ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

2016

Peer Reviewed
2016 Solar Research Conference

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Solar Home Systems vs. the Grid in Rural India: A Balancing Act of Risk and Reward

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Abstract

This paper examines the deployment of Solar Home System (SHS) solutions as a means to address rural electrification in India. This is explored through analysis of Uttar Pradesh and Bihar, states where less than 40% of households use electricity as their primary lighting source. Government solutions have been inconsistent in addressing the issue with most research and comparable case studies identifying small to medium enterprises (SME) as holding the key to rapid rural electrification.

The adoption rate of SHS by rural customers in India has been slow when compared to that of comparable rural electrification markets within Bangladesh and Sub-Saharan Africa. Recent survey data collected from rural households in Uttar Pradesh has helped shed light on some of the key factors behind the slow uptake of SHS experienced in rural India. In particular, respondents revealed perceptions of greater trust in Government authorities and the often unreliable grid based electrification solutions they provide as opposed to SME and their competing renewable based product offerings. There is a gap in understanding when it comes to establishing how valid these perceptions truly are. An aversion to risk, characterised by the low incomes of rural Indian customers further adds to the reluctance of the market to adopt SHS as a solution.

This paper quantifies perception validity on an income tier basis by assessing the ability of a grid connection to service a rural load profile in comparison to a SHS solution. This analysis utilises the optimisation tool HOMER Pro to take into account several sensitivities that impact each income tier. These include, amongst others, grid reliability, load profiles, grid tariff structures and SHS costings. The implication of this analysis is the identification of the target market for which SHS provides a better solution than grid connection. The analysis further identifies a price point at which an SHS solution satisfies energy requirements whilst remaining in keeping with the ability to pay for a particular income tier. The paper then leverages experimental results to create a five-pronged risk mitigation strategy which may be implemented to accelerate the adoption of SHS in the market.

This techno-economic analysis is then synthesised into concrete recommendations for both SME as well as the Indian Government in their effort to spread rural electrification through SHS at a higher rate. These recommendations further help to address validity issues surrounding consumer perceptions of trust and risk in a rural context.

1. Introduction

Access to clean, reliable energy is a human right that is often taken for granted in developed countries. It is estimated that approximately 1.3 billion people lack basic electricity access. The push for universal electrification is driven by two primary ideas, the first being that energy access is a value driver of economic prosperity, and the second being that the use of unclean energy sources like kerosene and dung have an adverse health impact. Of the population who lack electricity access, it is estimated that 95% of them live in Sub-Saharan Africa and developing Asia, with 84% being classified as rural (International Energy Agency, 2011). This work focuses on the rural electrification market in India, a major constituent of the global un-electrified population with 80 million rural households having minimal access to means of electrification. The vast majority of these households are extensively reliant on kerosene as a primary lighting source and tend to be clustered in the north of the country. This work analyses the particularly under electrified states of Bihar and Uttar Pradesh.

The Indian Government has launched several initiatives with varying degrees of success over the last fifteen years to try and address the issues at hand. In particular, Government initiatives have been directed at the extension of existing grid infrastructure. The official Government policy entitled the Rajiv Gandhi Grameen Vidyutikaran Yojana claimed to have electrified 95% of un-electrified villages as of January 2014 (Aggarwal, 2014). Further initiatives claim to have electrified 46% of the remaining villages as of May, 2016. However, these claims are not truly indicative of the real underlying issues, namely, poor grid reliability and a flawed definition of electrification. Grid reliability is an enormous issue and in states such as Bihar, village grid reliability can range from 6.3 daily hours in good months to 1.3 hours in bad ones (Oda & Tsujita, 2011). Additionally, the definition of electrification in rural India states that electrification is achieved for a village if infrastructure is provided, public places such as schools are provided with electricity, and if at least 10% of households in a village are connected. This definition suggests that in reality, several million households could go without electricity even once the Government has come and gone. These flaws suggest that a Government based solution may not be the answer to solving the electrification problem in India, thus implying that non-government organisations hold the key to true electricity empowerment.

Globally, Governments and SME have predominantly relied on three major technologies to tackle electrification issues. These include grid extension, distributed renewable energy (DRE) microgrids and solar home systems (SHS). The advantages and disadvantages of each are provided in Table 1.

