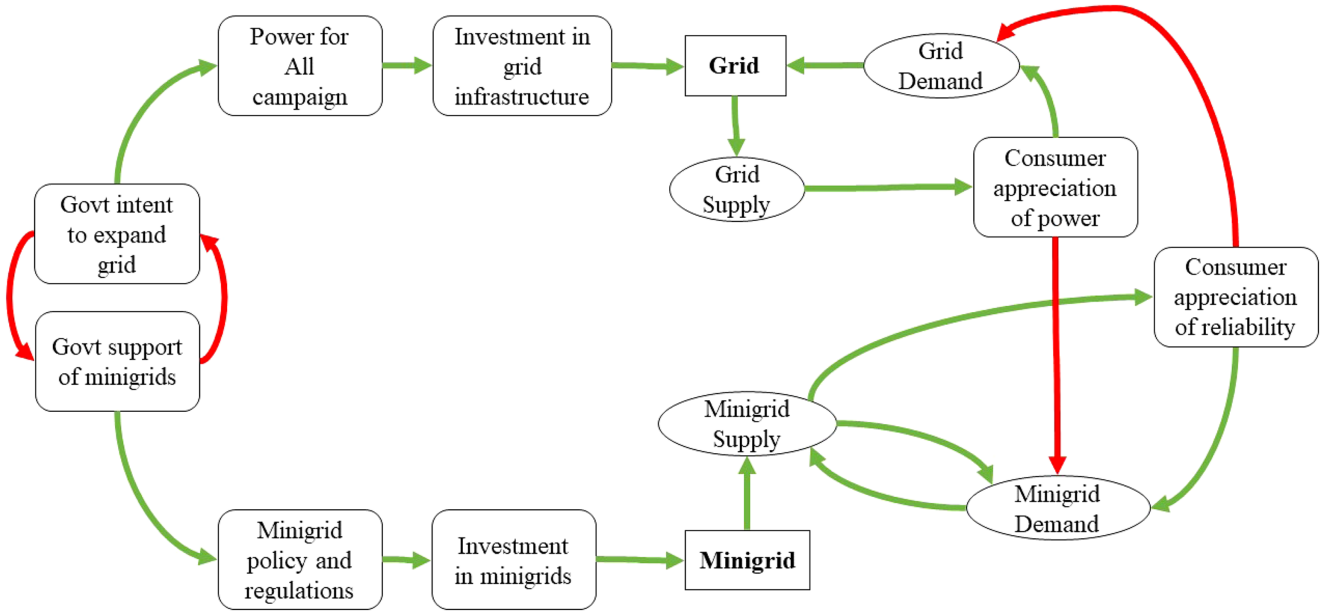

Figure 2. Electricity systems influence. This diagram indicates the direction of influence and growth of, electricity systems, using standard systems diagramming (green and red colour indicating positive and negative effect, respectively).

Stakeholders from multiple sectors acknowledged the urgency of electrification needs in rural areas of UP. Development and advisory organizations mentioned that UP is a priority for alternative village-level electrification options. Minigrids are promoted as more economically viable than the currently prevailing energy options like diesel generators or kerosene. Even limited but reliable power provided by minigrid systems (in most cases, allowing only 2–3 lights and a cell phone charger to be run in each household) is appreciated, since, as one analyst noted, "at least something is better than nothing; they're [currently] unelectrified". One analyst prioritized basic electrification by characterizing current minigrids as serving a "need", whereas grid provision of sufficient power to run an expanded list of appliances is a "luxury".

Stakeholders questioned the premise of electrification through grid expansion, due to the technical challenges to reliable grid service. They also emphasized that the unreliability of electricity from the grid and the limited transmission and sub-transmission capacity further constrain access, leaving decentralized generation as a viable option for electrification. In this regard, the current grid expansion drive through the Deen Dayal Upadhyay Gram Jyoti Yojana (National Informatics Centre, 2005) and Power for All campaign was criticized by some because, even with a sufficient increase in generation capacity (an assumption lacking consensus among respondents), power reliability will remain limited by transmission capacity and ability on the part of the electricity distribution companies for quick repair and maintenance of the network. There was additional doubt in the efficacy of the 24 × 7 Power for All initiative because the centralized system may not be the most efficient mechanism for rural electrification. UP in particular has a large number of remote hamlets, where extending the grid is both expensive and difficult to upkeep.

