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Decentralised electric power delivery for rural electrification in Pakistan

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ABSTRACT

The paper evaluates solar powered microgrids as a candidate solution for rural electrification in Pakistan where over 51 million people still live off-grid. Microgrids can significantly reduce the cost of providing basic electrification and may also be scaled up to provide higher levels of services efficiently through energy and cost sharing. A census of 6 off-grid villages highlights the demand for electrification. On average household report a willingness to pay of USD 1.78 per month for the provision of high quality lighting and USD 3.24 per month for the addition of a fan. Furthermore, households are willing to pay an additional USD 0.89 per month for a communal load. First order cost calculations show that this demand can be met through the use of various solar topologies, in particular decentralised microgrids by local entrepreneurs with suitable public sector subsidies. Recommendations to modify the current legal framework are also presented, so as to provide an enabling environment for rural electrification through solar microgrids.

1. Introduction

Access to electricity, even simply the provision of high quality lighting alone, has been shown to increase productivity and provide opportunities for economic development (Alstone et al., 2015; Herington et al., 2017). According to the International Energy Agency (IEA), more than 440 million inhabitants of developing Asia (China, India, Pakistan and Bangladesh) and a further 580 million in Africa have no access to any form of electricity (World Energy Outlook, 2017). Most of those who live *off-grid* do not have a choice in this regard, and must rely on unreliable and unhealthy alternatives, like kerosene oil (Lam et al., 2012; Baul et al., 2018). The major source of electricity i.e. the national grid is unviable for many of these isolated communities, as the large upfront costs of electrification through the national grid makes expansion prohibitively expensive for governments in developing countries (Thornburg et al., 2016; Ubilla et al., 2014). Therefore, a paradigm shift towards powering these villages through low cost (and consequently low-power) distributed renewable resources such as solar photovoltaics (PV) has been seen in recent years (Ubilla et al., 2014; Shenai et al., 2016; Madduri et al., 2016).

A recent innovation in the field of decentralised generation is the solar direct current (DC) microgrid (Gandini and de Almeida, 2017; Ramchandran et al., 2016; Nasir et al., 2018a). A microgrid is generally built around a centralised solar generation mechanism that provides multiple households with electricity through a DC cable network. While it requires up-front setup costs, a microgrid allows the provision of *basic electrification* (defined as high quality lighting and charging a mobile phone), to multiple households in a single community at a significantly lower long run cost compared to traditional power provision mechanisms. It is also a promising alternative to standalone solar systems and fossil fuel generation, as it presents a low cost, sustainable and green alternative.

Prominent practical implementations of microgrids include setups in India and Africa (Mishra and Ray, 2014; Palit and Sarangi, 2014; Palit et al., 2014). The most common commercial scale implementation is the “Mera Gao Power (MGP)” project in India which provides 5 W of DC electricity, enough to alternately power an LED light and a mobile-phone charging point, for each subscribing household in a village for about 8-h per day. MGP has reportedly connected over 100,000 households spread across 400 villages (Palit and Sarangi, 2014; Urpelainen, 2016). In 2012, the government of Uttar Pradesh, India and the Renewable Energy Development Agency, installed 1 kW DC microgrids in 11 districts covering around 4000 houses (Srivastava, 2013). Other, recent successful deployments include those in Cameroon and Papua New Guinea, that typically provide up to 10 W of power per household for 8-h daily operation (Loomba et al., 2016). Other small container based solar solutions on 12 V and 24 V are also being readily utilized in Africa (Azimoh et al., 2016; Xu et al., 2016; Blyden and Lee,

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2006). However, none of these systems provide a 24/7 supply to rural communities due to large costs required for generation and, in particular, storage requirements (Fossati et al., 2015).

Microgrids generally have been a successful solution for providing *basic* electrification in off-grid communities, however we have not seen an influx of these in Pakistan (Khan and Pervaiz, 2013). Pakistan is the sixth largest nation in the world with around 51 million people (24% of the population) living off grid with no access to electricity (World Energy Outlook, 2017). Given Pakistan's well documented power crisis and its historical similarities with India, which is itself at the forefront of the microgrid movement (Urpelainen, 2016; Harish et al., 2014; Chaurey and Kandpal, 2010), the lack of microgrids in the country is quite surprising. In this paper, we establish that there is both a demand for electrification in off-grid areas, and this demand can be met through new decentralised solar microgrid architectures. By conducting a census of multiple off-grid communities, we determine the demand for rural electrification through survey-based elicitation. We find that not only does demand exist for basic electrification; there is significant demand for services beyond high quality light and mobile charging. We combine these results with a detailed cost analysis of different solar solutions for electrification to show that this demand can be met feasibly through the use of solar microgrids. In particular, three different architectures: standalone solar PV systems, conventional microgrids and new decentralised microgrids (an innovative new architecture that can meet this more sophisticated demand (Nasir et al., 2018a)) are evaluated from their viability and long term levelized costs perspective. We find that decentralised solar microgrids, provide an efficient solution for rural electrification.

