THE FLETCHER SCHOOL

TUFTS UNIVERSITY

SURYA'S PROMISE: THE SCALING-UP (OR NOT) OF OFF-GRID SOLAR TECHNOLOGIES IN INDIA

A thesis
presented to the faculty
of
The Fletcher School of Law and Diplomacy

By

Kartikeya Singh

In partial fulfillment of the requirements for the degree of Doctor of Philosophy

2016

Dissertation Committee
Dr. Kelly Sims Gallagher
Dr. Jenny Aker
Dr. Ambuj Sagar, Reader

CURRICULUM VITAE

EDUCATION

Doctor of Philosophy
The Fletcher School, 2011 – 2016
Major: International Relations
Fields: International Environment & Resource Policy and International Negotiation & Conflict Resolution

Master of Environmental Science
School of Forestry & Environmental Studies, Yale University 2009 - 2011
Fields: Climate Change and Energy Policy

Bachelor of Science
Furman University, 2003-2007
Major: Ecology & Sustainable Development

PROFESSIONAL EXPERIENCE

U.S. Department of Energy – Office of International Affairs
South Asia Energy Officer, Office of Asian Affairs
Washington, D.C., 2015- 2016

Center for International Environment & Resource Policy (CIERP), The Fletcher School of Law & Diplomacy
Doctoral Research Fellow, Climate, Energy & Innovation Program
Medford, MA, 2011 - 2015

United Nations Institute for Training & Research (UNITAR)
Consultant, Multilateral Diplomacy Program
2010 - 2013

Republic of Maldives
Adviser/Attaché, UNFCCC
New York , NY, 2009-2012

Indian Youth Climate Network (IYCN)
Founder/Executive Director

New Delhi, India, 2008 – 2009

Center for Science & Environment (CSE)
Fellow, Climate Change & Energy
New Delhi, India, 2007 - 2008

PUBLICATIONS

Singh, Kartikeya. 2015. Business innovation and diffusion of off-grid solar technologies in India. *Energy for Sustainable Development* 30: 1-13.

Singh, Kartikeya. 2014. Establishing a Geoengineering Protocol. *Papers on International Environmental Negotiation (Eds. Susskind & Moomaw)* Vol. 19: 25 – 37. Program on Environmental Negotiation, Harvard Law School.

Singh, Kartikeya. 2011. India's emissions in a climate constrained world. *Energy Policy* 39: 3476-3482.

HONORS AND AWARDS

Hitachi Center for Technology & International Affairs Pre-Doctoral Research Fellowship, 2014 – 2015

Switzer Environmental Fellowship, 2014

Fletcher Ph.D. Summer Research Award, 2014

David L. Boren Fellowship, 2013

Fletcher Alumni of Color Association Scholarship, 2012

Hitachi Center Summer Fellowship, 2012

CIERP Pre-Doctoral Fellowship, 2011 - 2015

Fletcher Tuition Scholarship 2011 - 2013

ABSTRACT

India is a country where 300 million people still live without access to formal grid electricity, and where hundreds of millions more live with irregular supply through the existing grid network. This dissertation unravels the various factors that can influence unit scaling, understood for the purposes of this study as widespread diffusion of off-grid solar technologies, to help policy makers and financial institutions to mobilize efforts to effectively bring millions of people out of the dark.

To research this topic, an in-country survey of 69 off-grid solar energy providers from across the nation was conducted. Findings from that survey reveal that most off-grid solar energy enterprises are operating without the benefit of government subsidies and that more than half do not offer any form of financing to their customers when selling their products. Despite the lack of financing provided by the firms themselves, their combined off-grid solar product sales equal over 8.5 million units. More than half of the enterprises are selling their products in regions 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.) sold by a given firm negatively affects unit scaling, or the total number of products sold, for a firm but increases the likelihood that the firm is offering financing for its products.

The study thus concludes that to simply scale in number of units of products sold, a firm should focus on fewer product categories.

A deeper exploration on the question of finance - through interviews with firms, customers, informal sales agents - reveals that lack of adequate government-supported financing for the end user, often cited as the main barrier to the diffusion of the technologies, may be a less important factor than previously thought. For the customer, often the factors associated with the decision to purchase are more important than the ability to pay. Purchasing decisions are influenced by experience with a product, association with a sales agent or company, and/or exposure to technology through others in the community. Innovative business models can both make products more affordable (addressing the end users' ability to pay) and more accessible (addressing their decision to purchase). Thus chapter III suggests that the focus of finance should be for these innovative firms which are currently in need of capital to help scale-up their businesses.

Finally, chapter IV explores the case of Green Light Planet, a firm that may hold the key to scaling-up the diffusion of off-grid solar technologies in the developing world. The paper reveals that the company's business model innovation relies on networks of sales agents operating under a system of sales targets, incentives, and boosters to conduct high volumes of sales.

DEDICATION

This dissertation is dedicated to the people of my ancestral village of Jakkan in the state of Rajasthan in India. And to my grandparents Kalyan Singh and Sayar Kanwar Bhati who sadly did not live to see the promise of electricity to our family home.

Figure 1. Author's ancestral home in the village of Jakkan.

ACKNOWLEDGEMENTS

This dissertation would not be possible without the support of many people. First, I would like to thank my advisor, Dr. Kelly Sims Gallagher, for guiding me through this entire process. In addition, I would like to thank Dr. Jenny Aker and Dr. Ambuj Sagar for their insightful comments and instruction on how to deal with the mountains of data I collected.

I am deeply grateful for generous funding from the Fletcher School, the Center for International Environment & Resource Policy (CIERP), the Hitachi Center for Technology & International Affairs, the National Security Education Program (NSEP), and the Switzer Foundation which supported me while I conducted my research.

Collecting data on off-grid energy in India is challenging. Institutional support from the Shakti Sustainable Energy Foundation, the Consortium on Science, Policy & Outcomes (CSPO), the Brookings Institution, the Center for Science & Environment (CSE), The Energy & Resources Institute (TERI), the Yale School of Forestry & Environmental Studies, Outline India, and countless off-grid energy enterprises facilitated the process of data collection for this study.

Finally, for being my champions in this journey I would like to thank my parents, Dr. and Mrs. Karni and Raina Bhati, my sister Dr. Meha Priyadarshini and my wife Lara Berlin.

TABLE OF CONTENTS

ACRONYMS

AAP	Aam Aadmi Party
AMC	Annual Maintenance Contract
BOP	Base of the Pyramid
BPL	Below Poverty Line
CEEW	Council on Energy, Environment & Water
CEO	Chief Executive Officer
CER	Certified Emissions Reduction
CFL	Compact Fluorescent Light
CSR	Corporate Social Responsibility
DRE	Decentralized Renewable Energy
DSM	District Sales Manager
ETIS	Energy Technology Innovation System
GDP	Gross Domestic Product
GLP	Green Light Planet
GW	Gigawatt
IEA	International Energy Agency
IREDA	Indian Renewable Energy Development Agency
JLG	Joint Liability Group
kWh	Kilowatt-hour
LABL	Light A Billion Lives
LED	Light Emitting Diode
MFI	Microfinance Institution
MLA	Member of Legislative Assembly
MNRE	Ministry of New & Renewable Energy
MP	Member of Parliament
NABARD	National Bank for Agriculture and Rural Development
NDA	National Democratic Alliance
NGO	Non-governmental Organization
PAYG	Pay-as-you-go
PDS	Public Distribution System
PV	Photovoltaic
RB	Rural Bank
RGVEP	Rajiv Gandhi Village Electrification Program
RSM	Regional Sales Manager
SBA	Sales Business Associate
SEBI	Security & Exchange Board of India

SELCO	Solar Electric Lighting Company
SEWA	Self Employed Women's Association
SHG	Self Help Group
SHS	Solar Home Lighting Systems
SVO	Straight vegetable oil
S3IDF	Small Scale Infrastructure Development Fund
TERI	The Energy & Resources Institute
TL	Team Leader
T&D	Transmission & Distribution
UN	United Nations
UPA	United Progressive Alliance
USD	United States Dollar
VEC	Village Energy Committee
VESP	Village Energy Security Program
VLE	Village Level Entrepreneurs
WRI	World Resources Institute
ZBM	Zonal Business Manager

INTRODUCTION

*"Come, O **Surya**, of thousand rays, the store-house of all energies, the **Lord** of the world, have mercy on me thy devotee, accept this Arghya, O, Mother of the day[1]." ~Invocation of the Spiritual Sun, The Rigveda*

1.1 Why Energy Access

Access to energy is vital for economic development and the alleviation of poverty, which is why it was thought to be linked closely to meeting top-down approaches to addressing development, such as the Millennium Development Goals (Urban 2009). In the lead up to 2015, the International Energy Agency (IEA) stated that the "UN Millennium Development Goal of eradicating extreme poverty by 2015 will not be achieved unless substantial progress is made on improving energy access" (IEA 2010). Given that the goal of eradicating poverty was not met, and the world needed a revised post-2015 development agenda, access to energy through both centralized electricity grids and off-grid solutions has found well-deserved prominence

[1] S. Viraswami Pathar. 2000. *Gayathri Mantra.* Sura Books, Chennai: page 143.

in the newly adopted United Nations Sustainable Development Goals (UN 2015). India continues to face the immense challenge of trying to upgrade its existing electricity grid and provide electricity to over 300 million of its citizens (IEA 2015). This population, sometimes summed up as the "base of the pyramid" (BoP), spends less than US $75 a month on goods and services and represents 76% of the rural population, or 114 million households (Bairiganjan 2010).