Socio-political priorities for rural electrification support minigrid development, which provides lower-cost reliable electricity than the alternatives. Most consumers have the ability and willingness to pay for electricity from a minigrid, which is economically advantageous compared to kerosene or diesel alternatives (Sandwell *et al.*, 2016). In many semi-accessible villages, current electricity connections are reported to work for only about 4 arbitrary hours per day, so consumers with requirements for reliable power pay five times more to run personal diesel generators. One representative of the centralized grid mentioned while being interviewed that in less accessible villages, even those registered as living below the poverty line will convert to minigrid power when available "because you are offering a better solution, a cleaner technology solution [than current options]". Consumers are willing to pay for minigrid-generated power, which also minimizes the potential transmission losses that would otherwise occur through grid extension.

The opportunity for minigrid sector growth, indicated by the current demand–supply gap, is predicted to last at least a decade, if not longer. Minigrid developers are also aware of consumers' aspirational need for additional appliances that indicates an opportunity for continued expansion of system capacities. Minigrid projects provide additional co-benefits through local energy generation, for instance, advancing local economies through job creation. Overall, the benefits of minigrids are

acknowledged by all stakeholders to range from socio-economic to environmental.

3.2.2. Barriers

Despite the opportunities discussed above, stakeholder interviews revealed concern about several aspects of minigrid projects. The most important concerns were the internal challenges of minigrid operations, the ability of minigrids to compete with the grid, and the limited time over which minigrids will be relevant.

The first challenge to minigrids is their competitiveness with other electrification options. In the short term, minigrids are not an ideal electrification solution for all consumers; minigrid power can be 25 times as expensive as power from the grid per kWh, due in part to the fact that minigrid system sustainability is uncertain (due to the threat of grid encroachment), and in part because developers try to recover their investment within only a first few years, and grid power is cross-subsidised in rural areas. According to several critics, consumers face high electricity tariffs, while minigrid developers reap the benefits of a "feel good" solution without significantly improving the well-being due to the low quantity of energy provided. Not all populations want to or can afford the amenity of electricity from a minigrid. Tariff rates are a matter of concern, with much literature devoted to them (Palit and Bandyopadhyay, 2017), however, most of the survey respondents focused on other barriers.

Further, minigrids are not regarded by customers as permanent electricity solutions, since they limit electricity consumption to very small appliances and the tariff is high. They require careful regulation of consumption, and meters to allow varying demand are uncommon. Minigrid growth also tends to expand the same (limited) service to a broader population, not increase electricity provision to the power levels provided by the grid. In the long term, improved transmission capacity of the grid and technology enabled responsive maintenance services may make minigrids obsolete. The limited quantity of power provided by minigrids is a significant problem.

The second significant barrier to minigrid development is that they are currently viewed by many as a stopgap solution that will become irrelevant once the grid expands to areas currently considered to be remote or rural and supplies electricity more regularly. Minigrid developers realize that minigrids will not be relevant once the grid is present in all parts of India. Government confidence in its push for 100% electrification caused several government representatives to claim that "we don't need" minigrids, since once distribution issues are addressed, they perceived minigrids to be unnecessary. Minigrids are also viewed by some stakeholders as filling a "niche" market, with limited demand threatening imminent market saturation. These concerns with the longevity of the minigrid intervention raise questions around the need for ongoing funding to minigrid projects.

