Energy for Sustainable Development 30 (2016) 1–13

Contents lists available at ScienceDirect

Energy for Sustainable Development

Business innovation and diffusion of off-grid solar technologies in India

Kartikeya Singh *

Fletcher School of Law & Diplomacy, Tufts University, USA

ARTICLE INFO

Article history:
Received 25 July 2015
Revised 13 October 2015
Accepted 27 October 2015
Available online xxxx

Keywords:
Energy access
Solar
India
Innovation
Diffusion
Rural development

ABSTRACT

India is a country where 300 million people still live without access to formal electricity, and where hundreds of millions more live with irregular supply through the existing grid network. This paper examines business innovation in the diffusion of off-grid solar technologies in India. An in-country survey of off-grid solar energy providers from across the nation was conducted and coupled with extensive field interviews. Findings reveal that most off-grid solar energy enterprises are not operating in the government subsidy market and that more than half are not offering any form of financing to their customers when selling their products. Also, more than half of the enterprises are selling their products in areas where the electric grid is present. Analysis of data collected suggests that an increase in product categories (lanterns, solar home lighting systems (SHS), micro-grids, etc.) negatively affects unit scaling for a firm but increases the likelihood that the firm is offering financing for its products. In areas without the electricity grid, the number of off-grid solar technology options decreases because the firms operating in the area have fewer categories of technology options. This study finds that off-grid solar technology enterprises that focus on fewer technology categories are more likely to achieve unit scaling. This finding must be balanced with the fact that the extent of the grid has not inhibited the market for off-grid solar technologies, but rather affects the number of categories of technologies that can be offered in those regions. Development programs should thus recognize that those who need electricity access the most may be the ones with the most limited technology options.

Introduction

This study examines the existing and emerging business models for the distribution of off-grid solar technologies in India. It explores why certain models or type of networks help facilitate the diffusion of off-grid solar technologies more than others. For example, do firms that provide energy for multiple purposes achieve greater scale than those just providing energy for lighting? And what lessons can be learned from technology-type choice and its impacts on scaling? The study examines unit scaling of the number of products a company has distributed based on whether or not the firms are selling their products in areas connected to the electricity grid, and whether or not they are providing financing, or using government subsidies. It also assesses the number of states in which firms distribute, whether or not there is a provision for after sales support, and what types of products they are distributing.

Typology of off-grid solar enterprise business models

Both scholars and practitioners alike have attempted the classification of off-grid energy access enterprises. Almost as difficult to define as universal energy access, the challenge in off-grid energy access enterprise classification arises from trying to compare multiple technology types (solar, wind, biomass, etc.) while also having to differentiate between the motivation of the distributor (private vs. non-profit vs. government) and the multiple mechanisms they may employ in order to get their product to the customer. This study focuses on business model innovations in off-grid solar enterprises so the classification system will be informed by the types of off-grid solar technology businesses that operate in this market (see Table 1).

Formal vs. informal

Most studies of the off-grid solar market in India have focused on enterprises operating in the formal market or "under formal" regimes (Balachandra, 2011; Chaurey et al., 2012; Harish et al., 2013). These are registered established businesses small and large, which focused completely on solar technologies or part of a larger industrial conglomerate. They can also be recent start-ups that have emerged from the flurry of investment in energy access technology and business innovation. Examples of formal market players include TATA solar, the Solar Electric Lighting Company (SELCO), Orb Energy or recent entrants such as Green Light Planet or Mera Gao Power. There are, however, a large number of entrepreneurs who are operating in the informal market, assembling electronic components, ordering parts wholesale in order to create customized solar home lighting products for rural customers. The business models of these entrepreneurs operating in the informal market have not been studied in detail before, but they are nonetheless a crucial part of the local solar energy ecosystem and can be found throughout the country in areas where electricity access is lacking or unreliable.

* 1438 Harvard Street, NW, Unit 2, Washington, DC 20009, USA. Tel.: +1 864 640 0342.

http://dx.doi.org/10.1016/j.esd.2015.10.011
0973-0826/

Table 1
The typology of off-grid solar enterprise business models operating in India.

Typology of off-grid solar enterprise business models		
Type	Description	Examples
Formal	• Operate under formal regimes • Start-ups or established companies • Headquartered in cities	SELCO, TATA Solar, and Mera Gao Power
Informal	• Operate on the margins • Potentially high volume of sales • Highly embedded in local rural economy	Independent sales agents
Retail	• Relies on company or independently owned network of franchise shops • Concession goes to the retailer of product	Orb Energy and D.light Design
Direct marketing	• Relies on independent sales agents (village level entrepreneurs) • Targets "last mile" customers • Sales commission paid by company to sales agent on each product sold	Green Light Planet and Sakhi Retail
Sell	• Requires customer to travel to authorized maintenance and servicing center • Extreme case no after sales support or even warranty	Akshay Urja Shops and informal sales agents
Sell & service	• Quality after sales servicing support • Company technicians travel to customers' homes for servicing	
Full payment	• Off the shelf purchasing • Financing may or may not be available to assist customer • Customer owns product	TATA Solar, Orb Energy, and Green Light Planet
Rental	• Customer pays daily/weekly fee to an entrepreneur/company • No financing required because of small payments • Customer never owns the product	TERI's Light a Billion Lives
Pay-as-you-go	• Uses mobile money transfers and smart metering technology • Payments are tailored to match customer's energy consumption • Progressive purchase: a "pay-to-own" model	SimpaNetworks and OMC Power
Community managed	• Responsibility for management and ownership shared by community • Relies on communally agreed to governance structure, tariffs, and shared costs for maintenance	Sunlit Futures and Gram Oorja micro-grids
Entrepreneur based	• Responsibility of management and ownership falls on individual • Relies on social standing, capital and networks of entrepreneur in community	Orb Energy and MNRE's Akshay Urja Shops

Retail vs. direct marketing

The two main competing methods of distributing off-grid solar products are retail and direct marketing. Retail models such as Orb Energy's, can be based on a network of company or independently owned franchises run by entrepreneurs that must sell only Orb Energy's products. Retail models can also be as simple as D.light Design's, where the company's products are sold through various partner channels and independently-owned convenience stores like any consumer good. A portion of the profit (concession) goes to the retailer of the product. Direct marketing is a concept that has been employed to target the "last-mile" of service needs in rural areas. Operating through a network of local independent sales agents, known as "village-level entrepreneurs" (VLEs), who are not working full-time for the company, they serve as focal points for the sales of a company's products in their communities. VLEs relieve a parent corporation of the need to establish a physical presence. Establishment of a supply chain and better maintenance and repairs are added benefits of this model. VLEs often take a commission on sales as an incentive to participate in the company's model. Companies that are employing this model include Green Light Planet and Sakhi Retail.

Sell vs. sell & servicing company

Another way to differentiate off-grid solar business models in India is whether the firm is simply selling the product or is selling and providing after sales service. Some companies such as SELCO market themselves as a "servicing company," proud of the after-sales support and servicing that their company provides. Servicing companies have their own technicians that go to the customer's home to repair products whereas companies following simply the "sell" model require customers to take their product to an authorized servicing center (which may be located in the district headquarters). In the most extreme case, a "sell only" firm may provide no after sales servicing or maintenance and may not even provide a warranty. Examples of "sell only" firms include government authorized retailers known as owners of "Akshay Urja" shops, some firms from China and other markets starting to sell products in India and some informal off-grid sales agents.

Full payment vs. rental vs. pay-as-you-go

At the advent of off-grid solar sales in India, and arguably many other parts of the world, the simplest business model simply involved selling the technology to the customer. Governments have subsidized the costs to different degrees over time so that those who require financing can obtain it. This approach is still used by a large percentage of off-grid solar technology enterprises including SELCO, Orb Energy, Tata Solar, and Green Light Planet. However, attempts to reach customers from the base of the pyramid market who often lack the ability to pay upfront for goods and services or who lack access to formal banking has required innovative forms of financing to sell solar technologies. This has led to the emergence of rental models such as the Energy & Resources Institute's (TERI) "light a billion lives" (LABL) project that involves customers paying a small fee to rent lanterns every day from an entrepreneur who operates a solar charging station. Pay-as-you-go (PAYG) models are emerging where innovations for smart meters and mobile money transfers have taken root. This is relatively new in India as the Reserve Bank of India, the body responsible for banking and finance regulations, has only recently relaxed rules for mobile money payments in the country. Micro-grid companies such as OMC Power and Nature Infratec are using this technology to make payments for their customers easier. Simpa Networks is using this model for customers using solar home lighting systems in a "pay-to-own" progressive purchasing model. Customers pay for as much energy as they hope to consume using the balance on their mobile phone before they are allowed to have access to the electricity. This allows the customer to tailor their energy demand and mirrors utility-scale electricity models most closely. In the case of Simpa Networks, customers are essentially putting down payments towards eventual ownership of the asset.