Improved energy access also has implications for the peace and stability of the nation. Currently 106 of India's 629 districts are affected by internal insurgencies driven by unsatisfied tribals. Labeled "Maoists" or "naxalites," they have been left out of the mainstream development agenda. Local reporters have stated that "Maoist appeal among the young wanes precisely where electricity, phones and television spread" (Economist 2013). If this is true, India has the added impetus of meeting the energy access challenge to ensure national if not simply human security. India must do so in a manner that makes energy affordable, energy supply reliable, and meets the energy demands within the context of a climate constrained world (Singh 2011).

Finally, the approach a state adopts to energy access has implications for global discussions on climate and conventional air pollution. The political deadlock on climate change that persisted over the last few decades between the United States and rapidly emerging economies (such as China and India) was unresolved in large part due to the latter's argument for the need for development. Ensuring that the 300 million rural Indian citizens currently living in the dark are provided for through sustainable renewable energy technologies should thus be a priority (WRI 2010), as it can bridge the gap between the climate and development agendas. While current technologies alone may not solve the challenge of *genuine*[2] energy access in the long term, in the interim, they may provide an alternative to an inefficient and unreliable coal-fed national grid system. If, by 2020, India has not begun to develop in earnest alternatives to fossil-based energy supplies, the global carbon budget may be exceeded. This outcome would create a climate change scenario which, according to Meinshausen and colleagues, would far exceed the 2˚C guardrail (Meinshausen 2009).

Even with a recognized need for energy access, meeting demand will be complicated. According to the IEA, the challenge of electrification for countries like India will continue for decades. Though more people will steadily gain access to electricity, there will also be sustained population growth in areas with erratic or insufficient supply. Without adequate levels of investment, the total percentage of the population without access will steadily rise from 66% in 2009 to 80% in 2030 (IEA 2010). Furthermore, even under

[2] Genuine energy access here refers to the third and final stage of energy access as defined by the IEA (2010), "energy for modern needs" (2000 kWh/person/yr), which is considerably higher than "energy for basic needs" (100 kWh/person/yr).

the new policies scenario[3] India will only achieve 80% electrification by 2030, thus failing to meet the UN Sustainable Energy For All target of universal electrification (IEA 2015).

1.1.1Meeting the Challenge

The IEA has studied the implications of achieving modern energy for all. Their report envisages an increase in global electricity generation of approximately 840 TWh, or 2.5% more than is currently projected for 2030. The total investment required for the effort towards universal access is estimated to be $60 billion. Of the global population requiring access to electricity, 25% is expected to receive it via the grid, 35% via mini-grid systems and 40% via off-grid systems (IEA 2015). Finally, decentralized electrification is not synonymous with low-carbon energy. The IEA notes that currently diesel

[3] The New Policies Scenario of the IEA India Energy Outlook (2015) assumes the following: 1) enhanced efforts on village electrification and connection of households lacking electricity supply, with the aim to reach universal electricity access by 2018; 2) expanded efforts to strengthen the national grid and reduce losses towards the targeted 15%; 3) greater encouragement to private investment in energy supply, through loosening of existing restrictions and simplification of licensing procedures; 4) a strong push in favour of renewable energy, notably solar and wind power, motivated by the target to reach 175 GW of installed renewable capacity (excluding large hydro) by 2022; 5) efforts to expedite environmental clearances and land allocation for large energy projects; and 6) measures to increase fossil-fuel supply, notably of coal, in order to limit import dependence.

generators provide the bulk of decentralized electricity in India, followed by solar PV; however, due to declining costs, solar is expected to eventually overtake diesel. To address its energy access challenge, India must thus find a proper balance of centralized and decentralized systems.

A centralized grid-based system cannot solely meet India's energy requirement. The case of the largest blackout in human history, the grid failure that left 670 million people without electricity in most of northern and eastern India (Memmott 2012), demonstrated how hundreds of millions of people are energy insecure, despite living in large cities and in proximity to large, centralized power plants. A solution to these energy challenges may be to invest more to create a nation operating on decentralized energy systems that are efficient, secure, and sustainable (Lovins 1982). The IEA has modeled what the optimal split of decentralized and centralized electrification in India would look like geographically (see Figure 2). Lovins and Lovins argue that the multiple gains of an energy system that is highly decentralized include: (1) reduced threats to highly centralized critical infrastructure from natural supply disruptions and terrorist attacks; (2) enhanced energy security as the fuel supply is highly localized; and (3) environmental benefits through cleaner technology sources.

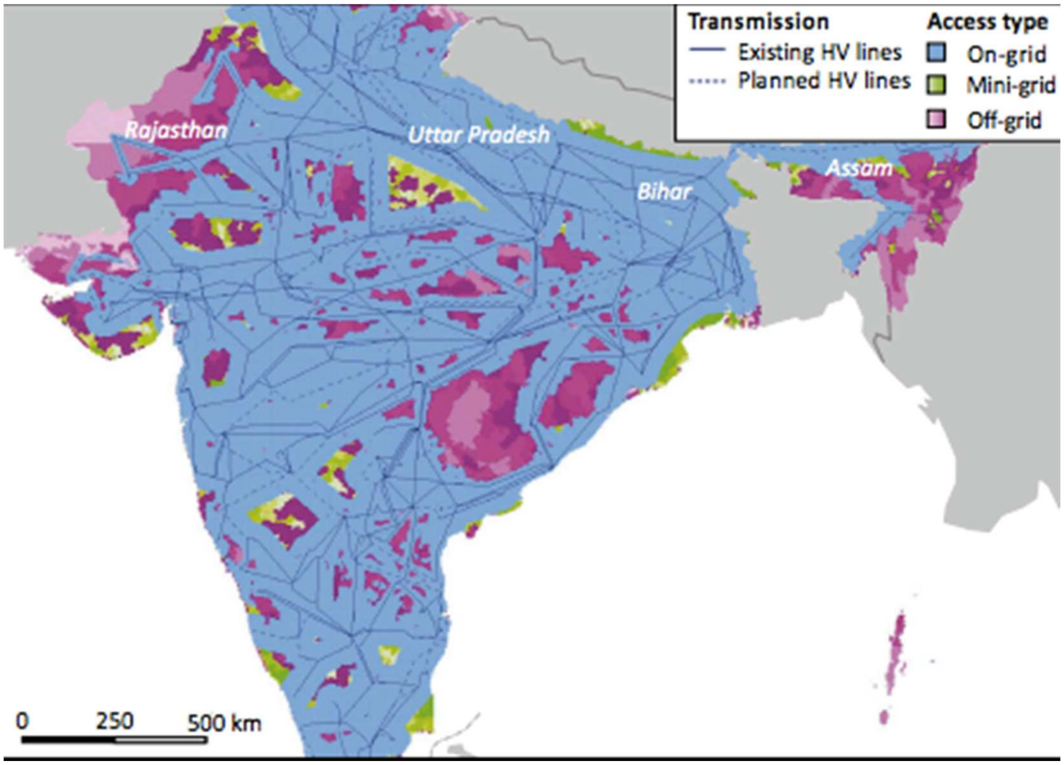


Figure 2. The geographic spread of centralized versus decentralized electrification options as modeled by IEA (2015).