The last challenge to minigrid operations is the need for a sustainable business model. Initial capital cost grants and subsidies are observed to be necessary parts of the minigrid business model (Knuckles, 2016). However, stakeholders indicate funding to be a significant barrier, as noted in existing literature (Comello *et al.*, 2017). Although one developer asks for over 50,000 Indian Rupees (about US$750 at the time of this study) from local entrepreneurs to set up facilities with capacities under 4 kW, most projects rely on external funding — which is not a sustainable solution. Often, a lack of funds for minigrid projects causes maintenance and evaluation programmes to be cut short, contributing to a lack of continued impact evaluation (at best) or the decay of a system well before the end of its lifetime. The funding issue raises questions, according to several interviewees, of whether communities are sufficiently prioritizing and investing in minigrids.

These three barriers to minigrid development have led to government advocacy for minigrid use only in the least developed areas, since they have limited impact in places with pre-existing or growing access to power.

3.3. Perspectives on the minigrid policies

The assessment offered in this section represents an analysis of the responses to the minigrid policies that were released over the course of 2016, with Table 4 offering an in-depth look at stakeholder perspectives by group.

Interview data reveal that attitudes towards the minigrid policies vary by stakeholder group. Nearly all respondents supported the minigrid policy and regulations — only one stakeholder proposed that the policies are not necessary. However, all respondent groups indicated a concern about how the exit strategies will be executed in the future, and several respondents suggested that requiring infrastructure to be compatible with the centralized grid would improve the current policy.

Government officials described a paternalistic satisfaction with the policy, which met their desire to support minigrid companies. Minigrid developers were pleased that the policies give them legitimacy to provide power in remote villages; and this legitimacy allows them to attract increased investment. NGOs also supported the improvement in policy support for minigrids, since it may allow minigrid power to become more affordable — completing "the obligation to serve the end user" (households). However, many stakeholders remained reluctant to call the policies successful, since purposely vague components are open to interpretation; and until any minigrid company utilizes the exit options, their efficacy will not be fully understood. The range of feedback received by different stakeholders is summarized below.

Table 4. Stakeholder perspectives on the minigrid policy and regulations

Stakeholder type	Positive feedback	Negative feedback	Other feedback
NGO/advisory	• Protects from worry about system payback time • Minimizes fear of disruption by grid • Helps minigrid development overall • Many aspects open to interpretation	• Not implemented fully • Minigrid market can grow without interference from the grid • Policymakers have poor understanding of situation • Does not require sharing of wires and lines	• Lacks specificity on how tariff should be set • Universal consensus received • No regulation needed • Should force integration of wires, networks
Government - renewable energy	• Attracts private developers by assuring protection of investment • Government ought to take care of minigrids, which exist with its permission	• Distribution companies are in loss and might be unable to buy out minigrid infrastructure (per exit strategies)	• Exit strategies will be needed when grid becomes reliable (2020 or later)
Minigrid developers	• "We feel safe while working in UP" • Exit strategies support developers • Gives legitimacy to developers • Decreases investor perception of risk; may increase foreign investment	• Will not work in favour of minigrids; Government will force minigrids out, and distribution companies will not compensate for infrastructure	

Responses have been aggregated by stakeholder type, but each comment may only reflect one individual's perspective. Only three stakeholder types are included here because the fourth interviewed stakeholder group, representatives of the national grid, did not have a sufficiently nuanced awareness and understanding of the minigrid policy and regulations.

3.3.1. Policy rationale

The minigrid policies drafted for India and UP are perceived as necessary by most stakeholders, and in fact, were noted for the near-universal consensus they received. Because UP is a "power deficit state" with a significant number of hamlets and many households unelectrified, minigrids are considered an important solution. The policy attracts private developers, who otherwise would worry that investment in minigrids posed too much risk. The policies also allow developers to sell electricity at a more affordable rate, since payback times are less threatened by grid disruption if developers can take advantage of the exit strategies mentioned in the policy. These strategies allow minigrid developers to recoup their investment when the grid threatens them but give them a safe space for operation in the meantime. Minigrid developers commented, "we feel safe while working in UP" and "[we] can operate without fear, without disruption" due to these exit strategies. Regarding the ability of the new policies to justify new investment in minigrids, one analyst commented:

> It is a business and [developers] are taking a fair chance, but they are solving for a … social sector challenge. Social sectors worldwide are funded by governments or with long-term sovereign lines. Even Indian infrastructure is funded by World Bank and ADB with 25–40 year lines. It's extremely unfair to expect private capital to go and solve for that problem without that certainty. Because [the] more uncertain a project, [the] higher the risk and therefore higher the risk premium. None of these projects, even at […] 100 rupees, can bear the risk premium that the sector presents. The IRRs [international rates of return] of the sector, given the uncertainty, should be in excess of 20–35%… That's assuming you're operating a minigrid for 10 years.