Community managed vs. entrepreneur based

The final classification for off-grid solar technology business models is community managed versus entrepreneur owned and operated. Community managed models primarily involve solar micro-grids that are owned, operated, and managed under the authority of a village governance body. This body can be charged with the responsibility of designating a tariff structure, a payment cycle (monthly versus weekly), and maintenance and servicing needs. Furthermore, the village authority under the leadership of the chief can establish dispute resolution mechanisms and enforce penalties for non-payments. Examples of such models include Greenpeace's 100 kW micro-grid in Dharnai, and SunLit Futures and Gram Oorja's micro-grid projects in Maharashtra. Entrepreneur models require an individual to take out a loan from a bank under the guidance or persuasion of an established off-grid solar energy enterprise, government institution, NGO, or foundation, in order to start their own solar business in their local community. This model relies on the social

standing, capital and networks of the entrepreneur in her or his community. This guarantees responsibility for after-sales support or servicing to the local customers and extends the reach of the parent firm. Examples include Orb Energy's franchisees who sell everything from solar lanterns to solar hot water heaters, TERI's micro-grid and LABL solar lantern entrepreneurs, as well as the government's authorized solar retail network of "Akshay Urja" shops.

Methodology

Target respondents and data limitations

The number of solar micro-energy enterprises participating in the formal market in India is debatable. The United Nations Foundation established an "Energy Access Practitioner Network" of which approximately 34 members from India fall into the category of solar PV-based energy providers. A report compiled by the Council on Energy Environment & Water (CEEW) in 2013 suggested that the number of solar off-grid entrepreneurs across the country (operating both in the formal *and* informal market) was 231 (CEEW, 2013). Finally, the most recent report compiled by the Climate Group analyzing the business environment for off-grid solar enterprises in India was based on analyses of 40 major players (TCG, 2015).

This study captured 69 respondents operating in the formal off-grid solar market in India. If the total estimated number of off-grid solar technology entrepreneurs operating in the formal market in India is approximately 100, the sample size used in this study represents 69% of this population. Because the questionnaire was distributed online, it eliminated the possibility of participation from small solar entrepreneurs operating in the informal market or who could not communicate in English. This is the primary difference between the methodology employed by this study and that of CEEW, which identified more players but captured less detailed information about each of those players. In addition, 14 in-person semi-structured interviews were conducted with the CEOs of off-grid solar energy companies operating in the formal market in the country to gain deeper insights about the industry beyond the information collected in the online questionnaire. Some of the data collected in the broader study also involved a telephonic survey of 170 government-authorized retailers of off-grid solar technologies from across the country.

Respondents were not compensated for participating in the survey. Because of a lack of quality data on the many enterprises operating in the off-grid solar sector in India, entrepreneurs, financial institutions, government and think tanks all desire access to this information. It is believed that respondents participated in the study because they believed that the results of the study (unique in the broad span of geography covered and the depth of information collected about each enterprise) might shed light on the overall health of the off-grid solar technology market and how they may improve their business. The accuracy of sales data provided by respondents in the questionnaire could be questioned because respondents are inclined to underreport in case details about sales are leaked to tax authorities. Underreporting of sales figures may be particularly true for smaller start-ups and entrepreneurs operating in the informal market. Much of the material asked for in the questionnaire was not sensitive information. Aggregated sales data over time for all the enterprises, which chose to disclose these details, provided an estimated snapshot of the extent of off-grid solar technology diffusion in the country. There have been varying reports of the number of off-grid solar technologies owned by people across India, including those reported through government census. None of these numbers are ever the same and it should be noted that this study provides yet another set of data which should be considered along with previous studies in order to continue to understand the complex landscape that is the off-grid energy access market in India. Detailed case studies of a few of the companies included field visits to their customers to verify responses from interviews and identify the challenges and opportunities post-deployment of various kinds of business models. These field visits were conducted primarily between April–September 2014 to villages in West Bengal, Bihar, Uttar Pradesh, Rajasthan and Karnataka. A total of 80 in-depth personal semi-structured interviews were conducted across a range of business models and companies represented.[1]

Survey questionnaire

A survey tool, consisting of a structured questionnaire, was developed for use in this study and included questions on the following issues:

- Types of products sold
- Number of products sold/distributed
- Geography of distribution
- Primary reasons customers purchase their products (lighting, etc.)
- Information regarding warranty
- Availability of financing to purchase products
- Participation in government subsidy market
- Information regarding research and development budgets
- Marketing
- After sales maintenance and servicing
- Perceived barriers to market entry and scaling up

Dissemination method

Several networks of energy and environment practitioners across the country were tapped to send out the online questionnaire via email, for example, the questionnaire was sent out through the UN Energy Access Practitioner Network to its India members. This list included members of the informal "renewable energy working group" which also includes several energy access practitioners as well as members of the Ashden Energy Collective, a consortium of India-based winners of the prestigious Ashden Award for sustainable energy. The largest online portal for solar business in the country operated by consulting firm, Bridge to India, was also leveraged to reach out to the off-grid solar energy entrepreneurs who may not have been part of the other networks. The survey tool was kept open for the collection of responses between April 2014 and December 2014. Participation was voluntary and respondents were assured that no information would be put in the public domain that related their enterprise name to any sensitive data.

Respondent types

Fifty (72%) of the respondents were private companies, fifteen (22%) were non-profit organizations, 2 (3%) were financial institutions, and 2 (3%) were self-classified as "other" (Fig. 1).

Method of analysis

A study as rich in data as this one requires a variety of methods of analysis to unpack all of the information gathered. For the purposes of this paper, the primary method employed to explore the quantitative data was statistical analysis. Using Microsoft Excel as an organizing tool, descriptive statistics was utilized to explore patterns and summarize the data.

Using STATA, linear regressions were conducted to reveal possible correlations between the variables unique to each enterprise. This method of analysis sheds light on the main question of this study: factors affecting the scaling-up (or not) of off-grid solar technologies

[1] Greater examination of customer data will be the focus of another paper as part of this broader study. Sample information gathered during those interviews includes: demographic information, employment-type, availability of grid access, house-type, household energy profile, technology purchased, how financed, maintenance issues, willingness to pay, money saved through fuel-switching, recommendations to others to purchase, etc.

Fig. 1. A graph representing respondent types of the online offgrid solar technology enterprise survey.

in India. Data from in-depth semi-structured interviews with the CEOs of off-grid solar enterprises and their customers were used to further explore and explain the results of the quantitative analysis. Detailed qualitative and quantitative analyses of the in-depth interviews with the entrepreneurs and their customers will be explored in subsequent papers associated with this study.

A note on comparison between types of enterprises: it could be rightly pointed out that one cannot compare enterprises that sell products to individual households such as solar lanterns with those who use a communally shared energy source (solar PV panels) to sell electricity to households. This could perhaps be considered a limitation of the study. However, in order to create consistency for comparison, an end-user perspective was used as the method of analysis, especially when incorporating sales data. Take for example that the industry-wide standard in the off-grid solar technology enterprise is to provide lighting and mobile charging at the very least whether through lanterns, SHS, or micro-grids. This study then assumes that customers that receive a "service" (electricity for lighting and mobile phone charging) through a communally shared energy source can be compared on average to those who receive electricity from individually owned SHS or lanterns for the same purposes. Secondly, that a firm's unit scaling is comparable when one assumes that one household is receiving on average the same service (particularly those sampled in this study) through micro-grids as they could through SHS or some types of lanterns that also allow for mobile charging.[2] Finally, several of the firms incorporated in this study cross the spectrum of types of technologies they provide — some that provide electricity to customers through a micro-grid also sell SHS and solar lanterns, while those that sell exclusively lanterns are starting to sell SHS and considering micro-grids as the next step. With this understanding and holding constant that several factors according to literature are common for an off-grid provider (such as after-sales support, the provision of a warranty, the provision of finance, the ability to have geographical spread across states in areas without or without the electrical grid, etc.), the comparison becomes quite logical as the best way to comprehensively study how off-grid solar technologies diffuse in India. The various firms become natural competitors rather than completely distinct entities. Regardless of the limitations, the challenge of conducting a comprehensive study of this sector is clear — it is too decentralized and the information difficult to collect. Thus this attempt becomes at least an important launching point to discuss how these low-carbon technologies do or do not achieve scale.

Theory

Scholars and practitioners studying factors affecting the scaling up of off-grid solar technologies cite various barriers to "success" or successful diffusion, including finance, technology-type, government policies, and socio-cultural factors. Pilot studies of technology deployment by companies and government programs are often the subject of these studies. Rarely has a scholarly study been undertaken that examines the entire market of businesses within a country, including various cases and geographies to give a bigger picture of how (or how not) this technology scales-up.