Table 1. Comparison of major electrification technologies in developing countries.

Solution	Advantages	Disadvantages
Grid Extension	Economical and theoretically unlimited capacity.	Poor reliability due to high transmission losses and administrative complexity.
DRE Microgrids	Reliable due to grid independence and non-reliance on a single power source.	Highly customised and potentially very high maintenance depending on sources of energy used.
SHS	Simple design leads to minimum customisation. Also benefits from grid independence.	Heavily dependent on environmental factors and requires well developed systems to collect revenue from clients.

It was further identified that SHS is a prominent technology for analysis in the rural Indian context. This conclusion was derived from analysis of the comparable markets of Bangladesh and Sub-Saharan Africa. Bangladesh has reported SHS to be a resounding success with 65,000 units being installed monthly (The International Finance Corporation, 2014) by SME supported by Government policy. Similarly, African companies such as M-KOPA in Kenya are able to scale SHS solutions rapidly, installing 15,000 units per month whilst utilising Pay-As-You-Go (PAYG) mobile financing. Consequently, SHS was chosen for analysis in this work due to the simplicity of the solution and the scalability of the solution experienced in other rural markets around the world.

The adoption rate of SHS by rural customers in India has been slow when compared to that of comparable rural electrification markets in Bangladesh and Sub-Saharan Africa. Recent survey data collected from rural households in Uttar Pradesh has helped provide insight into some of the key factors behind this slow uptake. As shown in Figure 1, rural customers reveal dissatisfaction with their current means of lighting. However, respondents revealed perceptions of greater trust in Government authorities and the often unreliable grid based electrification solutions they provide as opposed to SME and their competing renewable based product offerings (Urpelainen, 2016). There is a gap in understanding when it comes to establishing how valid these perceptions truly are. An aversion to risk, characterised by the low incomes of rural Indian customers further adds to the reluctance of the market to adopt SHS as a solution.

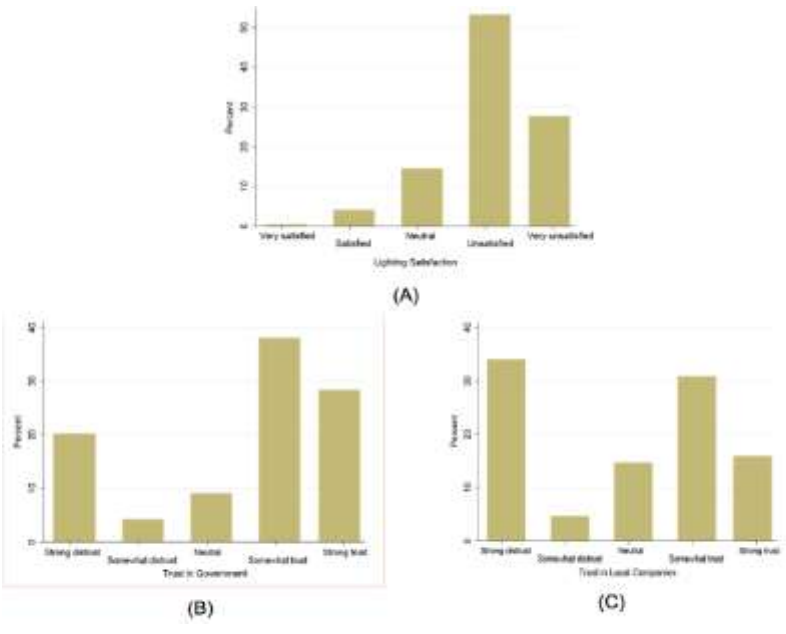


Figure 1: Responses to questions targeted at 1,597 rural households. (A) How satisfied are you with current lighting? (B) Do you trust Government authorities? (C) Do you trust companies operating in this area? (Urpelainen, 2016)

This work offers a new contribution to the investigative space as it provides a technical foundation on which the perceptions surrounding SME and the solar services they provide may be challenged. Similar work has been concerned with solution feasibility and optimal sizing of off-grid technology to suit specific rural sites. This work also touches on solution feasibility, but utilises a novel approach, presented in Section 3, to compare SHS to the grid and to determine its effectiveness in meeting consumer demand. These results are leveraged into concrete business model recommendations for institutions (SME or Government) looking to provide SHS solutions, characterised by a unique five-pronged risk mitigation strategy.