Despite the challenges posed by energy access, India is presented with an immense opportunity for the growth of a clean energy sector, with millions of new clean energy jobs. Indeed, decentralized renewable energy systems (DREs) in tandem with centralized systems might help India attain the status of a nation of "village republics," as envisioned by Gandhi. According to the World Resources Institute (WRI), the annual clean energy market for the rural BoP population is estimated to be $2.11 billion (Bairiganjan 2010). Stakeholders must turn this immense challenge into an opportunity: if India can get decentralized electricity access right, it has the power to put the world on a more sustainable pathway.

1.1.2 Introduction to Energy Access

What is the meaning of energy access? Access to modern energy of sufficient quantity and quality for human needs and income-generating activities is a necessary component in eradicating poverty and improving the livelihood opportunities of people in developing countries. Socioeconomic development thus depends on relieving the burden of energy poverty—a collaborative task that presents tremendous opportunities for industrialized and emerging economies alike. These include expanded markets and investments in energy services, larger economies of scale for clean energy and associated infrastructure, and cooperative innovation to meet the energy

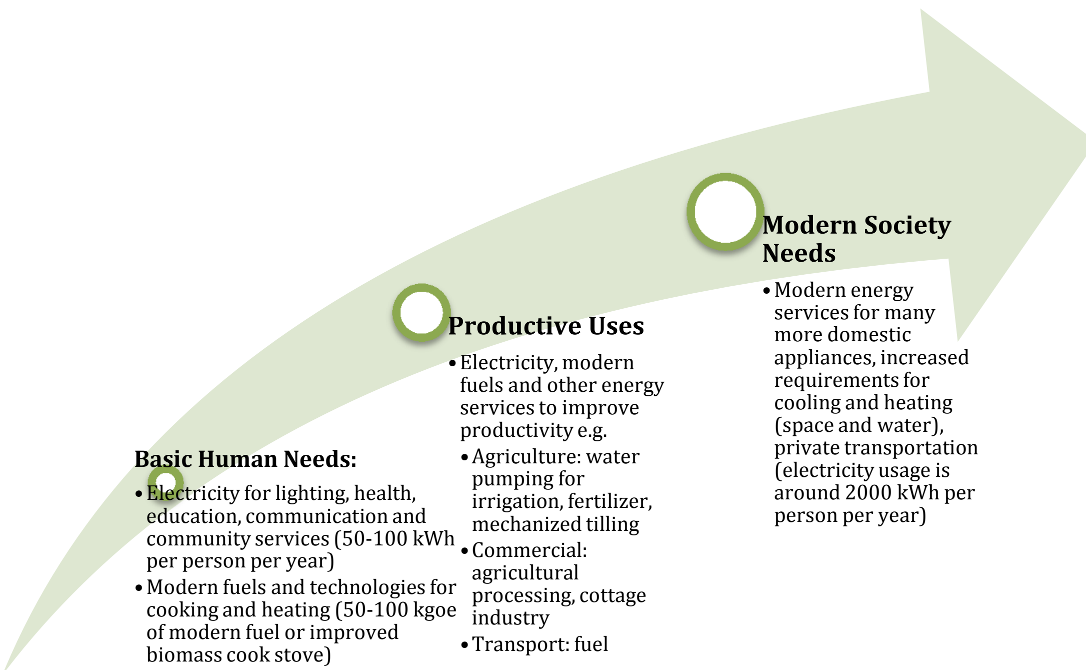


Figure 3. The energy access ladder has three levels including enough energy for basic human needs, for productive uses and for modern society needs.

needs of the billions currently without safe, reliable, and sustainable access (Bazilian 2010).

Unfortunately, there is no consensus amongst the global development community on what the term "energy access" means (AGECC 2010). The IEA has broken down energy access into three "incremental levels of access to energy services" (see Figure 3.) Sathaye et al. (2011) describe this categorization as an "energy ladder" and define it by the following levels of consumption: energy for basic human needs as described above (including cooking, heating and lighting and charging of small devices), energy for productive uses (including electricity or energy to increase the productivity of agriculture, commerce or transport) and energy for modern needs (including private transportation, space heating and cooling). This last category is on the order of 2000 kWh per person per year—twenty times the consumption level of basic human needs (AGECC 2010), but still far below the average per capita energy usage in the United States which is 82,198 kWh per person per year[4]. If the Indian government's "lifeline supply goal" for electrification is 1 kWh per household per day, and the average Indian household size is 5.4 people (Modi 2005), then comparatively, the annual per capita level of basic electricity access assumed in the Indian government's plan at present is 67.6 kWh. This number is within the range of annual energy for basic access of 50-100 kWh per person but far below the energy for modern needs as suggested by the IEA.

[4] World Bank Data (2012): http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE/countries

To understand the scale of both the challenge and opportunities in universal energy access delivery, it is useful to look at the resources needed to achieve full access at a global level. According to the IEA, achieving universal access by 2030 at the most basic level per household (enough to power a "floor fan, two compact fluorescent lights, and a radio for about five hours per day") will require 950 TWh per year, or almost 3% of estimated global power use in 2030 (IEA 2010). To achieve this level of energy access, approximately $700 billion, or $33 billion annually, needs to be invested between 2010 and 2030. These are not unattainable figures; the IEA estimates that necessary generating capacity for meeting the additional demand is 250 GW—China alone installed double that amount between 2005 and 2011 (EIA 2012). But a cost estimate that is closer to what might be deemed a "thrival[5]" level of access is more than twice the IEA projection—above $100 billion per year, or $1.5 trillion total by 2030 (Bazilian 2010). The difference in perceived investment needs underscores both the scale of the challenge and the need for innovative policies and technologies to address it.

[5] Thrival: defined as "development beyond survival," or the adequate quantity and quality of energy that is essential to create thriving communities. From: Singh, K., *Equitable Energy Access and Climate Change: Opportunities for Innovation* (Washington, DC: Consortium for Science, Policy, and Outcomes, Implementing Climate Pragmatism Framing Document One, 2012).

1.1.3 Delivery Types: Decentralized vs. Centralized

Discussions of how to achieve a universal level of energy access often engage in debate over the relative merits of centralized or decentralized (or distributed) generation. The international development community [6], including private, nongovernmental, and microfinance organizations, has focused mainly on micro- and off-grid energy in providing a basic level of energy access, for several reasons. First, environmental concerns—perceived resource constraints, concerns about GHG emissions, and local air pollution—are a factor in favoring clean, decentralized technologies. Second, end-use energy at the household level is easier to quantify and compartmentalize, and thus measurably increase through interventions in the energy supply chain. Third, decentralized energy innovation is appealing to the development community because it tackles an immediate challenge that development organizations have the financial and technical resources to address. For example, an NGO can more quickly and effectively deploy a micro-hydroelectric system to a poor community than develop an efficient coal-fed thermal power plant for base-load power generation. In the impoverished,

---

[6] While the World Bank and International Finance Corporation have historically supported financing large grid-connected centralized thermal power plants and hydro-electric plants, these institutions are in the midst of reevaluating how their policies on energy might conflict with their policies to address climate change. The World Bank recently announced its plans to limit funding for high-carbon energy projects as it lends its support to the global sustainable energy access for all agenda. See: "Toward a Sustainable Energy Future for All: Directions for the World Bank Group's Energy Sector."

rural regions in which development groups often work, this strategy is entirely appropriate, especially if the government lacks resources to extend a centralized grid to provide electricity. Thus, there has been an explosion of entrepreneurial activity in decentralized renewable energy generation, and a global drive to provide clean energy to the poor (Bairiganjan 2010). Some of the resulting solutions include off-grid solar energy systems to provide electricity for uses such as lighting and small appliance charging.

Large-scale primary energy, on the other hand, is generally seen as the domain of extractive industries, utilities, and national governments. Historically, postcolonial governments prioritized centralized energy systems that served urban and industrial customers, while often failing to extend electrification to their remote rural populations. Analogous to the false conflict between economic development and environmental protection, there is frequently an implicit—and mistaken—competition between grid (or centralized) and off-grid (decentralized) energy provision (Barnes 2004). Effective electrification will plainly require a diversity of approaches, in which both centralized and decentralized power sources are required. Top-down and bottom-up strategies are both essential to implementing this multi-track approach.

1.1.4 Decentralized Renewable Energy Systems

Because the unit of analysis of this dissertation is exclusively the off-grid sector and the technologies it employs, this section of the literature review will focus explicitly on decentralized renewable energy systems and enterprises.