Scaling of low-carbon technologies

The importance of studying the scaling of low-carbon energy technologies comes at a time when humanity must try to develop and thrive within the confines of global carbon budget, or risk dangerous impacts from runaway climate change (Meinshausen et al., 2009). Understanding and applying whether and how these low-carbon energy technologies scale, and what factors influence scaling may be a way to stave-off a runaway climate change scenario. A study conducted by Wilson (2009) reveals insights into the nature of low-carbon technology scaling including the suggestion that industry scaling "tends to be faster when unit scaling is faster." Certain factors appear to aid more rapid spatial diffusion. These factors include the level of a product's homogeneity, ready substitutability of the incumbent technology, and "an undifferentiated globalized market that is not constrained by localized intellectual property regimes and is not overly protected by trade barriers." Such products (such as CFLs and wind turbines examined by Wilson) can more rapidly diffuse from the "core" to the "rim." While this study cannot simply replicate Wilson's study using off-grid solar technologies (for reasons of lack of adequate data, particularly with regards to time and the diffuse nature of the technology and players), it aims to investigate whether off-grid solar technologies, and the firms that provide them in India, can provide insight about how this low-carbon technology may or may not scale.

Diffusion

Scaling of technologies requires understanding how they diffuse. Rogers (2003) states that perceptions of technology, as well as locally-present indigenous knowledge systems can play a large role in the diffusion of and acceptance of technologies. In addition to a technology's attributes that can influence its "rate of adoption,"[3] there are other culturally dependent factors, including "the nature of communication channels diffusing the innovation" and the role and respect of early adopters in communities. Specifically, Rogers states that diffusion happens through certain channels (interpersonal or mass media), over time (influenced by rates of adoption, the innovation-decision process, and the innovativeness of the individual) and facilitated by certain people (opinion leaders or change agents). Lessons learned from the dissemination of SHS through World Bank supported projects between 1993 and 2000 reveal that most were supported by some level of consumer awareness and marketing program (Martinot et al., 2001) thus following the mass media channel model of diffusion highlighted by Rogers.

The issue of networks in helping technologies diffuse is of high importance. Rogers defines a communication network as "interconnected

[2] Assumption: A firm providing 500 households with electricity for lighting and mobile phone charging through a micro-grid is equal to 500 units of "scale." A firm that is selling 500 SHS, 200 solar lanterns, and providing 300 households with electricity for lighting and mobile charging through micro-grids is equal to 1000 units of "scale."

[3] The five attributes include: relative advantage, compatibility, complexity, trialability, and observability. See Everett Rogers, *Diffusion of Innovations*, 5th Ed. (New York, NY: Free Press, 2003), p. 222.

individuals who are linked by patterned flows of information" (Rogers, 2003). Specifically, it is the opinion leader's "interpersonal networks that allow her or him to serve as a social model whose innovative behavior is imitated by many other members of the system." Off-grid solar technologies would likely diffuse faster in a village if the village head or someone of high social stature considers adoption first. Indeed, this seems to be the approach of off-grid solar enterprises utilizing a direct marketing approach. Communication network analysis as described by Rogers "identifies the communication structure in a system by using interpersonal communication relationships as the units of analysis in analyzing network data about communication flows." The various kinds of communication network structures include personal communication network, interlocking personal network, and radial personal network. Each of these may serve as the basis for observing off-grid solar technology adoption in rural India. The head of the village, a *Sarpanch*, may be connected to members of his or her own religion, caste, and social class affecting people in their personal, interlocking and radial personal networks with varying degrees of connectedness among the members to whom the *Sarpanch* is surely connected. It is important to note that some of these ties may be classified as weak or strong (sometimes influenced by physical distance) and can be defined as communication proximity, or "the degree to which two individuals in a network have overlapping personal communication networks."

Innovation systems

Solar energy technologies do not operate in vacuums. They are born and operate in complex systems where technologies interact with various networks and institutions from the stage of innovation to deployment. Sagar and Holdren (2002) argue that national energy innovation systems comprise of the network of institutions that develop, modify, and diffuse new energy technology. Other studies have revealed that the process of innovation emerges through the efforts of entrepreneurs and innovators who operate within the confines of an innovation system (Lundvall, 1992; Nelson, 1993). Thus, SHS technological diffusion and adoption are part of a wider solar energy technology innovation system (ETIS) and the solar ETIS, in turn, is part of the wider ETIS (Gallagher et al., 2012).

These systems may be different in different geographies and one could assume that India's ETIS and solar ETIS are different from those of neighboring China depending upon local technological abilities, government support, and trade barriers. A recent study analyzing the various providers of SHS in India has identified the need to create a strong ecosystem with greater information flow in order for the SHS sector to scale rapidly in India (CEEW, 2013). The various players and parts of the ecosystem described in the analysis include: "enterprises (both corporate and social ventures such as those discussed in the introduction section) of varying size, scale and operating in different locations" alongside a finance ecosystem which at present is not uniformly well connected to the needs of the enterprises.

Business innovation

Tawney et al. (2013) state that innovation in the business models that help diffusion and adoption of off-grid solar technology might address the challenges associated with finance, lack of supply chains, and after sales support. Indeed the off-grid solar technology market is "entering a new phase that is being led by entrepreneurs [operating both in the informal as well as formal markets as discussed earlier] providing solar portable lights," and while the scale is currently small and costs present a barrier, "the technology is improving at a rapid rate and business models are maturing" (Birol, 2011). For solar lantern technology, Chaurey et al. (2012) compare the ownership versus fee-for-service/rental models of dissemination. Their results reveal that a central charging station model (rental model) is not viable even with 100% capital subsidy support. This is because the households were "unwilling to pay a daily rental that is more than the effective daily cost of owning a solar lantern."

As alluded to before, cases of technology deployment have been unsuccessful when companies have not established a proper supply chain to provide the maintenance and replacement parts for the technologies (Bairiganjan and Sanyal, 2013). Rural base of the pyramid (BoP) customers must be able to consistently use these end-use energy products. Failure of a technology to work due to improper system management can affect technology adoption by the same community down the road. A particular example comes from a village in the northwestern Indian state of Rajasthan, where a community had been given LED-based solar home lighting systems for which there was no local provider to replace the specific system's batteries or provide bulbs, much less the 12 watt solar panels (Singh, 2007). Within a year, several households' systems fell into disrepair with no local knowledge or expertise in how to fix or maintain the products. Bairiganjan and Sanyal (2013) suggest filling this gap with VLE networks that can work with local villagers to improve the access of different products across remote rural areas.

These findings support the Tawney et al. (2013) argument that business and finance innovations (including not only the products but also the processes) are required to help address the energy access challenge. An evaluation of cases from the Indian state of Karnataka reveals that "the viability of SHS market is critically dependent on the role that banks play as intermediaries between consumers and solar firms in rural areas" (Harish et al., 2013). Martinot et al. (2001) and Gallagher (2014) would add that the SHS industry as a whole could use market-formation policies such as effective equipment standardization and certification procedures to ensure quality of service and affordability. Wong advocates easy access to credit for users as well as a robust complaint system to address some of the maintenance and supply chain failures associated with SHS technologies (Wong 2012). Such studies have important implications for off-grid solar technology providers who are attempting to establish an appropriate price point for their product and design effective systems for the adoption of their technology.

It is important to note that while the geography of the innovation system that gives rise to these technologies certainly matters (Asheim and Gertler, 2005), not only is the flow of technology no longer unidirectional (North-South) as Gallagher (2014) confirms, but the discourse on conditions that promote North–South technology transfer (Forsyth, 2005; Paulsson, 2009) has "acknowledged the need to adapt technologies to local contexts and the potential for technologies to be transferred between developing countries" (Tawney et al., 2013). With mounting empirical evidence from impacts of decentralized energy deployment in rural communities (Ranganathan, 2003; Singh, 2007; Dehejia, 2012), it is safe to say that "significant differences between the technologies appropriate in each [North and South] context suggest[s] that developed countries may lack the innovation capabilities necessary to meet the energy access challenge [of the global South]" (Tawney et al., 2013). If this is true, then one might expect the most successful off-grid solar technology providers to be started in the global South or have significant links through partnerships with supporting institutions in the countries in which their technologies are deployed.

Given that the Indian government has created targets for using only off-grid renewable energy technologies to electrify 25,000 of the remotest villages and is increasingly championing solar projects that use domestically sourced components, one might expect the diffusion potential of off-grid solar technologies to be quite high in the country. An analysis conducted by Chaurey et al. (2012) attempts to place the potential of solar lantern diffusion in India at 46 million households, simply based on their analysis of rural households that pay up to 10% of their monthly bills on fuel (kerosene). If policies are enacted to create greater technological or fuel choice for energy rather than simply subsidizing kerosene for lighting, the diffusion potential might increase dramatically.

Finally, policies that alter the private market to create structural incentives may not be enough to drive the diffusion of off-grid solar technologies. Tawney et al. (2013) emphasize that "pro-poor energy innovation can be understood as a process that explicitly involves the poor as end-users of the resulting solutions." Empirical evidence from the field (Bazilian et al., 2008; Bardouille, 2012) reveals that extensive stakeholder engagement throughout the energy solution development and deployment process is central to the long-term success of efforts to expand access to energy. The task of this study then is to shed light on the factors and practices unique to a firm that affect the scaling-up (or not) of off-grid solar technologies in a country with one of the largest un-electrified populations in the world.