The fear of minigrid failure exhibited in the above quote is an indication of general hesitation towards the role of minigrids in electrification efforts. Minigrid developers view the grid as a serious "risk" or competitor, despite their own growing prevalence in the sector. The minigrid policy was formed to directly diminish their hesitancy, and indeed has addressed the most significant concerns expressed by developers.

3.3.2. Criticism and barriers to policy progress

Criticism of the policy by government officials centered around the exit policies and the perceived likelihood of their success. Because minigrid exit would depend on the integration of their facilities with the grid infrastructure, distribution companies would be required to compensate minigrid companies for electricity bought or infrastructure taken over. Since these companies are already in deep financial loss, they might not be able or willing to purchase facilities at prices desired by developers, who could then be forced to accept prices including much more significant capital depreciation than is now assumed.

Stakeholders with advisory roles, including NGO and research organizations, added criticism of the minigrid policy for its lack of specificity and understanding. One criticized policymakers for a poor understanding of the needs of poor, rural consumers. In addition, the minigrid policy and

regulations do not consider additional, more innovative pathways to minigrid-grid co-existence such as integrated networks that would allow grid and minigrid players to share infrastructure and minimize the cost of interventions. Since the policy specifies that minigrids integrating with the grid must satisfy certain technical requirements, it seems to undermine itself by not setting these requirements for minigrids in the first place. Several interviewees also felt that the government should not interfere with or regulate tariffs, since the market would self-regulate through energy service companies (ESCOs) and consumer agreement.

Finally, minigrid developers and analysts criticized the policy for insufficient support to their business. The regulations do not specify, under the exit strategies, how tariffs would be set when the grid buys minigrid-generated electricity. Minigrids are very sensitive to small price changes, and developers felt that they might be cheated in the future. Overall, there was significant doubt that the exit strategies would work out in favour of minigrids; developers wonder if the government will force them out without full compensation for their assets.

The potential for integration, one of the most important aspects of the policy, was generally viewed with concern. While the policy contains vague components that allow for discussion, they are convoluted in practice and do not provide many developers with the confidence to continue their work that had been hoped for. The lack of confidence in exit strategies for minigrids is especially problematic due to the belief, mentioned above in subsection 3.2, that minigrids will only be relevant for the next few years before the grid reaches all parts of India.

3.4. Considerations from the consumer perspective

While consumers were not included in the interview pool for this study, their perception of minigrids is among the most important — since they are the most affected by the pursuit for universal electrification in India. However, many stakeholders indicated concern about this group, since their intentions, needs, ability, and willingness to pay for power are not well-understood.

Several NGO representatives mentioned the problem of differentiation between minigrid and grid-provided electricity. Many rural consumers consider minigrids to provide only lighting, whereas grid connections provide *bijli* (full electricity) — descriptions assigned due to the difference in the profiles of grid versus minigrid electricity (Graber *et al*., 2018). Stakeholders considered this difference to be harmful, since high-level representatives and planners predict the grid and minigrids to eventually compete within the same market, while customers still view them as separate services. At the same time, most consumers appear to understand the main differences, pointing out an inverse relationship between electricity reliability and power due to the current offerings of the grid or minigrid systems. Still, despite their low power provision, minigrids are able to provide electricity services while circumventing the mistrust with which many rural consumers perceive the centralized grid. This appears to be due to their acknowledgement of an imperfect service and ability to focus on their strengths — although they may provide power for only 6–7 hours a day, for instance, they are consistently able to provide that service. Further, customers are more satisfied with the presence of a local minigrid technician who is trusted by both the provider and the community to maintain the system and collect bills.