Decentralized renewable energy enterprises (DRE) as defined by the World Resources Institute are "companies that supply clean power for a community in a specific geographic region" (Bairiganjan et al., 2010). For the purposes of electricity generation, these enterprises can utilize small hydro (up to 100 kWh) and biomass gasification (up to 50 kW for a cluster of villages, according to Ghosh et al. (2006)). Solar home lighting systems (SHS), or "solar-based electricity generating and storage systems designed to provide power to individual households," are also DREs. Solar lighting systems "use photovoltaic panels to generate electricity combined with a battery and a controller to regulate charging and discharging" (Bairiganjan et al., 2010). On the whole, DREs can utilize a suite of technologies classified as decentralized renewable energy systems. Decentralized renewable energy systems include solar home lighting systems, biogas plants, clean cook stoves, biofuels, micro-hydro plants, biomass gasification based electricity plants, and micro-wind.

When looking at decentralized renewable energy systems from a household unit level of analysis, there are three types of end use energy needs that are being provided for: lighting, cooking, and some small scale industrial processes (which may also include heating and refrigeration; beyond the household, energy is also required for irrigation, agro-processing, and transportation). As described in the section above, the different fuel types used for each of the activities form what is called the "energy ladder," with each rung corresponding to a different income group and increasingly commercial forms of energy used to undertake the same type of end-use activity (Hosier 1987, Reddy 1994). Different types of renewable technologies may be used to meet these different end use demands (Kammen 2004). For example, for cooking, biogas and clean/efficient cook stoves may be used. For lighting, solar energy systems are most likely to be used for individual households, whereas micro-hydro, micro-wind, biofuel, and biomass gasification-based electricity generation may be used at a village scale. For small-scale industrial processes (such as pumping water for irrigation, drying and processing of crops, and local transport) for a village or remote hamlet, it is more likely that a micro-grid powered by solar, photovoltaics, biomass gasification, micro-hydro, micro-wind or biofuel may be used.

1.1.5 Some Issues Affecting DRE Deployment in India

After experimenting with several programs for different technologies to be deployed in rural India, the government recognized the need to meet the needs of villages in an integrated manner. In 2004, the Ministry of New & Renewable Energy (MNRE) launched the "Village Energy Security Program" (VESP), but discontinued it in 2012 due to various challenges (Palit et al. 2013). The program was intended to meet the "total energy requirements" of 75 rural communities in 9 states through the deployment of a combination of biomass gasifiers, straight vegetable oil (SVO) systems, biogas plants, and improved cook stoves in each village. Unfortunately less than half (42%) of the projects surveyed by researchers were fully or partially operational. Palit et al. (2013)

state that the reasons for the projects' failure include inability to overcome the challenges of: (1) low concentration of electricity demand, making distribution expensive and difficult; (2) poverty and consequent low demand for electricity; (3) difficulty on part of users to pay for electricity due to low disposable income in such remote areas; (4) difficulty in operation and maintenance due to remoteness of villages; (5) limited technical knowledge of the Village Energy Committee (VEC) members (who were charged with day-to-day operation and management of the technologies deployed) and; (6) weak biomass fuel supply chain linkages. The failure of the VESP also rests on the fact that, when working with integrated energy planning for villages, not all technologies can be promoted in the same way (gasifiers vs. cook stoves). As Palit et al. rightly point out, certain energy systems require clusters in order to have the economies of scales to function. Other technologies depend on a steady supply of fuel input at fixed prices, as is the case with biomass-based energy projects.

In addition to the various challenges associated with renewable energy technologies deployed in rural areas mentioned above, there are a few other factors to note. With technologies such as biomass gasifiers, Ghosh, Sagar and Kishore (2006) state that the "scaling up is significantly hindered by limited manufacturing capabilities—most gasifier manufacturers have small workshops, or are fabricators that produce gasifiers in a manner akin to craft production." "Deployment in such a situation," they add, "has taken place by replication of the small-manufacturing model rather than a shift to mass-production techniques within larger engineering firms." For technologies such as SHS, other challenges affect deployment. Harish et al. (2013) note that the role of banks as intermediaries between solar firms and customers is critical. In addition to providing access to credit, they also ensure good service and maintenance. So the success of the SHS market in India may depend on a strong link with a robust banking sector.

1.1.6 Solar Home Lighting Systems (SHS)

It is firmly established that universal energy access will have to be accomplished with a mix of centralized, micro-grid and off-grid options (IEA 2015). Given the history of the deployment of SHS and its target population in many parts of the world, for the purposes of this study, I have distinguished off-grid solar energy as a type of DRE that is useful for mainly lighting needs for the rural BoP population. In this final section preceding the problem statement, I will examine the issues (technological, social, financial, and business models) pertaining to SHS deployment, the primary unit of analysis of this dissertation.

1.1.7 Technology

As far as the technology is concerned, the power generation of SHS is dependent on intensity and duration of solar radiation (Kamalapur 2011, Raman 2012), and large losses of power conversion can be attributed to the battery and other components (Kumar 2009). Even so, solar photovoltaic (SPV) serves as an attractive source of electric power to provide basic services such as lighting and drinking water for lower-income rural communities, and has thus been championed by multilateral and bilateral financing agencies (Chaurey 2010). Lahimer (2013) adds that there are no civil works required for the installation of SHS, which makes them the technology of choice for expanding electricity access. As of 2015, the number of households around the planet served by SHS was approximately 20 million (IRENA 2015). While India and China both have large numbers, more than 1 million and more than 400,000 respectively, it is Bangladesh that tops the list with approximately 3.2 million installed units and a target of 6 million by 2017.

1.1.8 Social

The argument for deployment of SHS has been two-fold: 1) it is a cost-effective alternative to grid expansion in remote areas with dispersed population that is incapable of consuming large base loads; and 2) there are environmental benefits when substituting kerosene or coal-fed grid-based electricity with a low-carbon technology. Case studies reveal savings in electricity where users are using the SHS to supplement grid electricity, savings from reduced consumption of kerosene, and provision of alternative income opportunities (Harish 2013). Kerosene substitution through deployment of SHS is "reported to be as high as 15.2-21.3 liters /month in Argentina, 12.0 liters/month in Burkina Faso and 5.0 liters/month in Bolivia (Chaurey 2010). As a result of this substitution the same analysis concludes that, "over 70% of SHS have an annual emissions reduction potential in excess of 200 kg CO_2/SHS." In India alone, the annual "Certified Emission Reduction (CER) potential of SHS deployment could theoretically reach 23 million tons."

In addition to the ecological benefits of SHS deployment, the potential to generate wealth through employment in this sector is sizeable. The estimated employment generated through solar photovoltaic (SPV) off-grid deployment in India stands at 90 jobs per MW of capacity installed, with 30 jobs through direct employment and 60 through indirect employment (IRENA 2012). In sum, this figure amounts to 72,000 people employed through India's off-grid SPV sector, of which approximately 48,000 are indirect jobs including "dealers, marketing staff, lantern manufacturers, manufacturers of SHS kits, battery manufacturers, lamp manufacturers and others" (MNRE 2010). The added employment benefits of deploying SHS might facilitate policy development that accelerates or expands the range of diffusion of this technology across geographies.

1.1.9 Finance

The IEA argues that the difficulties of raising finances for "off-grid electrification of low energy expenditure households is the most challenging" factor limiting diffusion (2011). Pode (2013) similarly argues that "the high upfront cost of SHS and the absence of payment flexibility [is] deterring the penetration [of the technology] into larger market of lower-income group rural population." In India, the costs of providing off-grid SHS at 73 KWh per person a year are approximately $417 (IEA 2007). Compared with the global average cost of $41 per person annually for providing grid-connected energy access (to those for whom it is more appropriate) at 73 KWh, these costs seem exorbitant. An analysis of the operational costs of 13,000 SHS deployed in Morocco revealed that 40.5% of the costs are attributed to installation, 41.4% to operations and management activity, and 18.5% to general management (Carrasco et al., 2013). Details of this study link the maintenance costs to the mean SHS density, suggesting that dispersion and inaccessibility of installations in a project area can drive costs higher. The costs of the PV systems (equipment) in the Moroccan study are further broken down to reveal that solar panels represent just 15.5% of the total cost as compared to the battery, which is 18.5% of the cost. This price differential has important implications for SHS designers who may want to minimize costs attributed to expensive battery technologies.