Results and discussion

Grid and geography

To test whether or not the market for off-grid solar technologies was limited by the extent of the electric grid, the study asked enterprise owners whether or not they distributed their products or operated in areas with central grid connectivity. Responses revealed that a majority of enterprises provided solar-based energy in areas with grid access. While 19% of the respondents stated that they did not operate in areas serviced by the grid, 36% said "yes" and another 45% responded "sometimes" suggesting that their operations across the country were varied but that their technologies would reach the market regardless of grid presence.

India's struggle to meet its electricity demand nationally has resulted in inadequate service of electricity to even those villages that have access to the grid. One of the interesting caveats in the government's electrification program, for example, is that only 10% of the households in the village need to be connected to the grid for the entire village to be technically defined as electrified. This glaring case of conflicting political goals and realities of implementation of policy could, theoretically, render the entire country "electrified," but 200–300 million people will still be without access to grid power.[4]

India also faces high transmission and distribution (T&D) losses. Losses through transmission and distribution of electricity are a big contributor to power deficits running as high as 4350 MW (Singh, 2013). Official T&D losses stand at 23% of electricity generated—one of the highest in the world. Independent analysis and a survey of various states reveal, however, that the figure may be as high as 53% in some states (Navani et al., 2012). The main reasons for T&D losses are poor infrastructure and power theft (Gregory, 2006). There is a vicious cycle driven by the challenge of T&D losses: "in the absence of a realistic estimate of T&D losses, it is not possible for regulatory commissions to correctly estimate the revenue requirements and avoid the situation where the consumers pay for the inefficiencies of the utilities" (Bhalla, 2000). Furthermore, the lack of realistic estimates of T&D losses acts as a disincentive for private sector participation in power distribution, investment that the sector desperately needs in order to become strengthened.

Bhalla cites that large-scale rural electrification through long 11 kV and low tension lines along with haphazard growths of the sub-transmission and distribution system with the short-term objective of extension of power supply to new areas is also to blame for the shortage of electricity supply. Even Singh (2009) states that in order for the Indian power transmission system to be more efficient and reduce greenhouse gas emissions from the sector at large, a switch from low tension to high-tension lines would be helpful. This presents an interesting dilemma for the country that needs an efficient transmission and distribution system to better utilize its limited energy resources but is also trying to rapidly expand energy access to new areas. These factors combined with the results of the survey essentially support the hypothesis that the market for off-grid solar technologies in India is not limited by the extent of the electricity grid.

If not limited by the grid, perhaps certain geographies play a role in a firm's ability to scale. An analysis conducted by Sanyal (2014) maps out the micro-markets for energy access entrepreneurs and identifies the states with the highest rates of electrification using government census data (see Fig. 2 map on left). According to the data, states in the north and east of India have higher rates of rural un-electrification followed by states in western India. When comparing state-wise electrification data with data collected by the online survey of off-grid solar energy providers, an interesting story emerges. Respondents were asked which states their products and services were offered in. The map on the right shown in Fig. 2 depicts the spread of states from which the respondents draw their collective experience in distribution of off-grid solar technologies in India. As depicted by the color gradient (from yellow to red), some states have a higher concentration of off-grid solar energy enterprises operating in them than others. The states that correspond with the lowest level of rural un-electrification are also the places where several firms from the survey claim to be selling off-grid solar technologies. Only the states of Bihar, Orissa and Uttar Pradesh in the east and north respectively have rural un-electrification rates above 50% and correspond with a large number of off-grid solar technology providers selling products there, thus, further reinforcing the hypothesis that the market for off-grid solar technologies in India is not limited by the extent of the electricity grid.

Products offered and uses

Respondents were asked to identify which off-grid solar energy products they offered to ascertain the distribution of product-types among the respondents. For the purposes of this study, the options provided to the respondents included: 1) lanterns; 2) solar home lighting systems (SHS); 3) micro-grids; and 4) others. The latter could include devices like solar street lighting and solar hot water heaters. The group of respondents participating in this survey largely provided solar home lighting systems with lanterns and micro-grids ranking second and third, respectively but not by much (Fig. 3 graph on left). The results are depicted by type of provider (private, non-profit, etc.) and reveals that private companies operating in this market are focusing on SHS first, followed by micro-grids and then lanterns whereas non-profits are focusing on lanterns first, then SHS followed by other products then micro-grids.

Respondents were also asked to choose how best to describe what services their customers derive from their products. The options included: 1) extending work hours; 2) lighting for children's studies; 3) for field (outdoor) use; and 4) for powering appliances such as televisions, fans, and mobile phones. Respondents were asked to select all that applied to their products. Powering appliances such as mobile phones, fans, and televisions led the primary purpose of purchasing products while lighting needs seemed to be the secondary focus. Enhancing productive hours and portability (outdoor use) ranked third and fourth respectively (Fig. 3 graph on right). Once again, the figure differentiates between different provider-types and one can see that customers of non-profit distributors see the main benefit of the products purchased being "lighting for children's studies" whereas the primary use identified by customers of private companies is "powering appliances" followed by lighting.

The difference between private companies and non-profit distributors' perceived benefit for their customers from their products might be based on their marketing strategies. Many charitable trusts and non-profit providers may be beholden to donors who wish to see the impacts of their products reported and often these are tied to development goals such as education and healthcare improvements. As such, lighting needs provided by lanterns, as a primary perceived benefit for the customers of non-profit distributors is not at all surprising. The second point of interest that arises from this data is that powering

[4] Definition of electrified village under the Ministry of Power's Memorandum No.42/1/2001-D(RE), February 5, 2004.

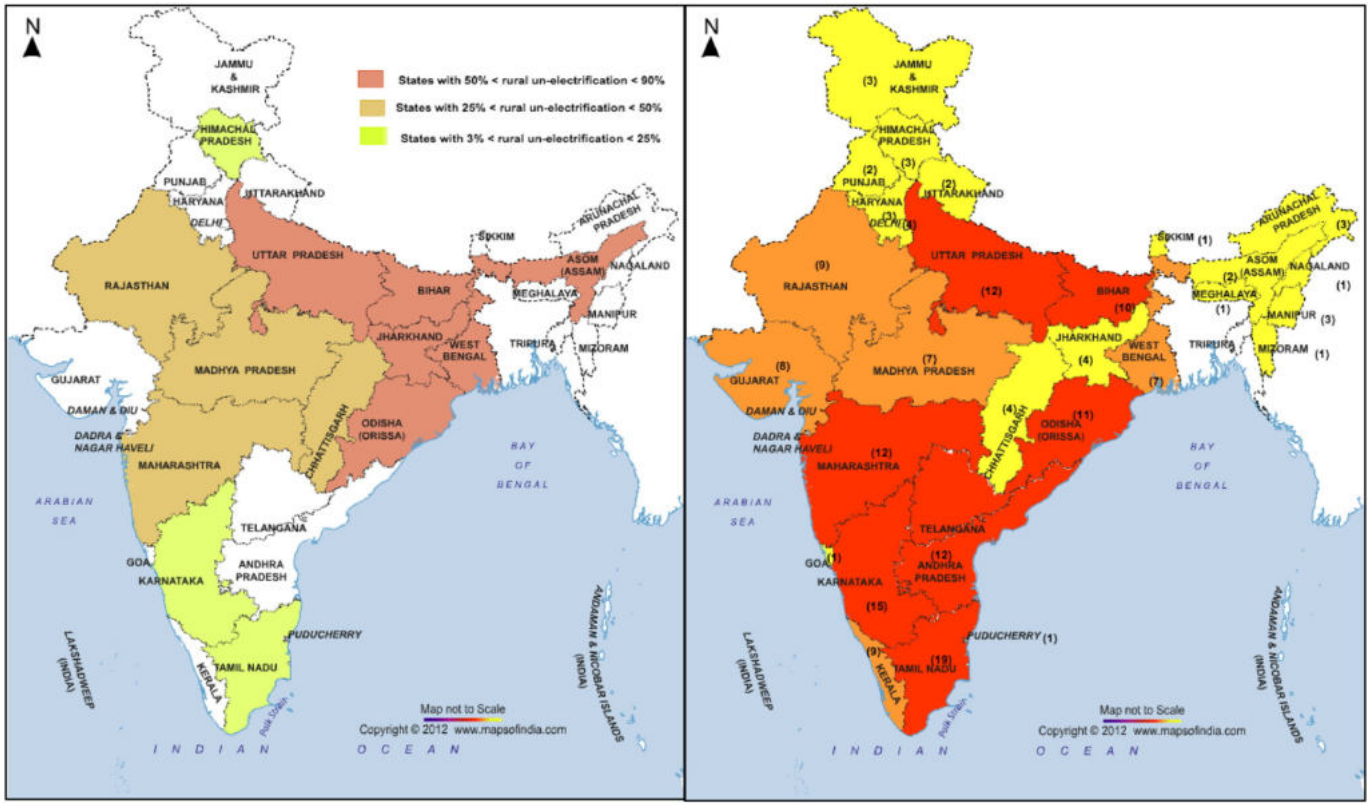

Fig. 2. Comparison of un-electrification rates with number of off-grid solar technology providers distributing per state based on survey.