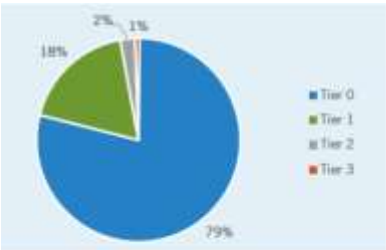
2. Market Analysis

In order to effectively challenge the market perception of SME and the solar solutions they provide compared to Government grid solutions, it is important to segment the market into appropriate tiers characterised by income and electricity access in order to provide sharper focus to the results. The framework utilised was developed by The Council for Energy Environment & Water and uses many metrics, however Table 2 provides a summarised version.

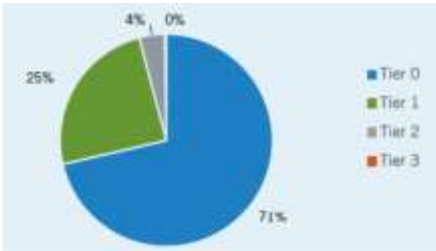
Table 2. A framework for market segmentation. (The Council on Energy, Environment & Water, 2015)

Tier / Dimension	Tier 0	Tier 1	Tier 2	Tier 3
Capacity	No electricity	1-50W	50-500W	>500W
Duration	<4 hrs	4-8 hrs	8-20 hrs	>20hrs

Capacity is defined as the peak power that could be drawn from an electricity connection should a customer have the ability to pay for it. Duration refers to the number of daily hours a household has power available. A market segmentation of Bihar and Uttar Pradesh utilising this framework is presented in Figure 2.



(A)



(B)

Figure 2: Market segmentation in (A) Bihar and (B) Uttar Pradesh (The Council on Energy, Environment & Water, 2015)

The overall markets sizes of Bihar and Uttar Pradesh are 16.9 million and 25.5 million households respectively. It is evident that the vast majority of households are placed in Tiers 0 and 1 and the primary restrictive bottlenecks faced by households are a lack of capacity and poor duration. That is, many households are placed in these tiers because they have no access at all to grid infrastructure. Additionally, several households are placed in these tiers because although they have grid infrastructure available, extremely poor reliability limits access.

It was further identified that customer willingness and ability to pay for energy is linked to the risk taking propensity, and consequently trust in SME for each tier of the market. Ability to pay is defined as the maximum amount an individual is willing to pay for a service and is characterised by existing grid tariffs and expenditure on stopgap services such as kerosene. Conversely, willingness to pay is variable and dependent on the overall perceived quality of available services (Jacobs, 2016). Furthermore, awareness of solar products in the market is high, however, perceived product quality is low due to the prevalence of low quality products such as solar torches (Urpelainen & Yoon, 2015). These factors all contribute to consumer perception of SME and SHS compared to the grid and reveal issues that must be addressed in order to change these perceptions.

3. Method

3.1. Aim

The aim of the work is to determine the effectiveness of an SHS solution to service the needs of rural households in each tier of the market. Solution effectiveness is determined by monthly cost and annual capacity shortage. Hybrid Optimisation of Multiple Electric Renewables (HOMER), is a software that determines optimally sized solutions, costs and associated technical parameters when provided with accurate inputs and sensitivities.

3.2. Method

1. For a Tier 0 household, determine and input the load profile into HOMER. This load profile should reflect daily household energy usage.

SHS Simulation

2. Add a PV array component and input associated capital costs, maintenance cost and technical parameters.
3. Add a solar irradiance resource specific to household location.
4. Add a battery component for storage and input the associated capital cost, maintenance cost and technical parameters.
5. Run a HOMER optimisation simulation across the sensitivities of project lifespan and annualised capacity shortage. Choose an appropriate cost of capital.
6. Aggregate results for optimised solutions based on sensitivities provided and determine most effective solution.