1.1.10 Business Models

Innovation in the business models that help diffusion and adoption of this technology might address the challenges associated with finance, lack of supply chains, and after-sales support (Tawney 2013). Indeed the SHS market is "entering a new phase that is being led by entrepreneurs providing solar portable lights," and while the scale is currently small and costs may present a barrier, “the technology is improving at a rapid rate and business models are maturing” (Birol 2011). Thus business and finance innovation (including not only the products but also the processes) is 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 2013). Martinot et al. (2001) 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 (2012) 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. Such studies have important implications for SHS providers who are attempting to establish an appropriate price point for their product and design effective systems for the adoption of their technology.

1.2 Research Question

This study seeks to answer the following question: What are the firm-level characteristics that affect the scaling-up (or not) of off-grid solar technologies in India?

For the purposes of this study, scaling is defined as the number of products (units) that an off-grid solar enterprise manages to distribute or sell. Recognizing that there are a variety of off-grid solar technologies of varying capacities and varying levels of services, a unit is defined by a basic level of service to a household, consisting of one light and one mobile phone charging portal. This unit-level service can be delivered through individual solar lanterns, through a basic[7] micro-grid connection to a household from a central solar PV station, or through individualized SHS.

For this research question, the different factors associated with the deployment of off-grid solar technologies (such as technological specifications, after sales support, financing, etc.) are the independent variables and the level of scaling is the dependent variable. King states that "in order to better evaluate a theory, [one must] collect data on as many of its observable implications as possible" (King 1994). Thus the independent variables are differentiated based on the type of technology being deployed, the financial mechanism used to disseminate, the support networks for maintenance, etc. This qualitative study was designed to be emergent in nature, to accommodate the results of the statistical analysis of the DRE system market in India. The primary descriptive and inferential questions to be explored in this study are as follows:

---

[7] A "basic" level of service for a household through a micro-grid or through an individual SHS would be one to two light bulbs along with mobile phone charging.

- *Do firms that provide energy for multiple uses have higher unit scaling or greater geographical spread than firms that simply provide energy for lighting?*
- *What lessons can be learned on technology-type choice and its impacts on diffusion through the historical analysis of growth of a SHS provider?*

To explore this question, DRE providers who simply provide one energy service solution are distinguished from those who provide two or more by considering them as separate independent variables. Energy for powering mobile phones is likely to be part of most off-grid solar energy enterprises' product portfolio in addition to lighting. This should not be a surprise, given that the latest population census data released by the government of India notes that more people have access to mobile phones in India than toilets: 563.73 million and 366 million respectively (Telegraph 2010). These figures indicate that cell phone technology has sufficiently permeated both the urban and rural market in India, often in places that do not have access to reliable electricity. Furthermore, having access to mobile phone technology has helped improve rural livelihoods by providing farmers with real-time information on markets to sell their crops for higher revenues (Aker 2010, Sife 2010). In addition, mobile health clinics have helped increase the access to health care thanks to mobile phone technology.

- *To what extent does the provision of financing expand the diffusion of decentralized energy products?*

Due to high up-front costs for the end-user, access to financing has long been stated as a barrier to the diffusion of off-grid solar technologies. One way in which this perceived barrier has been addressed is through the channeling of large government subsidies towards end-user financing for such technologies. Another way this barrier has been addressed is through microfinance institutions (MFIs) or self-help groups (SHGs) that provide small customized loans to base of the pyramid (BoP) energy customers. If the primary barrier to diffusion of off-grid solar technologies is the inability of the end-user to pay, then one would expect off-grid solar technology firms to rely heavily on government subsidies, MFIs, or SHGs to facilitate the sale of their products. Previous studies indicate "if appropriately designed, loans offered by MFIs can provide clients with access to high quality modern energy services by closely matching loan payments to existing energy expenditures or income flows" (Morris 2007). Should this be the case, the answer to the question above would suggest that those solar DREs that are coupled with MFIs or government subsidy-providing banks would demonstrate the greatest amount of scaling in terms of products distributed to the rural BoP customer. Should this not be the case, then the question becomes: what financing models – other than end-user financing – allow solar technology companies to expand the diffusion of their products?

- *Is the diffusion of decentralized lighting technologies limited to areas without grid access? What does competition between the grid and DRE providers look like, and what are its impacts?*

The implication here is to test whether there will remain a market for solar DREs despite government intervention to create a centralized grid electricity system (or, whether the government should centralize the grid at all.) As discussed above, the government plans to achieve universal electrification by 2018. Arguably this would affect the market size for off-grid solar technologies. However, Sreekumar and Dixit state that while 90.6% of Indian villages are electrified, only 56% of the households in them are (Sreekumar and Dixit, 2011). This distinction suggests that while people may not be physically distant from the grid, their homes may still lack physical access and thus they may still require off-grid solar solutions. Furthermore, if people are purchasing solar lighting products even when they are connected to the grid, the assertion is that the reliability of electricity is so erratic, or that the desire of people to save money on utility bills is high enough, that solar DREs have a market nearly everywhere in the country and are not simply bound to areas without better access. To explore these questions, I ask providers whether or not they operate and distribute products in areas with grid access.

- *What is the role of networks in accelerating diffusion of solar lighting products? What methods or type of networks help facilitate diffusion of products more rapidly and profusely?*

Bairiganjan and Sanyal (2013) note the role of village level entrepreneur (VLE) networks in delivering consumer goods to the Indian rural market place. Understanding that supply chains present a considerable barrier to the dissemination and maintenance of products such as SHS in rural areas, an examination of providers that experiment with different models of VLE networks reveal insights into which are more successful at accelerating diffusion. To answer this question, I examine a few different providers who use unique VLE networks to facilitate the sales of their products. The annual sales of products by these providers sheds light on how diffusion of off-grid solar technologies with the help of such networks occurs. Organizations such as Frontier Markets open kiosks in remote areas to facilitate bulk purchasing and a single-point for sales and after-sales support, whereas Green Light Planet has a network of "saathis" (friends) who work full-time as sales agents in the field. Other organizations employ part-time sales agents, who may have other full-time jobs but also act as a local point person to handle sales and communication with the provider. Comparing the extent of diffusion achieved by such models helps answer this question.

1.3 Organization of the Dissertation

The core of this dissertation is made up of three self-contained papers to be submitted to peer-reviewed journals.

The first paper, Chapter II, has already been published in the journal, *Energy for Sustainable Development.* In Chapter II the main research question is, what are the firm-level factors that affect the scaling-up (or not) of off-grid solar technologies in India? The primary methodology employed includes a structured online survey of 69 off-grid solar technology firms from across the country. The survey asks questions about the business models of each firm as well as their sales data. Quantitative analysis of the responses is conducted by using independent variables relating to the companies' business models, such as the provision of finance, or conducting sales in areas with the grid electricity, and estimating their relationship with the dependent variable, scaling, represented by the unit of sales of each firm.

Chapter III asks the question: what is the role of financing in the diffusion of off-grid solar technologies in India? This research is supported by fieldwork involving site visits to customers of several different off-grid solar technology firms in various villages across different states. Methods include a structured telephone interviews of operators of government authorized solar retail shops (known as "Akshay Urja" shops), semi-structured in-person interviews with representatives of various off-grid solar technology firms operating both in the formal and informal market, semi-structured interviews with the customers in villages who are utilizing off-grid solar technologies, and semi-structured interviews with financial institutions.

Chapter IV presents an in-depth case study of the firm with the largest number of sales of off-grid solar technologies in India. Examining the growth story of this firm (as well as its business model) helps explain some of the factors such as the use of networks in how off-grid solar technologies may be diffusing in India. The main tool used for qualitative inquiry was semi-structured interviews conducted with various employees of the company. In addition, a structured survey was conducted of 15 Green Light Planet customers in several villages of Vaishali district in the eastern state of Bihar in July 2014. To identify and analyze the role of networks in GLP's business model, a combination of observation, process tracing, content analysis, quasi-statistics, constant comparison, and analytic induction were utilized.

The concluding chapter explores the key findings and the limitations of this study. Furthermore, the chapter explores the policy implications of this research. In addition, this chapter identifies future studies that should be conducted to understand how off-grid solar technologies do or do not achieve scale in a country like India.