other appliances takes the lead over lighting uses for customers as reported by the firms. More than one expert interviewed in India during the fieldwork to support this study stated that secondary technologies might be driving the diffusion of solar energy technology. For example, few providers offer solutions that do not come with mobile phone charging ports on their solar lighting device. In a country where more people have access to mobile phones than toilets (Telegraph, 2010), and the average rural customer may be paying anywhere between $0.8–0.16 per complete charge of their phone at a local shop, the need for solar as more than a lighting solution becomes evident. The advent of the low-watt LED television is sure to push the efficiency and use of off-grid solar technologies further. This potential trajectory highlights the overlaps between technologies in the technology innovation systems discussed previously. As companies such as Orb and Onergy start providing yet another product as part of their "solar package" the same 40 watt SHS can now not only power light bulbs but also provide enough electricity to power a family's new television. Likely to readily adopt advanced technology, the base of the pyramid consumers consider televisions to be an "aspirational product" (Prahlad, 2010). Thus "PV-TV" which combines the power source with an emergent aspirational product is perhaps the next technological wave that will drive solar technology diffusion for the off-grid market.

After sales and warranty

After-sales servicing is a major factor affecting the success of off-grid solar energy enterprises. Thus respondents were asked whether or not they provided after-sales support for maintenance of products. Sixty-

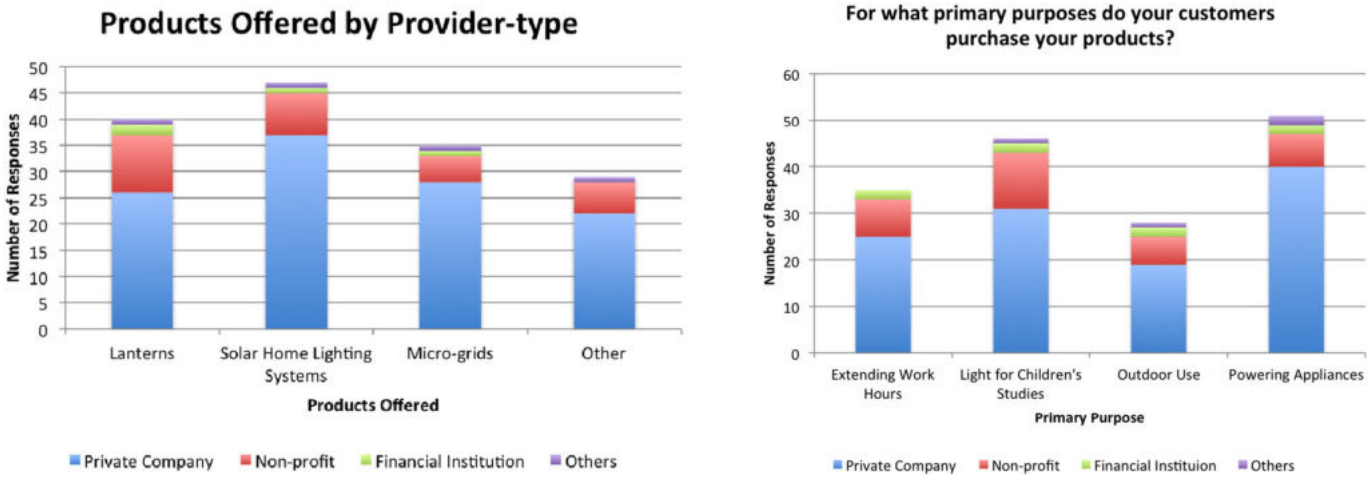

Fig. 3. The graph on the left depicts the distribution of products offered by type of provider and the graph on the right depicts the distribution of use of products by provider type.

three (90%) respondents stated, "yes" (outer ring of Fig. 4). When asked what type of after-sales support was offered, the responses can be categorized into the following: maintenance through service centers, replacement of entire products, on-site maintenance with the help of technicians, over the phone service, and linking customers directly with product manufacturers for further assistance.

The available warranty options were categorized into one year, two years and three or more years. Twenty-five (36%) of the respondents offered a one year warranty, thirteen (19%) offered a two year warranty and thirty-one (45%) offered a warranty for three or more years (inner ring of Fig. 4). Outside of the warranty period, several firms offer customers the option of signing annual maintenance contracts (AMCs) for an additional fixed charge.

Since their advent, proper maintenance and after-sales support have been a challenge for sustaining of off-grid solar technologies in the field post-deployment. Customers and practitioners in the field have noticed sales agents who sell low-quality products and disappear when the product needs servicing. This phenomenon has affected perceptions of off-grid solar technologies in many communities in India. Furthermore, it may have the effect of "ruining the market," a condition best described as unwillingness by rural communities to purchase solar technologies from new firms after having or hearing about a bad experience someone had with prior solar technologies and distributors. While not everyone is able to offer quality after sales support or warranty, the results of this survey indicate that the majority of off-grid solar firms operating in the formal market today are providing it and have at least one year of warranty insuring the servicing of their products. This consistency in the industry should then have no impact on the overall ability of any one firm to achieve unit scaling simply using warranty and after sales service provision as factors.

Financing and government subsidies

As discussed previously, financing is a key part of the larger energy technology innovation system and no study of the off-grid solar technology sector is complete without examining this element critical for its diffusion. Respondents were asked whether or not they operated under or used government subsidies to sell their products. An overwhelming number of respondents (72%) did not sell products using the government subsidy mechanism (outer ring of Fig. 5). Respondents were also asked whether they provided financing for their products to their customers. Forty-five (65%) of the respondents provided no financing while the rest offered a mix of financing from micro-finance institutions (MFIs), self help groups (SHGs) and rural bank (RB) branches (middle ring of Fig. 5).

Finally, respondents who did not offer financing for their products were asked how they sold their products or services. The majority of respondents (82%) conducted their business through direct sales (cash only) while the remainder relied on funds from bilateral aid, disaster relief funds, political funds allotted to Members of Parliament (MP) or Members of State Legislative Assembly (MLA) and corporate social responsibility (CSR) or other grant funding (inner ring of Fig. 5).

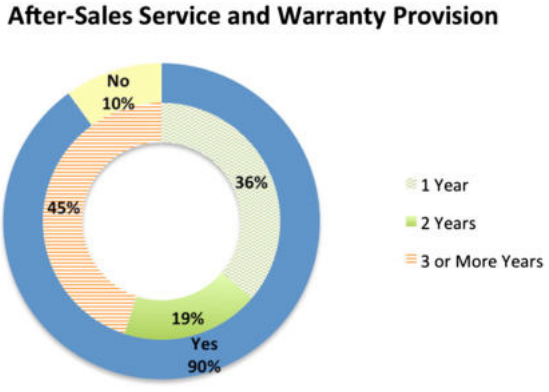

Fig. 4. This graph depicts the results of after-sales service provision and number of years of warranty provided by the firms interviewed.

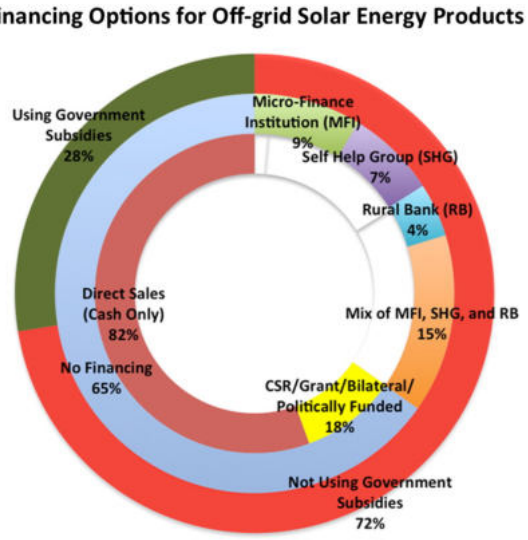

Fig. 5. The outer ring of this graph depicts whether or not the respondents are using government subsidies. The middle ring depicts the types of financing provided by the providers to their customers. The inner ring depicts the breakdown of no financing.

The topic of financing for off-grid solar technologies is beyond the scope of this paper but for the purposes of this study we will merely explore the results of the responses in brief. Interviews conducted in the field with experts and practitioners to supplement the online survey shed light on issues surrounding government subsidies and financing for off-grid solar products. One practitioner established that the procedure for procuring subsidies through the government for solar projects no matter how small or large is just too complicated and takes too long. While subsidies may make sense for large (multi-megawatt) grid-connected solar development projects, for the thirty[5] government approved "channel partners[6]" that sell products in the off-grid market, subsidy procurement becomes rather difficult as the customer base has lower load requirements and there are many small individual projects. This claim does not suggest that all end users do not need subsidies in order to purchase off-grid solar technologies.