Grid Experiment

7. In a new HOMER simulation, import the household load profile used in Step 1.
8. Add a grid resource and input tariff costs in $USD/kWh.
9. Modify the grid resource such that it becomes unreliable with reliability figures being derived uniquely for each tier. Reliability figures vary from month to month and are expressed in hours of useable power per day.
10. Run a HOMER optimisation simulation for a chosen project lifespan. Remember to choose an appropriate cost of capital.
11. Determine the effectiveness of the solution across sensitivities.
12. Repeat the experiment for each of the four tiers.

3.3. How are results determined?

HOMER provides a plethora of results including system sizing, cash flow projections and levelised cost of energy (LCOE) per kWh for each sensitivity analysed. Annualised capacity shortage and monthly service cost are calculated for each solution and these two concepts are utilised to determine the overall effectiveness and value proposition of a particular service. Annual capacity shortage provides valuable insight into the reliability of a service. The equation for the monthly cost of an SHS solution is given below:

$$SHS_{monthly} = E * (1 - f) * 30 * LCOE * R$$

Where E is daily energy usage, f is capacity shortage and R is the exchange rate (USD to INR). The grid based equation is similar and uses the state tariff as the LCOE. It additionally accounts for monthly connection cost and expenditure on kerosene to supplement poor grid reliability.

4. Key Data Sources and Experimental Inputs

A limitation of HOMER is that the quality of results is directly proportional to the quality of the input data. Consequently, significant effort was invested into the sourcing and creation of accurate input through amalgamation of several sources of data.

4.1. Component Costing and Modelling

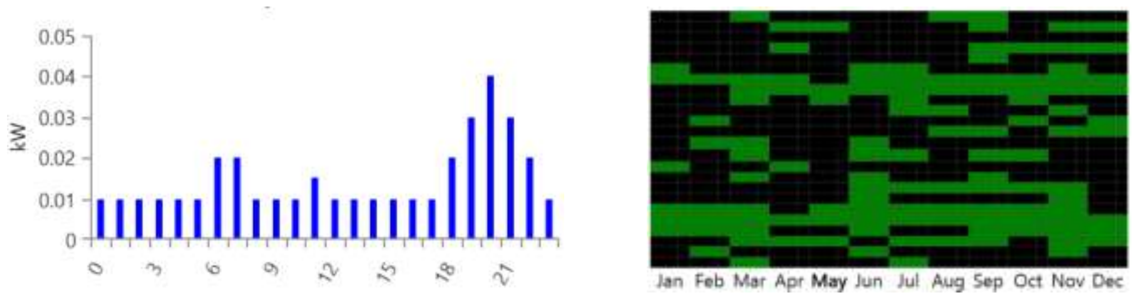
PV arrays and batteries form the backbone of SHS solutions and HOMER allows for the accurate modelling of component behaviour for both components. Through analysis of e-commerce sites and work by leading financial institutions the cost of PV per kW for use in the experiment was determined to be $600 USD (Orlandi, et al., 2016). HOMER is also able to model parameters such as component lifetime, de-rating factor and ground reflectance. Using similar methods, the cost of a 12V 1kWh lead acid battery was estimated at $120 USD (Levin & Thomas, 2016). Factors such as minimum state of charge and float life are also modelled by the software.

4.2. Solar Irradiance Data

The rural locations selected for the experiment were in the district of Sakri in Bihar and Bisalpur in Uttar Pradesh. Annual Global Horizontal Irradiance (GHI) data was sourced from NASA Surface meteorology and Solar Energy databases for the latitude and longitude of each location.

4.3. Load Profiles

Load profiles provide typical household hourly demand based on household appliance usage over the span of 24 hours. Several recent surveys and research studies from rural villages across India were amalgamated to create load profiles for each tier of the market, accounting for appliance ownership per tier as well as peak periods of usage (Mishra & Singh, 2013) (Sahu, et al., 2013) (Sen & Bhattacharyya, 2014). An example load profile for Tier 0 is shown in Figure 3(A).



(A) **(B)**

Figure 3: (A) Hourly load profile for a Tier 0 household. (B) Monthly grid reliability data for a Tier 2 household (green rectangles represent an hour of power availability.

