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Solar microgrids in rural India: Consumers' willingness to pay for attributes of electricity

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ABSTRACT

This paper assesses consumer valuation of different attributes of electricity supply to elucidate the conflict between solar microgrids and the centralized utility grid in India, as well as to provide insight into supporting government policies and structures. The study contributes significantly to the understanding of the role of microgrids in complementing a centralized system and its value as a sustainable energy solution for development.
Electricity reliability, power, price, and hours availability are studied through a choice experiment, a method uniquely able to disaggregate the willingness to pay for each attribute. Household surveys were carried out in 22 villages across 4 districts in the state and covering a total of 216 households. Results indicate that consumers value (in order of strength of preference) electricity power, reliability, and price. Further, despite 9.4 h of electricity supply per day from the main grid, as compared to an average of only 7.2 h from microgrids, the respondents exposed to both systems were almost twice as satisfied with the microgrid's reliability. Based on these findings, the study provides four policy recommendations for strengthening the rural electricity supply sector and enhancing electricity access in India.

Introduction

Many developing countries facing energy poverty, especially in South Asia and sub-Saharan Africa, utilize off-grid electrification—in conjunction with national efforts to bring consumers onto the centralized grid–to meet the rural energy demand. When growing off-grid systems meet centralized grid expansion, households are presented with a market choice; and thus pricing, reliability, quality, and quantity of supply become attributes used by households to indicate preferences. Due to a highly irregular centralized electricity system in rural India, consumers face trade-offs between these attributes and frequently choose off-grid options despite its apparent higher cost. Whereas aspects such as high price and high reliability are generally bundled together in urban areas, it is generally not possible to correlate the same attributes in rural communities due to income inelasticity.

Policymakers can facilitate the development of a sustainable model for community electricity provision for both consumers and electricity providers by understanding the value of various electricity attributes to different stakeholders, especially household consumers. This research analyzes rural consumers' valuation of electricity attributes and willingness to pay (WTP) for electricity supply with those attributes, by using a choice experiment that analyzes: reliability (quality and hours of supply), power (adequate availability of electricity), and price. The results can inform the energy policy discourse in India and therefore assist in the determination of grid and microgrid interactions in rural areas.

The study was conducted in Uttar Pradesh (UP), the most populous state in India and the state with one of the largest numbers of unelectrified households (Rural Electrification Corporation of India, 2016). Uttar Pradesh has also experienced recent policy changes in the electricity sector, with microgrids being considered as a distinct electricity alternative, in addition to an extension of the grid to improve household level access. The recent Minigrid Policy and Minigrid Regulation in the state have attempted to address the interaction between these two electricity supply options.

The remainder of this section briefly discusses the rural electrification setting in India. Section 2 provides the methods adopted for the study and the frameworks for data collection and analysis. Section 3 provides a brief review of choice experiment theory in the electricity sector. This is followed by an analysis and discussion of the results in Section 4. The final section isolates the key findings and suggests relevant policy recommendations for enhancing energy access as our conclusions.

This work attempts to inform the rural electricity sector not just in India, but potentially in other countries in sub-Saharan Africa and Southeast Asia, where grid and microgrids have the potential to interact. The results will allow policymakers, investors, and stakeholders to

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better understand how microgrids can complement and even compete with centralized grids, depending on the attributes of their electricity supply.

Rural electrification in India

The database from the Sustainable Energy for All (SE4ALL) Global Tracking Framework emphasizes that the access to energy in India (as a percentage of the population) has improved from 45% to 79% from 1990 to 2014 (The World Bank, 2017). Further, electricity access has reached 99.25% of Indian villages (Ministry of Power, 2017). Despite this, rural electrification in India continues to face considerable challenges with >42.3 million households still lacking access to electricity (Rural Electrification Corporation of India, 2017). Financial restrictions and operational inefficiencies of the electricity distribution companies (discoms) amplify the challenge of electrification and force the discoms to prioritize urban households over rural ones—both in terms of connections and supply of electricity. Rural households have lower demand and limited payment capacity, as opposed to their urban counterparts, accounting for this prioritization.

More importantly, the lion's share of rural households that are connected to the grid have yet to receive reliable and adequate electricity supply, despite current and past government mechanisms to encourage rural electrification. Even a village with very few homes physically connected, if exhibiting access to the distribution network, is counted as 'electrified' for state purposes.[1] In addition to the 230 million people still without access to electricity, another 20 million households reportedly remain underserved by current services, receiving less than four hours of electricity per day (Rural Electrification Corporation of India, 2017).

Insufficient access is enhanced by a wide gap in inter-state electricity provision and urban-rural divide (Rural Electrification Corporation of India, 2017; Office of the Registrar General, 2011). The International Energy Agency (2012) gives India an energy development index of 0.30; a value that is significantly affected by a low fraction of modern fuels used at the household level—evidence of continued unequal access. For instance, the 2011 census identified average state electrification levels ranging from 100% in Andhra Pradesh, Goa, Gujarat, and Punjab to <50% in Bihar, Jharkhand, Nagaland, and UP (Rural Electrification Corporation of India, 2017). Distribution also exhibits income bias with nearly 70% of rural unelectrified populations residing in the lowest 40% of income groups (Banerjee et al., 2015).