CHAPTER II: BUSINESS INNOVATION AND THE DIFFUSION OF OFF-GRID SOLAR TECHNOLOGIES IN INDIA

2.1 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 their products, whether or not there is a provision for after-sales support, and what types of products they are distributing.

2.1.1 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 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).

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, 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, 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, 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, informal sales agents

Sell & Service	• Quality after sales servicing support • Company technicians travel to customers' homes for servicing	SELCO, Orb Energy
Full Payment	• Off the shelf purchasing • Financing may or may not be available to assist customer • Customer owns product	TATA Solar, Orb Energy, 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, 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, MNRE's Akshay Urja Shops

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

2.1.1.1 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 2012, Harish 2013). These are registered established businesses, small and large, 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, many entrepreneurs who are operating in the informal market, assembling electronic components, or ordering parts wholesale, 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.

2.1.1.2 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 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" (VLE), 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.

2.1.1.3 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 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.

2.1.1.4 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.

2.1.1.5 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 nonpayments. 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.

2.2 Methodology

A structured survey of off-grid solar energy enterprises from across India was conducted and was the main method of inquiry for this study.

2.2.1 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).

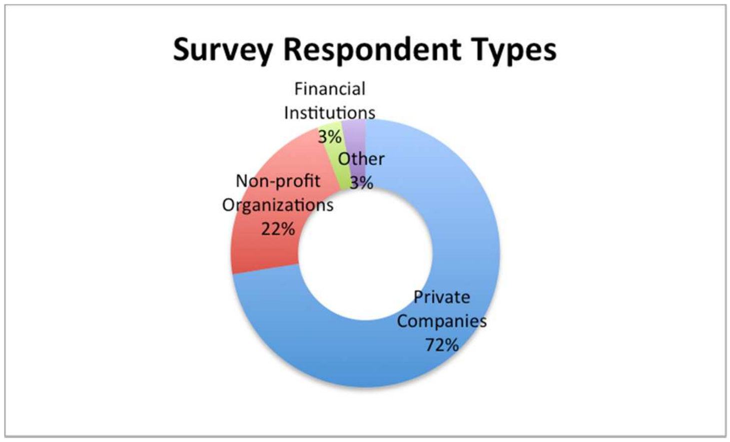


Figure 4. A graph representing respondent types of the online off-grid solar technology enterprise survey.

Of those surveyed, 69 responses were received from firms 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. Based on conversations with energy access experts and practitioners, it is assumed 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 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 to 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[8].

2.2.2 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

[8] Greater examination of customer data are the focus of Chapter 3. 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.

- 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

2.2.3 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.

2.2.4 Respondent types

Fifty (72%) of the respondents were private companies, fifteen (22%) were non-profit organizations, 2 (3%) were financial institutions, and 2 (3%) self-classified as "other" (Fig. 4).

2.2.5 Method of Analysis

A study as rich in data as this one requires a variety of methods of analysis to unpack all 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 another main stated question of Chapter 2: which factors affecting the scaling-up (or not) of off-grid solar technologies 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.

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 that 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, 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 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[9]. 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

[9] 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 1,000 units of "scale."

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,[10] 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.

2.3 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 this technology scales up (or does not).

[10] 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.

2.3.1 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 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 (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.

2.3.2 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,"[11] 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 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 individuals who are linked by patterned flows of information" (2003). Specifically, it is the

---

[11] 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.

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 networks 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 amongst 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."

2.3.3 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 is part of a wider solar energy technology innovation system (ETIS); the solar ETIS, in turn, is part of the global ETIS (Gallagher 2012).

These systems may be different in different geographies; one could assume that India's ETIS and solar ETIS is different from neighboring China's, 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 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.

2.3.4 Business Innovation

Tawney et al. 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 (2013). 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 and Kandpal compare the ownership versus fee-for-service/rental models of dissemination (2012). 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 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 north-western 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 innovation (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 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 (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 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 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 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 and Kandpal (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 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.

2.4. Results and Discussion

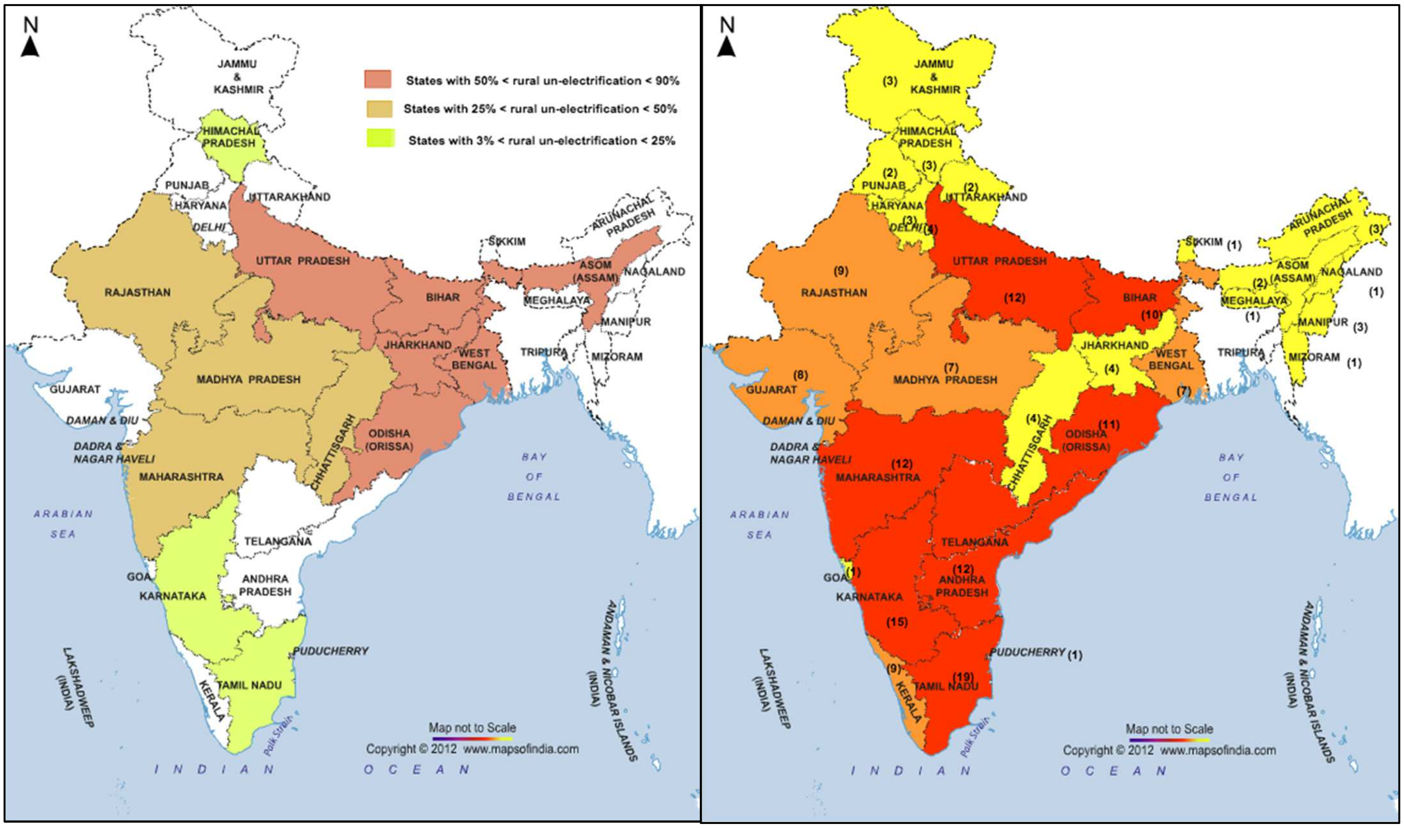


Figure 5. Comparison of un-electrification rates with number of off-grid solar technology providers distributing per state based on survey.

2.4.1 Grid and Geography

To test whether 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 must 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[12].

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 4,350 megawatts (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 reveals, however, that the figure may be as high as 53% in some states (Navani 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

---

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

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.