4.4. Grid Reliability

Grid reliability profiles were created for each tier and provide an indication of how many daily hours of power are received by households in each tier. Amalgamation of existing sources was also used in the creation of these profiles (The Council on Energy, Environment & Water, 2015) (Oda & Tsujita, 2011) (Harish, et al., 2014), as well as the use of a purpose developed outage randomiser software to distribute hours of power over each hour in the day. An example grid reliability profile for Tier 2 is shown in Figure 3(B). Each rectangle on the vertical axis represents one hour of the day.

4.5. Grid Tariffs and Kerosene Expenditure

The grid tariff for both metered an unmetered connection was determined using the state rural tariff schedules of Bihar and Uttar Pradesh. In Bihar, Tier 0 and 1 households fall under the Kutir Jyoti (KJ) tariff structure as opposed to the regular rural domestic tariff structure. Monthly kerosene expenditure was also estimated using state kerosene costs per litre and survey data revealing monthly household kerosene usage (International Finance Corporation, 2014).

4.6. Cost of Capital

The official interest rate of 6.5% proposed by the Reserve Bank of Australia in June 2016 was used for this work. It is acknowledged that project specific risk premiums could increase this rate, however, in order to reduce ambiguity between projects it was intentionally un-adjusted.

5. Results

The experimental results for each tier are presented in Table 3.

Table 3: Summary of key experimental results[1]

Tier	Grid		Solar Home System				Competitive
	Capacity Shortage (%)	Monthly Cost (Rs.) (Metered/Unmetered)	Capacity Shortage (%)	Lifetime (years)	System Spec.	Monthly Cost (Rs.)	
0	81.8	**UP:** 172/297 **Bihar:** KJ: 161/177 Domestic: 206/287	10	15	PV: 111W Batteries: 1	165	**YES**
			15	10	PV: 101W Batteries: 1	158	
1	78	**UP:** 191/312 **Bihar:** KJ: 179/192 Domestic: 224/302	10	15	PV: 175W Batteries: 1	231	**YES**
			15	10	PV: 155W Batteries: 1	216	
2	57.3	**UP:** 319/372 **Bihar:** 349/362	40	15	PV: 579W Batteries: 2	523	**CONDITIONAL NO**
3	21	**UP:** 709/297 **Bihar:** 601/289	40	15	PV: 2.18kW Batteries: 5	1521	**NO**

Although several lifespan and capacity shortage sensitivities were simulated, Table 3 provides a summary of the most salient results. In particular, it is noted that SHS is a very effective service for Tier 0 and 1 households from the perspective of capacity shortage and retail competitiveness when compared to the grid. SHS for Tier 2 is classified as being conditionally competitive due to the fact that whilst capacity shortage figures are better than the grid, the monthly cost to receive an SHS service is significantly higher than regular grid expenditure. Thus, it remains at the discretion of the customer as to whether the incremental benefits are worthwhile. SHS is not a competitive solution for Tier 3 households as the size and complexity of the required systems are not feasible for consumer use. Additionally, SHS solutions for this

[1] The exchange rate is assumed to be $1 USD = 66.7 Indian Rupees (October 2016)

tier are not cost competitive with the grid. It is anticipated that for Tiers 2 and 3, co-existence with the grid will be a beneficial solution, however, this has not been explored in this work.

6. Risk: The True Driver of Solution Acceptance

The above results provide a techno-economic foundation on which the perceptions of the market may be challenged, however, the analysis is a small piece of the overall puzzle surrounding risk in such projects. There are several consumer and business side risks faced in the push for SHS adoption. Amongst others, SME face the risk of customer payment default, technology failure and regulatory changes. Meanwhile, the issue of consumer perception of SME and SHS is founded on several risks including perceived product quality and the risk of paying for a solution they know little about to a company they have no institutional trust in. In order to mitigate these risks, a five-pronged strategy for institutions looking to propound SHS (SME or Government) which leverages the experimental results is proposed:

1. **Provide clear value propositions, characterised by product quality and customer service**. It is important to communicate the benefits of SHS technology compared to the grid, particularly the improved capacity shortage and monthly cost. These may be effectively incorporated into business models to provide value, further supplemented by high levels of customer support and product maintenance.
2. **Incorporate a relentless drive to pursue complementary policy from policymakers.** More effective policy related to the reallocation of the existing kerosene subsidy as well as policy pertaining to the definition of electrification are urgently needed. The development and implementation of such policy will be instrumental to long term SME security, customer affordability and the market adoption of SHS.
3. **Ensure that innovative financing mechanisms such as PAYG are utilised** in order to reduce the identified cost gap between consumer ability to pay and actual solution cost. The use of these methodologies reduce financial risks to both customers as well as investors.
4. **Develop strategic synergies with partner companies** in order to diversify the value proposition to customers and to provide increased institutional trust through clear accountability and expertise. Leveraging relationships with financial institutions and telecommunications companies allow for SME to focus on core competency. By creating such synergies, customers are provided with solutions that have wider institutional backing, facilitating trust. Simultaneously, the overall risk borne by SME is reduced as accountability boundaries are made more explicit.
5. **Use technology to build customer relationships and to evolve with customer needs over time.** The use of remote feedback technology allows for a greater understanding of customer behaviour patterns, thus allowing SME to constantly provide solutions that meet customer needs. Additionally, the use of super-efficient appliances within product offerings is worth exploration as they have been proven to significantly reduce overall costs to customers (George, 2016). In an effort to evolve with customers, it is important to note that such evolution might one day involve co-existing with a grid should Government policy remain unchanged.

7. Key Recommendations for SME and Government

7.1. Target the Right Market

- Tier 0 and 1 are the most appropriate market segments for SHS solutions. This appropriateness is gauged based on the reduced annual capacity shortage and retail competitiveness of SHS compared to grid based solutions for these tiers. In the states of Bihar and Uttar Pradesh alone, this represents a market of 40.8 million households.

- Tier 2 households offer potential for SHS solution adoption, however, the solution is only more effective than the grid from the perspective of capacity shortage and not from a monthly cost perspective.

7.2. *Communicate the Rewards Effectively*

- It is critical for SME and Government to effectively communicate that an SHS solution mitigates the restrictive bottlenecks of capacity, poor supply reliability and service affordability.
- Marketing strategies should focus on the immense benefit that is associated with energy access, these benefits facilitate poverty alleviation through provision of vast social, economic, health and environmental benefits.
- Address issues surrounding solution awareness along with consumer willingness to pay by leveraging business models focused on high quality products and convenient financing based on retail competitive pricing outlined in Table 3.

7.3. *Engage Actively with Risk*

- In order to mitigate stakeholder risk, this work proposed a five-pronged approach that builds on the techno-economic findings. This approach is designed to be incorporated into the core business models of SME looking to capitalise on the opportunity present in the rural Indian market.

8. Conclusion

In conclusion, this work was inspired by the staggering number of under-electrified rural Indian households. The high usage of kerosene in the market suggests the existence of an economic opportunity for the application of renewable energy driven by humanitarian motivations. The adoption of SHS as an electrification solution has been slow in India when compared to similar markets. This adoption lethargy is heavily attributed to the greater perceptions of trust that consumers have in Government institutions as opposed to SME who hold the expertise to provide solar solutions. Related to public perception of SME is the market awareness of the technology combined with their willingness and ability to pay for it. These factors all play an integral role in the consumer perception of risk surrounding a solution and consequently their willingness to adopt it. By first breaking the market down into tiers based on electricity access, it was proven that the perceptions surrounding the quality of Government grid based solutions compared to SHS are not entirely valid. That is, the trust given to the grid by consumers by virtue of it being a Government initiative is unfounded.

This conclusion was arrived at through techno-economic analysis using HOMER and it was found that SHS provides a more effective solution than the grid for Tiers 0 and 1 of the market. Effectiveness was defined as being the ability of a solution to meet expected household load profiles whilst maintaining retail competitiveness. The impact of this result were linked to stakeholder perceptions of risk and a strategy was recommended for mitigating these risks. The key recommendations derived from this work are useful in identifying consumer perception validity regarding SHS and SME whilst shedding light on the factors behind slow solution adoption in the rural Indian market.

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