Since the start of India's first Five Year Plan in the 1950s, several regimes of the government have attempted grid expansion and off-grid rural electrification; however, these efforts have faced economic and technical challenges (Krithika et al., 2015). The low population density in off-grid areas makes the expansion of physical infrastructure uneconomical, and technical challenges, such as poor quality of service due to high transmission and distribution losses and administrative inefficiencies at discoms, prevent consumers from taking up a connection (Palit and Chaurey, 2011; Bhattacharyya and Palit, 2016). Therefore, despite grid expansion attempts, the challenge of electrifying remote locations continues to exist in India (Rural Electrification Corporation of India, 2016).

Electricity discoms also face financial difficulties. They are rarely able to recover the cost of supply through nationally regulated tariffs, loss accumulated by discoms increased from INR 0.76 per kWh in 1998–99 to 1.45 in 2009–10 (Maithani and Gupta, 2015). In 2014–15, the gap remained INR 0.58 per KWh even after government subsidy (Palit and Bandyopadhyay, 2017). In many cases, the cost of supply has increased because of rising trends in generation, operation and maintenance, and interest expenses, whereas the tariff has not increased commensurately. Political cycles aggravate financial difficulties in many cases, and tariff rationalization has become a major challenge for the electricity regulators (Min and Golden, 2014). Min and Golden observe that line losses vary according to the election cycle, correlating positively with incumbent re-elections and indicating that payments are less strictly enforced during re-election periods (2014). This finding corroborates anecdotal complaints by representatives of the centralized grid of insufficient payments to sustain the grid.

Despite challenges to the electricity sector, the Indian Prime Minister announced in August 2015 the intention to "electrify every village within the next 1000 days" and provide each household with an electricity connection by 2019[2] (Prime Minister's Office, 2015). Studies indicate that the population without electricity access in India consists of mainly three groups of consumers: those residing in remote, inaccessible villages where extending the central grid may be technically or economically infeasible; those residing in unconnected hamlets of grid connected villages; and non-electrified households in villages where the grid has reached (Palit, 2015). Most unelectrified households and habitations are located in the states of Assam, Bihar, Jharkhand, Odisha and UP (Perwez and Harinarayanan, 2016). In the case of UP specifically, rural household electricity connection was reported at 28% in May 2016, as compared to 36.8% of all households and 23.8% of rural households in the state that were electrified when reported by the 2011 Census of India (Rural Electrification Corporation of India, 2016). These statistics indicate an increase in rural household electrification rates of only 4.2% over a period of five years.

Microgrids in India

The challenges faced by the electricity sector in India raise questions of whether the grid can provide all households with a reliable and sustainable supply of electricity to rural areas. A lack of confidence in this likelihood has led to the emergence of renewable energy-based distributed generation or microgrid[3] solutions as an alternative in India. Numerous service providers run microgrids based on renewable energy, such as solar, biomass, and small hydropower in eastern and central states (GNESD, 2014). Microgrids thus have become accepted as a viable alternative to the grid for connecting unelectrified populations and providing supply on a sustainable basis (Urpelainen, 2016; Cust et al., 2007). Several international development organizations, such as the World Bank, now promote microgrids as an integral off-grid development tool (Banerjee et al., 2015).

The interest of international agencies in renewables integration has increased the focus on microgrids, and the potential of stand-alone renewable off-grid systems in developing countries to create economic, development, and environmental advantages has been discussed extensively in previous literature (Martinot et al., 2002; Reiche et al., 2000; GNESD, 2014).

Microgrids in India have emerged within the last two decades as a solution to low rural electrification rates. Microgrid systems in India are both state-owned and private, and most solar microgrids tend to exhibit similar profiles. Rural electricity can be constrained to a narrow voltage range and features reliability of timing, providing power for around 4–8 h per day (Perwez and Harinarayanan, 2016). While AC

[1] As per the definition of village electrification in India, a village is deemed to be electrified if: (1) basic infrastructure such as distribution transformers and distribution lines are provided within the inhabited locality; (2) electricity is provided to public places like schools, panchayat offices, health centers, dispensaries, community centers etc.; and (3) the number of households electrified is at least 10% of the total number of households in the village. This definition is proposed for change by the current Government of India.

[2] The Prime Minister of India has launched a new scheme Pradhan Mantri Sahaj Bijli Har Ghar Yojana –"Saubhagya" on 25 September 2017 to ensure electrification of all willing households in rural as well as urban areas of India. The target to complete the works of household electrification is 31st December 2018.

[3] Microgrids are small, self-contained electricity grids with a dedicated generator and load. In this study, the term 'microgrid' is used to refer to all systems with generating capacity <1 MW, although these systems can be broken into subcategories such as microgrid, minigrid, picogrid, and nanogrid. The state and national policies in India use the term 'minigrid'.