Though the government has indicated through policies and allocation of funds that solar should be subsidized, procuring loans for solar home lighting systems for poorer income households is still a challenge. Often bank branches consider the customers and the technology too high risk to receive subsidized loans. This is often the result of the banks themselves not being properly educated on the government policies surrounding the subsidy for solar or lacking the capacity to follow up on whether the firm is meeting the terms of the agreement with the customer on ensuring after sales maintenance and servicing for duration of the payback period of the subsidized loan. Lack of proper after-sales service by some firms has often left banks with customers defaulting on loan repayments. Having a staff member dedicated to managing the relationship with local bank branches seems to be a time-intensive yet successful strategy for a firm that wishes to sell products using government subsidies. Most firms however, particularly startups with limited staff and capacity, can scarcely afford allocating

[5] Ministry of New & Renewable Energy (MNRE) officials claimed that of 40 solar companies who were channel partners of the government in 2013–2014, 30 have products for the off-grid market. The applications received by MNRE in 2015 from companies to become channel partners for the off-grid market number over 100.

[6] Channel partners are companies that have been vetted by the government as meeting all the standards and specifications on technology used and after-sales support provided.

time and resources towards managing relationships with banks. Furthermore, most bank branch managers work on two-year rotation cycles, thus requiring the relationship to be rebuilt every two years with the bank, especially if the new manager also does not prioritize solar loan lending.

Debate exists about whether or not a subsidy for off-grid solar technologies, as it is currently provided, should be continued. One practitioner commented that subsidies might have been useful for their firm in the beginning to incentivize customers who hitherto did not even have much awareness about the technology. However, according to that same practitioner, now that the market penetration of solar is significant, subsidies may no longer be required. An industry veteran noted that government subsidies have not helped the ecosystem of off-grid solar technologies and their required support structures in the country to grow. Yet another practitioner lamented the financial losses his firm incurred from an eight-month delay from the central government in releasing subsidies that he had already discounted to his customers at the time of sales. Government authorized independent retailers of off-grid solar technologies (known as Akshay Urja shops) might disagree with such statements. Of the 60 respondents of a telephonic survey of Akshay Urja shop owners from across the country, most cited the need for continued government support in order to make sales. A dealer of Tata Solar products clarified that financing for the urban and peri-urban middle-income group of customers may still be needed as solar technologies supplement other sources of energy (grid electricity) and solar technology is an additional product for the consumer. However, financing solar for the end user for the BoP market may not be required as they are likely to be spending household income on energy as a basic need and switching fuels from kerosene to solar is not only more reliable as an energy source but often provides cost savings. While that claim may be debatable, assuming the energy demand in rural areas is less than those in urban areas, customers in rural areas maybe purchasing smaller watt capacity and therefore less expensive solar products than those in peri-urban middle-income groups where entire households full of electrical appliances with larger loads require higher capacity solar photovoltaic panels.

Whatever may be the case on whether or not end-user subsidies or financing is required, the findings of this study suggest that off-grid solar technology firms in India are currently predominately not relying on government subsidies to sell their products, and the majority do not provide financing options directly to their customers. Since the start of this study, a new government has come to power in India. Three important policy decisions have been made: 1) a financial inclusion program to provide access to formal banking and thereby direct subsidies to hundreds of millions of people; 2) the desire to provide universal electricity for all by 2019 and a doubling of the goals for solar energy to 100 GW in the country's mix by 2022 and 3) the review of subsidy plan for off-grid solar technologies to move from implementation-based model to a "result-linked benefit" model (Thakkar, 2014). Advancing financial inclusion is likely to provide millions more people access to products such as solar home lighting systems and decide how to spend their government subsidy money for energy which might currently be spent on kerosene. Coupled with new targets and timelines for provision of energy access and the boost for solar energy, these factors are likely to positively affect the diffusion of off-grid solar technologies in the country over time.

Partnerships sought by off-grid solar energy enterprises

Recall the reference to differing forms of partnerships employed by off-grid solar enterprises that use retail versus direct marketing as their core business models. Thus, in order to get a sense of what network respondents believed would help them distribute more off-grid solar products in India, they were asked what kinds of partnerships they were seeking. Options provided to them included 1) government; 2) non-profit organizations; 3) financial institutions; 4) agri-business; 5) distributors; and 6) others. Responses were once again differentiated based on the type of provider responding (Fig. 6). Results indicate that most respondents wanted partnerships with financial institutions followed by non-profits, distributors and agri-business. The government was the least favored partner by all category of providers surveyed from the major list of choices (excluding "other") (Fig. 7).

Based on discussions with practitioners and experts, there are various explanations for these findings. Related to the previous question on financing, it should not be surprising to find that off-grid solar technology providers would like it to be easier to work with financial institutions, particularly rural bank branches that can facilitate giving loans to families who wish to purchase solar home lighting systems. In addition, micro-finance institutions can be useful partners for micro-energy enterprises because they can facilitate micro-payment collection for products like solar lanterns or give out solar loans to rural entrepreneurs to set up a franchise. This is particularly important as millions of potential solar technology customers lack access to formal banking institutions. Non-profit organizations, which proliferate across India, can provide valuable networks for micro-energy enterprises to tap into in order to have the trust from a community to purchase solar products. Recall the role of trust through locally imbedded agents being a major factor that facilitates the diffusion of technologies (Rogers, 2003). Similarly, partnerships with agri-business would be useful for marketing to the rural farmer who can use a variety of off-grid solar products for outdoor use (portable lanterns, solar irrigation pumps, etc.). Quality distributors can be leveraged to strengthen the supply chains and after sales service networks which are crucial for the success of any off-grid solar energy enterprise.

Government has largely been seen as cumbersome and difficult to work with. Micro-grid operators have been struggling with the lack of clear policies on what would happen to their investments should they come into competition with the central electricity grid. Some are frustrated at the fact that subsidies for solar technology, the benefits of which companies passed onto their customers, have not been delivered to the firms and were delayed by at least eight months from the Ministry of New & Renewable Energy. Others cite the cumbersome process of becoming government channel partners or lagging standards and specifications for solar technologies that are not keeping pace with industry innovation worldwide. Still, some would like to work closely with state governments where they can and at least maintain good relations with government agencies where they can make business easy and do a better job of enforcing penalties against fraudulent or foreign competitors not meeting performance standards.

Sales data

Respondents were also asked to report the number of off-grid solar technologies they had sold, including lanterns, SHS, or individual home connections as part of a solar micro-grid since they started operations. Only 57 respondents reported their figures bringing the sample size down from the original 69. A scatter plot of the sales data (Fig. 7) reveals that forty-four (77%) of off-grid solar energy providers have a per unit sale or per home access of 20,000 or less. Eight respondents (14%) had sales between 20,000 and 64,000. Three respondents (5%) had sales between 120,000 and 160,000 while two respondents (4%) sold over 3 million solar products (not depicted in the scatter plot).

These results indicate that the unit scaling of the majority of the off-grid solar technology industry is quite small compared the number of households without access to electricity. Also the industry is largely quite young, averaging seven years of operations. Age is not necessarily related to the unit scaling of an organization however as two of the largest distributors by unit of products sold are approximately six to seven years old. The unit sales also suggest that the firm size of many of the players is small. The customer base is diffuse and there is enough room for many players to participate and make a profit in a market estimated to reach US$150 million by 2018 (Davidsen et al., 2015).

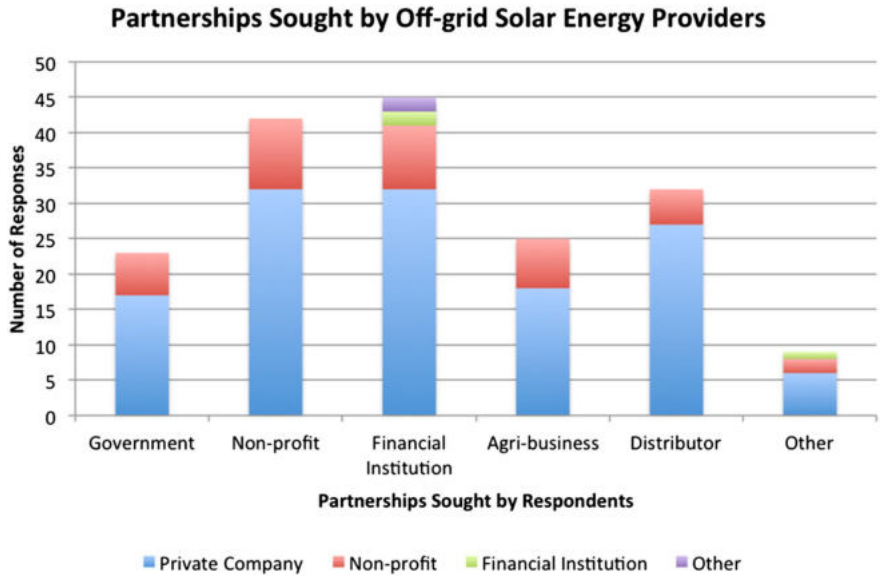

Fig. 6. This graph depicts the partnerships sought by off-grid solar energy providers in India by provider-type.