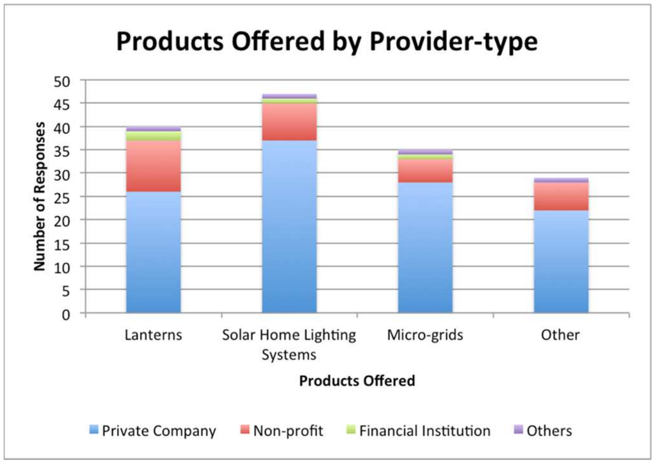
Bhalla notes that large-scale rural electrification through long 11kV and low tension lines along with haphazard growths of the sub-transmission and distribution system with the short-term objective of extension of power supply to new areas is also to blame for the shortage of electricity supply. Even Singh (2010) states that 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 et al. (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. 5 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 figure two 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. These findings further reinforce the hypothesis that the market for off-grid solar technologies in India is not limited by the extent of the electricity grid.

2.4.2 Products Offered and Uses

Respondents were asked to identify which off-grid solar energy products they offered to ascertain the distribution of product-types amongst the respondents. For the purposes of this study, the options[13] provided to the respondents included: 1) lanterns; 2) solar home lighting systems (SHS); 3) micro-grids; and 4) others. This last category could include devices like solar street lighting, solar water heaters, etc. 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. 6 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.

[13] Respondents had to choose at least one of the options.



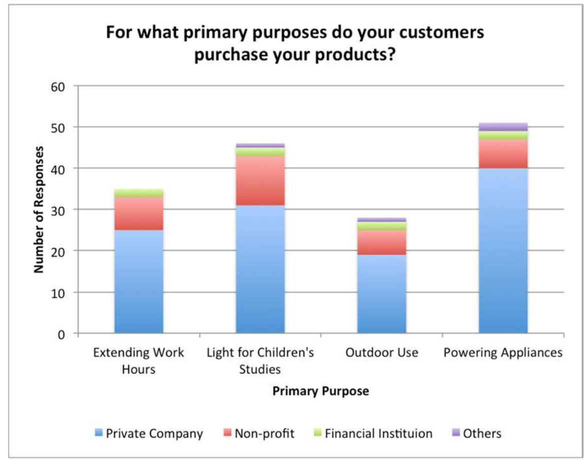


Figure 6. The graph on the left depicts the distribution of products offered by type of provider and the graph on the right depicts the distribution of use of products by provider type.

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. 6 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 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 $0.16 – 0.80 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.

2.4.3 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-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. 7). Outside of the

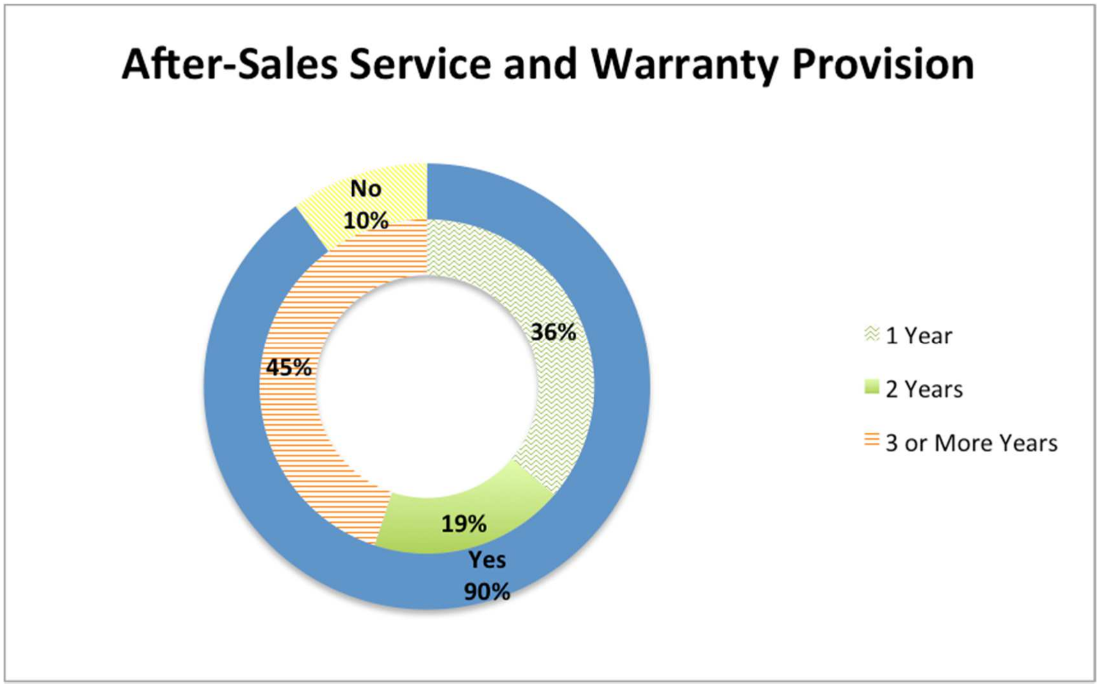


Figure 7. This graph depicts the results of after-sales service provision and number of years of warranty provided by the firms interviewed.

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 the 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.

2.4.4 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. 8). 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. 8).

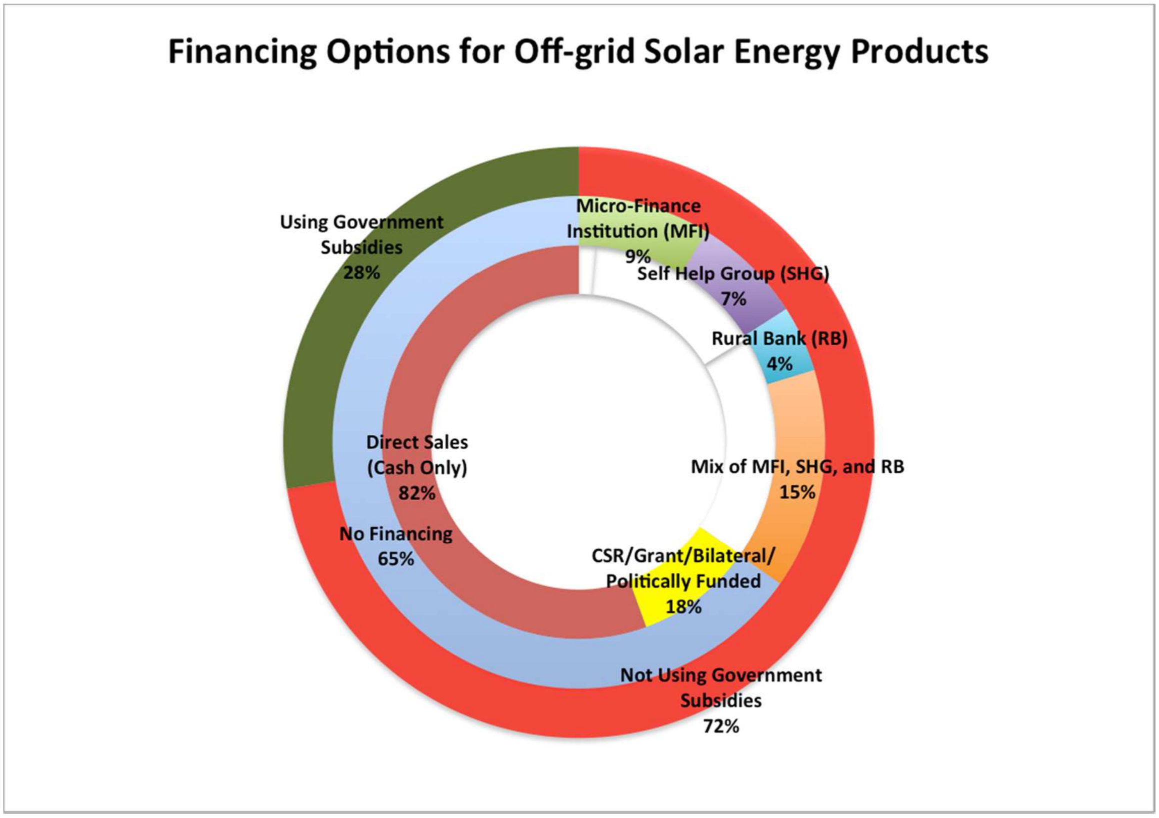


Figure 8. The outer ring of this graph depicts whether or not the respondents are using government subsidies. The middle ring depicts the types of financing provided by the providers to their customers. The inner ring depicts the breakdown of no financing.