The unwillingness or inability of consumers to pay for electricity, especially unreliable electricity from the grid, continues to be a barrier to government-sponsored rural electrification efforts (Urpelainen and Yoon, 2016). Indeed, the need for an alternative to this service forms the major narrative of private minigrid success. The outcomes of a study on the consumer willingness to pay indicate that consumers value large quantities of electricity and reliability over other attributes of electrification, and that in some cases, they prefer no electricity than settle for an expensive or unreliable option (Graber *et al*., 2018). Consumer preferences appear to favour different electricity attributes depending on the amount of exposure they have experienced. Therefore, the strength of consumer preference and willingness to pay for electricity reliability and quantity indicates an opportunity for minigrid success.

4. Discussion

Two main points illuminated by this study need to be considered as the minigrid sector in India progresses. First, the development of minigrids in parallel with national grid extension implies a need to prepare for future system integration. Second, some general gaps in agreement across stakeholder groups are made apparent by this study and should be addressed.

4.1. Integration implications

Several salient points were revealed during the interview process, which indicated the expectation of future challenges with grid-minigrid integration efforts. There appears to be a lack of awareness of the practical and technical difficulties of grid-minigrid integration. Some of these challenges are relevant to policy outcomes.

The national and UP minigrid policies were intended to protect minigrids in the future, when grids and minigrids have access to the same market. At the time of the study, a village was likely to have access to either grid or minigrid power (or neither); only a few villages had access to both systems, and even in such villages, access still tended to be divided by hamlet. When the centralized grid expands to all parts of India, per the targets of the national plan, there are three broad options for minigrid operators: the grid and minigrid must compete for consumers, they must pool

resources and "share" consumers and infrastructure, or minigrids will be bought out of the market. These options are poorly understood since, as was emphasized by many during this study, the functioning grid and minigrid overlap almost nowhere in UP. However, issues around integration are expected to become increasingly important over the next few years.

In the case that the grid expands into a community previously served by a minigrid and they opt to interconnect and "share" infrastructure, technical difficulties are expected. The voltages of each system's operation are different, ranging from a few volts DC to 230 V AC, and minigrids have limited interconnection ability. Further, under the current scenario where the grid fails to provide power 24 hours per day, islanding will occur and require an additional set of capabilities. More closely coordinated interconnection standards would solve this problem (Palit and Bandyopadhyay, 2016). Organizations in advisory roles as well as a representative from the Central Electricity Authority indicated that sharing distribution networks would minimize duplication of efforts and create more efficient systems.

To complicate the issue, stakeholders in advisory roles say that minigrids "are not a stopgap, they are a complement to the main grid". For instance, some predict that minigrids could serve consumers during peak demand when the grid is overloaded, while supplementing grid power at other times. One developer also commented that grid representatives ought to appreciate minigrids for their ability to take some of the responsibility for serving consumers. Clearly, neither the role nor value of minigrids in the recent push for electrification are consistently understood throughout the sector — and this introduces many difficulties in proceeding with minigrid development.

The diversity of systems identifying themselves as minigrids adds to the sector's complications and confusion. The term "minigrid" refers to both small systems that can only feed in power at the distribution level and larger systems that could use a point of common coupling with low voltage transmission feeders. For instance, many systems observed in this study used low capacity DC, which would not be easily integrated with the centralized grid due to the costly addition of inverters and inter-connections systems that would be required. Technical and quality barriers to integrations with the grid are cost prohibitive for small systems and may prevent minigrid operators from taking advantage of all exit options in the national minigrid policy. Furthermore, the lack of explicit guidelines for the interconnection of minigrids with distribution companies (discoms) may be dissuading both from attempting this process.