Factors affecting off-grid solar enterprise scaling

Arguments could be made that the sample size for running regressions using this data set is too small, but such an exercise incorporating sales data from micro-energy enterprises has not been undertaken before. Results from such an exercise can be used as a guide to study what the factors affecting scaling of such enterprises may be and support them in the future with in-depth case studies.

Running linear regressions using STATA on the data collected revealed correlations between some of the variables. Variables expressing relationships include binary variables such as F_i (offering financing to customers for products), and linear variables including G_i (firm sells products in geographies with the electricity grid (yes, sometimes, never)), S_i (number of states firm sells products in), P_i (number of categories of products the firm sells including 1) lanterns; 2) SHSs; 3) microgrids; and 4) others), and Q_i (number of products sold or unit scaling)

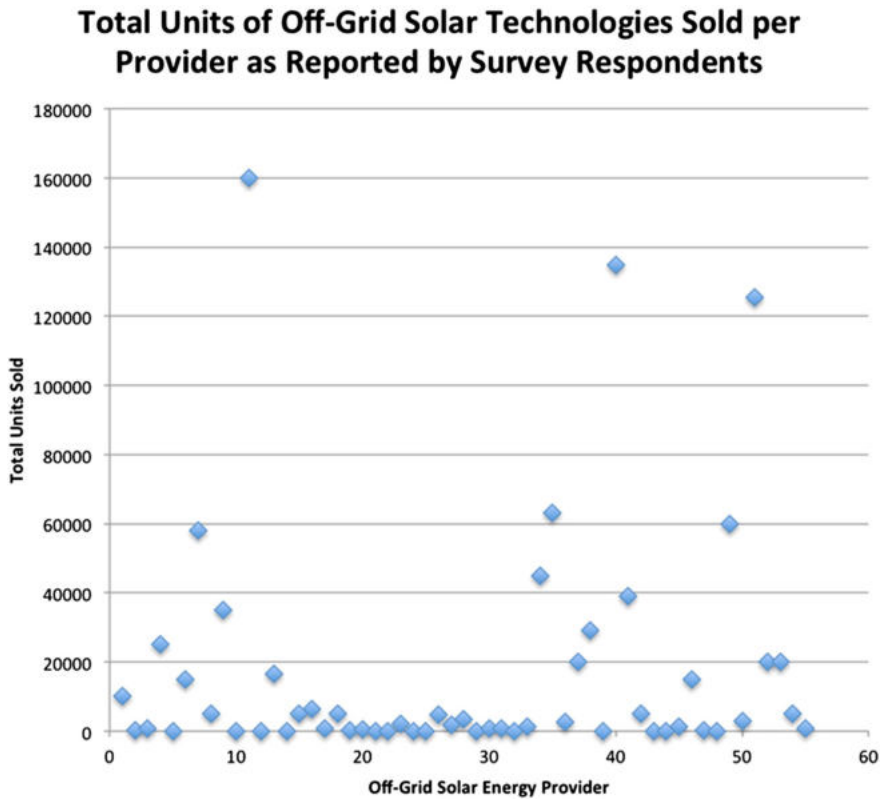

Fig. 7. Scatter plot of sales data from 57 respondents of the off-grid solar technology market survey. For easier visualization, the highest sales figures (over 3 million products) have been removed (only 55 points visible in this graph).

for all firms ($_i$) where $i = 1,2,3,\ldots 56$. Table 2 depicts the regression results with statistically significant ($p < 10\%$ and $p < 5\%$) relationships highlighted.

Regressions showing relationships included the following:

$$G_i = \beta_0 + \beta_1 P_i + \beta_2 S_i + \beta_3 Q_i + u_i$$
$$F_i = \beta_0 + \beta_1 P_i + \beta_2 S_i + \beta_3 Q_i + u_i$$
$$P_i = \beta_0 + \beta_1 S_i + \beta_2 G_i + \beta_3 Q_i + u_i$$

The results of the regression indicate that the further from grid-connected geographies one ventures, unless there are multiple firms overlapping in the region, the less likely the people there are to have multiple technology options for solar energy (they will only have lanterns, or only SHS, or only micro-grids). This is because the firms that are operating in those areas do not diversify the types of products they provide. Also, firms that are operating in areas without the grid may be targeting a completely off-grid market as they expand to other states. Two factors important regarding learning that may affect the scaling-up of off-grid solar technologies are important to note with these findings: 1) the lack of multiple technology-type interaction in these geographies may be affecting the learning among companies (the fact that it is limited or not happening); and 2) companies choosing to only specialize distribution in areas devoid of grid connectivity but across states may find it difficult to carry the learnings from one state to the next because of the complex nature of state policies, socio-economic factors and cultures present across a country as diverse as India.

A number of additional factors associated with the interplay between the grid and the nature of diffusion and business of off-grid solar technologies may explain what may be happening. Off-grid solar technologies, like any new innovation introduced in rural communities require trust from the community to be readily adopted. Distributing in more remote areas may also require that the vendor target a respected member of the community to be the brand ambassador of their technology. Therefore, firms in more remote areas may incrementally introduce new and diverse technology options. Given that the firm is the risk taker in introducing a new technology in these areas, s/he may conduct an assessment and choose the technology for the community based on what s/he deems appropriate. Further research would be needed on the awareness level about solar technologies of people in remote or grid-less areas that may or may not affect their comfort in adopting new technologies. Another likely scenario explaining this result is that areas near the grid may have higher population densities and more established supply chains that a firm can use, thus increasing the market of technology options a firm is willing to provide to the local population. If this is correct, then the extension of the grid and its associated infrastructure may be an important prerequisite for the diffusion of all sorts of consumer goods and technologies into new areas.

The number of technology-type options a firm provides seems to have a number of relationships with other characteristics unique to a firm. First, the more technology-type options a firm provides, the more likely it is to be operating in more than one state. Note that providers from the online survey were also categorized by the number of states in which they operate (Fig. 8). Overwhelmingly, most providers only operate in one state. Second, the more technology-type options a firm provides, the more likely the firm is to provide financing to its customers for off-grid solar technologies. Both of these relationships may correlate with the maturity of the firm, or at least should be the firms from whom the industry may want to learn about the business of off-grid technology scaling. While the market for off-grid solar technologies is quite large, the ability to sell across multiple states and to be able to provide more types of products and financing seems like a recipe for success. However, another relationship specifically between the number of categories of products a firm provides and its unit scaling indicates that the more a firm diversifies its portfolio of products, the lower its unit scaling will be (at least for some time). It might be easier for a firm to focus on one product and achieve unit scaling through large volume of sales, however it may be missing out on capturing different market segments (customers who prefer micro-grid connections or larger capacity solar home lighting systems instead of just solar lanterns). Product diversification may also impact the quality of after sales support, the supply chain and the growth of the firm at large. This is a potentially important lesson for firms who wish to weigh their options of how, where, and what type of technologies they choose to distribute. More importantly, firms should reflect on these findings and ask whether or not unit scaling is important for them in the long run.

Table 2
Regression results.

	In grid	Categories of products	Financing	Unit sales
In grid		**−0.435**** (0.0255)		−35,954 (0.809)
Financing				41,202 (0.859)
Categories of products	**−0.212**** (0.0255)		**0.123*** (0.0559)	**−216,308*** (0.0503)
Government subsidy				−147,203 (0.549)
Number of states	**0.0275*** (0.0621)	**0.0470**** (0.0250)	−0.00372 (0.708)	14,218 (0.382)
Firm type				−195,285 (0.216)
Marketing				165,074 (0.511)
Unit sales	−4.57e-08 (0.731)	**−3.37e-07*** (0.0713)	−4.03e-08 (0.657)	
Warranty				−128,198 (0.296)
Constant	2.168** (0)	2.914** (1.11e-10)	2.914** (1.11e-10)	1.088e + 06* (0.0692)
Observations	56	56	56	56
ss	0.123	0.189	0.083	0.139

*p < 0.10; **p < 0.05.
The values in bold indicate statistically significant relationships.

Conclusion

While research is required, based on the results of the online survey and the extensive field work conducted to support the broader study on factors affecting the scaling up (or not) of off-grid solar technologies in India, several conclusions may be drawn from these data. The statistical analysis supports the claims by some experts that the market for off-grid solar technologies is indeed determined by the seller. End users are not able to articulate what they need, particularly those users in areas without grid access who may need the technology options the most. Furthermore, modularization of products may help achieve unit scale as the firms selling the highest volume of products are providing compact solar products. The modular products are also quite homogenous and would be supported by Wilson's (2009) hypothesis of homogeneity affecting the scaling up of low-carbon technologies. Supporting Rogers' (2003) theories, these firms also have a highly networked local staff, highlighting the importance of last-mile village entrepreneur networks in deployment of higher volumes of modular products. While multi-functionality of a product did not seem to impact unit scaling, the fact that companies see their customers as needing the products for more than lighting is a sign that the arrival of aspirational low-watt appliances such as televisions may actually serve as the driver of the diffusion of solar technologies.