Finally, we make policy recommendations based on our findings and the current legal and economic conditions in Pakistan. In particular we identify the need for the governments to provide an enabling environment for private parties to provide electrification through the use of microgrids. This can be done by introducing more flexibility in the law governing the generation and distribution of electricity in the country, which is the largest hurdle in the adoption of microgrids in Pakistan.

Given the interdisciplinary nature of the paper, for clarity of exposition, the remainder of the paper is organised as follows. We first detail the methodology employed in both the demand and supply side analysis. Results from both are then presented together, to allow for easy comparison and to highlight the existence of unmet positive surplus, i.e. the existence of demand and viable costs. Finally, in light of our results, we conclude the paper with policy recommendations in both the Pakistani and global context.

2. Methodology

We establish the feasibility of solar electrification (through decentralised solar microgrids) by conducting both demand and supply side analysis. Demand is established through willingness to pay elicitation, while feasibility of supply is determined through detailed system cost analysis.

2.1. Demand assessment methodology for rural electrification

To ascertain the demand for micro-grids, we elicited willingness to pay by conducting a household census across 6 villages in two clusters in the Multan district of Punjab. These areas are characterised by “bad line coverage” due to their proximity to the Chenab River and its regular flooding, making a reliable connection to the national grid unfeasible. Fig. 2.1 and its corresponding table lists the villages covered by our census and provide their geographical location

The census instrument covered all 138 households in the area that were designated as off-grid, i.e. they are not covered by the national electricity grid. We elicited willingness to pay for different bundles of electricity services, to gauge the demand for such services, while also recording basic socio-economic characteristics. Participation in the census was voluntary and respondents could choose to not answer any or all questions.

2.1.1. Willingness to pay elicitation

The primary purpose of our census was to measure the demand of electrification. We relied on survey-elicitation to determine willingness to pay (WTP). Respondents were asked if they were willing to pay a preselected price for a set of services. If respondents responded in the negative, they were asked the maximum they were willing to pay.

Households were asked about three different levels of service, which were chosen to replicate services provided by existing commercial low-power microgrids, such as Mera Gao Power, and those made available using decentralised microgrids architecture. The prices at which these services were offered were randomised between three rate plans, which presented increasing prices for each level of service. This was done to control for any anchoring effects caused by the initial price offered. The literature on WTP highlights the existence of strong reference dependence, where the initial price offered acts as a “reference point” effecting the respondents underlying value for a good or service (Johnston et al., 2017).

Due to the proximity of households inside each village, prices were randomly allocated at the village level, instead of the household level. Table 2.1 provides details of the level of services and their respective prices per month under each price plan.

2.1.2. Socio-economic characteristics of households in our data

Table 2.2 provides summary statistics for the socio-economic indicators of the households in our sample. As can be seen from the table, households in our data are generally low income, with an average per capita income of USD 26.2 per month, which is less than a dollar a day per person.[1] A possible caveat, as highlighted by past literature, is that self-reported income is typically underreported (Debowicz et al., 2013; Bank, 2007). To control for this, we follow the literature and requested self-reported monthly expenditure as well. We find that the expenditure on food and other general expenses, which are typically used as proxies for income, closely match income. Similarly, instances for meat and fruit consumption are also low, coming out to about once a week for both on average.

In addition to self-reported data on household characteristics, we collected information on the structure of the house. This was for two reasons; first the development literature suggests that the structure of the house is a good proxy for wealth. Second, decentralised microgrids allow for some of the resources to be deployed at each house, and the structure of the house is important from a deployment aspect. We found that the vast majority of houses (92, or 66.2%) had temporary foundations (mud-based houses), locally referred to as *kacha* houses (loosely, ad hoc). The remaining houses (bar 1 *pakka* or permanent house) were a mixture of modern building materials and temporary foundations. These results further strengthen the low income and low wealth results from Table 2.1. This result should however not be surprising. House location, vis-à-vis grid electrification, should be considered a function of household income and wealth, as property rates in localities with easy access to basic utilities would be higher.

2.2. Supply assessment methodology for rural electrification

To assess the feasibility of meeting the demand for rural electrification, we analyse the long run levelized cost of multiple solar solutions. We first present the details of three solar architectures of

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[1] Responses were collected in Pakistani Rupees (PKR). All PKR values used in the analysis throughout the paper, have been converted to US Dollars using the exchange rate of USD 1 to PKR 105. This was the average exchange rate during the census period. Furthermore, the use of a single exchange rate throughout the analysis is an affine transformation, and therefore does not affect any results.