Weaknesses of the centralized grid pose additional challenges for interconnection. The grid's unreliability implies that the grid cannot serve as a source of continuous supply to minigrids, nor are they capable of continuously absorbing the power they generate. Thus, in order for the minigrid to complement the grid, it would need to add storage capacity or choose hybrid diesel systems, in turn increasing the cost of power. Consumers would be unlikely to pay for a higher tariff for an interconnected electricity system that would be able to take advantage of this relationship during peak hours. Additionally, the current weak financial condition of state-owned distribution companies has caused many to question their ability to ensure steady and continuous payment. While contracts with smaller players are legally possible, the organizational challenges of discoms make these contracts practically infeasible for small systems with small payback periods.

Finally, the ownership of physical assets under integration scenarios is uncertain. Minigrid players tend to purchase lower quality equipment and install their own lines because project-specific distribution wires are cheaper and more quickly installed. Therefore, minigrids exhibit lower quality infrastructure than that mandated by the grid, forcing the grid to overlap those efforts as it expands. If minigrids installed distribution networks of higher quality for their operation, these could serve as essential public infrastructure that could be shared under future integration. However, in such cases the investment required will be more, thus lowering the immediate viability of mini-grids, or they have to charge still higher tariffs, which are already high *vis-à-vis* regulated centralized grid.

4.2. Stakeholder agreement (or lack thereof)

The unique stakeholder perspectives collected can be utilized to inform the future of the sector, as well as to identify points at which consensus-building is necessary to move minigrid work forward.

Broadly, there is a notable difference in statements among government officials, namely from grid personnel versus those from renewable energy agencies. There does not seem to be agreement on the basic facts of electrification, such as whether the central grid is generating excess power and unable to distribute it or has insufficient generating capacity. In addition, renewable energy experts seem skeptical of the implications of the 24×7 Power for All campaign, which set targets for grid expansion and the electrification of rural areas via centralized systems in the very near future. Even though renewable energy agencies are responsible for some off-grid electrification projects under the broader umbrella of electrification efforts, there seems to be little coordination with other government agencies regarding their message, reasoning, or belief in the ability of off grid renewable energy systems to provide services to the population.

The perspectives of minigrid developers tend to be even more extreme than those of government officials. While developers positively referenced government efforts at policy support, they expressed significant distrust in the government. They seemed to simultaneously doubt imminent

grid expansion while fearing, in some cases, its competition to their service.

Financially, government representatives indicated that minigrids will never compete with the grid due to their limited power generation, and service providers cannot recover enough funds from consumers to make larger systems viable. This opinion opposes that of many developers, who continue to believe in the potential for minigrids to compete with the grid in an electricity market. One developer opined that if certain conditions are met, there will be no need for minigrids in India. These conditions are: (1) electricity supply is reliable; (2) electricity supply is unlimited; (3) grid power is metered; and (4) people pay for electricity.

Finally, there is a dispute regarding whether minigrids will be beneficial at all in terms of rural development. Some view minigrids as a stopgap solution to electrification; some perceive them as a lasting service; while others do not think they are needed at all. The significance of these differences of opinion indicate challenges for future cooperation among various stakeholder groups. The priorities of the national government, indicated by policies like the 24×7 Power for All campaign, were viewed with skepticism by most groups. While the new minigrid policies seem to have better incorporated feedback from a variety of perspectives to create a better supported document, more consistent communication around the specifics of these policies could help to improve its reception throughout the country.

5. Conclusions

The minigrid policies released by both UP and the national government represent a politically expedient effort to bridge the gap between the opportunity for minigrids to provide electrification services and the desire to expand the grid. However, the stakeholder analysis indicated limitations of these policies. First, the policy was intended to support and protect minigrid developers, but these entities still do not have confidence in a supportive environment. Second, stakeholders must recognize the urgency of grid-minigrid interconnection and align their institutional goals. Third, consumers have been widely left out of this politico-economic debate, and their priorities ignored in the framing of the minigrid policy. The consumer perspectives need to be better integrated to formulate a successful and efficient minigrid intervention in India.