On financing, the subsidy regime established by the government may not have helped the ecosystem of services and technologies around off-grid solar technologies to thrive. Results suggest that frustration and difficulty in working with the government in this process led many

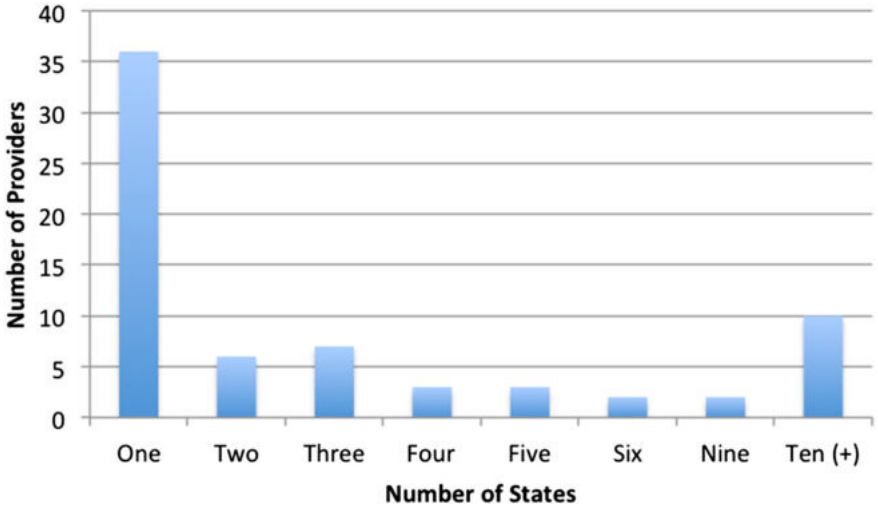

Fig. 8. This graph depicts the distribution of the number of states the firms surveyed operate in. Overwhelmingly a large number of respondents only distribute products in one state.

players to operate outside the subsidy regime. While it is debatable whether end-users need financing in order to purchase off-grid solar products, it is clear that much business is still being conducted with millions of customers in different income groups without subsidies or financing provided by the firm. Business innovation thus may have found a way to operate in an environment that still lacks access to formal banking systems and requires strong supply chains and after sales networks in order for technologies to be maintained post deployment.

Finally, providing a broader array of technology options may actually have a negative impact on unit scaling. A closer look at some of the individual firms that stand out in unit scaling matches these results. The value of scaling must of course be questioned in an industry that should be trying to move from providing technologies to quality energy services. Finding a balance between simply achieving scale in numbers and assuring that quality, defined by sufficient energy and an ecosystem of support structures for the technology post deployment, is essential if one is to genuinely provide access to energy for improving the livelihoods of those who need it most. Lastly, business innovations will continue to evolve to meet the growing energy needs of those living with lack of assured centralized grid energy supply and thus drive the diffusion of off-grid solar technologies.

Acknowledgments

I would like to thank my advisors Dr. Kelly Sims Gallagher, Dr. Jennifer Aker and Dr. Ambuj Sagar for their guidance and the generous funding from the Center for International Environment & Resource Policy at the Fletcher School of Law & Diplomacy, Tufts University. In addition I would like to acknowledge the funding of the National Security Education Program (NSEP) to allow me to travel to India and for my hosts, the Shakti Sustainable Energy Foundation in New Delhi. Finally, I would like to thank the organizations that facilitated data collection including the United Nations Energy Access Practitioner Network, the Ashden Energy Collective, and Bridge to India.

References

Asheim BT, Gertler Meric S. The geography of innovation. In: Feldman, et al, editors. Oxford handbook on innovation. Oxford: Oxford University Press; 2005. p. 291–317.
Bairiganjan S, Sanyal Sanjoy. The last 50 mile: using LVE networks for increasing clean energy access. New Ventures India: Hyderabad; 2013. p. 1–49.
Balachandra P. Modern energy access to all in rural India: an integrated implementation strategy. Energy Policy 2011;39:7803–14.
Bardouille P. From gap to opportunity: business models for scaling up energy access. Washington, D.C: International Finance Corporation; 2012.
Bazilian M, de Coninck H, Radka M, Nakhooda S, Byd W, MacGill I, Bradley R. Considering technology within the UN climate change negotiations. Amsterdam: Energy Research Centre of the Netherlands; 2008.
Bhalla MS. Transmission and distribution losses (power). National conference on regulation in infrastructure services: progress and way forward. New Delhi: TERI; 2000.
Birol F. Energy for all: financing access for the poor. Paris: International Energy Agency; 2011.
CEEW. Developing effective networks for energy access: an analysis. New Delhi: Council on Energy Environment & Water; 2013. p. 1–58.
Chaurey A, et al. New partnerships and business models for facilitating energy access. Energy Policy 2012;47:48–55.
Davidsen AAKP, Singh Jarnail, Shiv Jay, Walker Paul, Parrish Sarah, Sitasabeshan Subaskar. The business case for off-grid energy in India. New Delhi: The Climate Group; 2015. p. 1–108.
Dehejia V. The cookstove conundrum. New York: The New York Times; 2012.
Forsyth T. Enhancing climate technology transfer through greater public-private cooperation: lessons from Thailand and the Philippines. Nat. Res. Forum 2005;29(2):165–76.
Gallagher KS. The globalization of clean energy technology: lessons from China. Cambridge, MA: MIT Press; 2014.
Gallagher KS, Grubler Arnulf, Kuhl Laura, Nemet Gregory F. The energy technology innovation system. Annu. Rev. Environ. Resour. 2012;37:137–62.
Gregory M. India struggles with power theft. BBC World News 2006.
Harish SM, et al. Adoption of solar home lighting systems in India: what we might learn from Karnataka? Energy Policy 2013;62:697–706.
Lundvall B-A. National systems of Innovation: towards a theory of innovation and interactive learning. London: Pinter; 1992.
Martinot E, Cabraal A, Mathur S. World Bank/GEF solar home system projects: experiences and lessons learned 1993–2000. Renew. Sust. Energ. Rev. 2001;5:39–57.
Meinshausen M, Meinshausen Nicolai, Hare William, Raper Sarah CB, Frieler Katja, Knutti Reto, Frame David J, Allen Myles R. Greenhouse-gas emission targets for limiting global warming to 2 degrees C. Nature 2009;458:1158–62.
Navani JP, Sharma NK, Sapra Sonal. Technical and non-technical losses in power system and its economic consequence in Indian economy. Int. J. Electron. Comput. Sci. Eng. 2012;1(2):5.
Nelson R. National innovation systems: a comparative analysis. New York: NY, Oxford University Press; 1993.
Paulsson E. A review of the CDM literature: from fine-tuning to scrutiny? Int. Environ. Agreements Polit. Law Econ. 2009;9(1):63–80.
Prahlad CK. The fortune at the bottom of the pyramid. Upper Saddle River: New Jersey, Pearson Education, Inc.; 2010.
Ranganathan M. Participatory approach for linking rural energy transitions and developmental needs in Uttar Pradesh, India. Boiling Point 2003:15–7.
Rogers E. Diffusion of innovations. New York: The Free Press; 2003.
Sagar A, Holdren JP. Assessing the global energy innovation system: some key issues. Energy Policy 2002;30:465–9.
Sanyal S. Identifying micro-markets for clean energy access. Retrieved April 30, 2015, 2014, from http://www.nvindia.biz/resources-micro-markets-for-clean-energy-access.html, 2014.
Singh K. In India's sea of darkness: an unsustainable island of decentralized energy production. Consilience: J. Sustain. Dev. 2007;1(1):5.
Singh A. Climate co-benefit policies for the Indian power sector: domestic drivers and North-South cooperation. Clim. Pol. 2009;9(5):529–43.
Singh RK. NTPC coal imports said to double on shortage: corporate India. Bloomberg News 2013.

Tawney L, Miller Mackay, Bazilian Morgan. Innovation for sustainable energy from a pro-poor perspective. Clim. Pol. 2013:1–17.
TCG. The business case for off-grid energy in India. New Delhi: The Climate Group; 2015. p. 1–108.
Telegraph. India has more mobile phones than toilets. London: The Telegraph; 2010.
Thakkar MASJ. Review of subsidy plan for off-grid solar applications. Economic times. New Delhi: Times of India; 2014.
Wilson C. Meta-analysis of unit and industry level scaling dynamics in energy technologies and climate change mitigation scenarios. Interim report. Laxenburg, Austria: IIASA; 2009. p. 1–119.
Wong S. Overcoming obstacles against effective solar lighting interventions in South Asia. Energy Policy 2012;40:110–20.