Further work will be required in the sector to create agreement between minigrid developers and grid representatives, especially on the topic of technical and contractual system requirements. Nearly every interviewee considered for this work had a strong opinion about the specific requirements that ought to be promoted in the policy, but many different iterations of these suggest that negotiations would be required to reach a compromise. As several stakeholders pointed out, it will be in the best interest of all parties to agree on technical and contractual requirements so that future interconnection of grid and minigrid systems can be achieved with minimal duplication of infrastructure or ambiguities in contracts.

Furthermore, the impending competition between the grid and minigrid is likely to be more affected by consumer perceptions than acknowledged by many stakeholders. Regardless of the stakeholder debate about minigrids as a stopgap or permanent electrification solution, consumer perceptions of this service ought to be more heavily considered and allowed to imply that perhaps minigrids alone are not a long-term electricity solution.

The perspectives that emerged during this study can direct future work in the minigrid sector. Conclusions, while focused on the state of UP, can surely be extrapolated to other states of India exhibiting low electrification rates, such as Assam, Bihar, Madhya Pradesh, and Odisha, and other developing countries where grid access and reliability are low, including the countries in sub-Saharan Africa. Other lessons may be more broadly applicable. For instance, it is evident from this analysis that the centralized grid system currently exhibits more potential for improvement of reliability than the minigrid systems do for the improvement of power provision. These two attributes — reliability and peak power — were shown to be the most important to consumers (Graber *et al*., 2018). To be successful, minigrid developers could consider expansion opportunities, for instance through modular systems that can expand with increasing local demand.

Overall, it seems clear that solar minigrids are necessary for the development of rural India but need further technological and business innovation to be viable long-term solutions to other challenges, such as low carbon development pathways. Further development of minigrid systems and their integration into national electricity programmes and infrastructure can assist in their use to improve renewable energy profiles and development throughout India.

Acknowledgements

We would like to thank the following individuals who were essential to the completion of this work: representatives of the organizations referenced throughout this study for sharing their opinions through interviews; the professors of the University of Michigan School of Natural Resources and Environment (now the School for Environment and Sustainability) who provided consultation in the methods and analysis utilized in this study, especially Paige Fischer, Avik Basu, and Maria Carmen Lemos; and the University of Michigan School of Natural Resources and Environment for providing funding to make this research a reality.

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A. Appendix

Stakeholder interview guide

The following interview guide was used to direct conversations with the policymaker stakeholder group. Similar guides were created for each group of stakeholders. Because this study followed the responsive interviewing model, only a few basic questions were prepared for each stakeholder — after which, a conversation was expected to follow.

Background

1. Can you tell me a little bit about your job within the government of Uttar Pradesh?
2. What are your organization's goals with respect to electricity?
3. How does this relate to the official objectives of Uttar Pradesh and India for providing electricity to citizens?

Electric Utility

4. What are the different ways that consumers can get electricity in Uttar Pradesh?
5. Are there any major challenges in providing electricity to all Uttar Pradesh citizens?
    1. What are some of these challenges?
    2. What obstacles does the government specifically face?

New Uttar Pradesh Minigrid Policy

6. Can you tell me a little bit about how this policy was developed?
    1. What factors influenced the adoption of the new policy?
7. What are your personal thoughts on this new policy?
8. [if not addressed] How do you feel the introduction of this minigrid policy will change the electricity situation in UP?
9. What do you think is the role of minigrids in providing electricity?
    1. How would you feel about the introduction of more minigrids throughout Uttar Pradesh?
    2. What sorts of changes in the relationship between discoms and minigrids do you anticipate?
10. The new policy introduces specific minigrid subsidy and tariff constraints. How do you anticipate these will change the electricity situation?
11. If a mini-grid and the grid coexist in one village, what problems do you foresee?
    1. What sorts of experiences have you had that cause you to feel this way?

Political implications

12. How do you anticipate electricity provision affecting voting in elections?
    1. Have any particular parties been successful at incorporating energy policy into their work? (if so, how?)
13. How do you think the new minigrid policy will affect particular elections in the future?

Conclusion

14. Is there anything else you would like to tell us?