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. 8).

The topic of financing for off-grid solar technologies is taken up in the next chapter 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[14] government approved "channel partners[15]" 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.

---

[14] 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.

[15] 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.

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, and particularly startups with limited staff and capacity, can scarcely afford allocating 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 does not prioritize lending loans for solar technologies.

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 predominantly 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 let them 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.

2.4.5 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

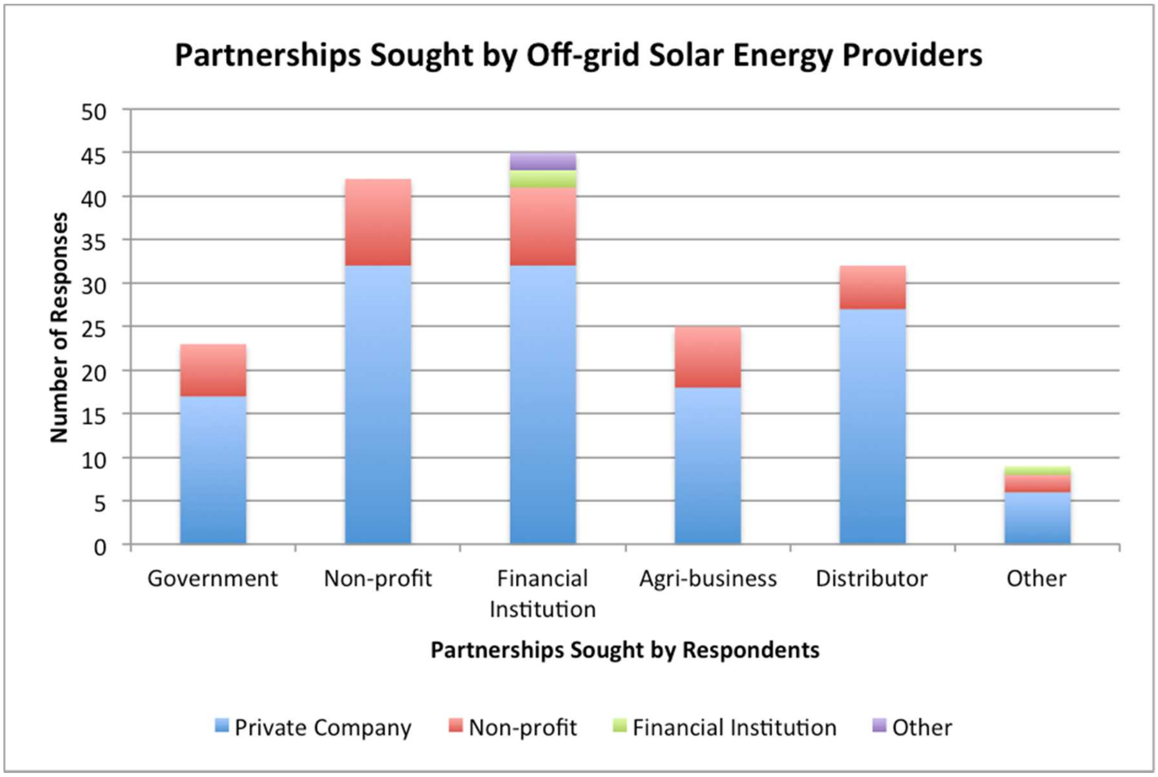


Figure 9. This graph depicts the partnerships sought by off-grid solar energy providers in India by provider-type.

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. 9). 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. 9).

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.

2.4.6 Sales Data

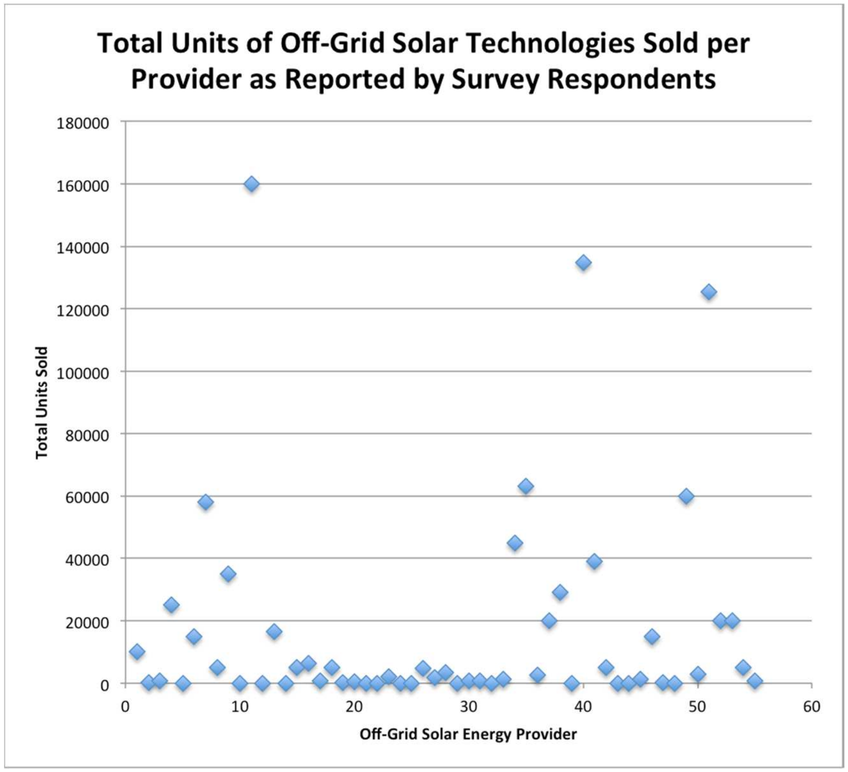


Figure 10. Scatter plot of sales data from 57 respondents of the off-grid solar technology market survey. For easier visualization, the highest sales figures (over 3 million products) have been removed (only 55 points visible in this graph).

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 56 respondents reported their figures bringing the sample size down from the original 69. A scatter plot of the sales data (Fig. 10) 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. However, services provided by solar energy can be shared thus the overall number of people with access to the technology may be substantial. Additionally, the industry is largely quite young, averaging seven years of operations. Age is however not necessarily related to the unit scaling of an organization 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 2015).

2.4.7 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. Furthermore, such a model for comparing how an off-grid solar firm might scale has not been created before. With additional data points over time or at a global scale linear regression would become the appropriate statistical analysis tool to employ. 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.

Based on the hypotheses outlined in the introductory chapter, 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) micro-grids; and 4) others), and Q_i (number of products sold or unit scaling) for all firms (i) where $i = 1,2,3,\ldots 56$. Additional variables in the regression include *SB* (whether government subsidies were used to distribute the product), *T* (firm type including 1) private; 2) non-profit; 3) financial institution; and 4) other), M (marketing budget), and W (warranty provision). The tables below depict the regression results with statistically significant (p<10% and p<5%) relationships highlighted.

Table 2. Summary Statistics

	mean	sd	min	max	sum
Unit Sales	154416.30	736497.63	1	4700000	8647313
Firm Type	1.39	0.73	1	4	78
Number of States	4.80	6.74	1	23	269
Marketing	0.75	0.44	0	1	42
R&D	0.59	0.50	0	1	33
After Sales	0.91	0.29	0	1	51
Government Subsidy	0.27	0.45	0	1	15
Categories of	2.30	1.08	1	4	129

Products					
Financing	0.36	0.48	0	1	20
In Grid	1.80	0.72	1	3	101
Warranty	2.07	0.89	1	3	116
Observations	56				

The following regression ($Q_i = \beta_0 + \beta_1 G_i + \beta_2 F_i + \beta_3 P_i + \beta_4 SB_i + \beta_5 S_i + \beta_6 T_i + \beta_7 M_i + \beta_8 W_i + u_i$) aims to estimate the relationship between overall unit scaling and all the factors unique to a firm.

Table 3. Factors Affecting Unit Scaling

	Unit Sales
In Grid	-35,954
	(0.809)
Financing	41,202
	(0.859)
Categories of Products	**-216,308***
	(0.0503)
Government Subsidy	-147,203
	(0.549)
Number of States	14,218
	(0.382)
Firm Type	-195,285
	(0.216)
Marketing	165,074
	(0.511)
Warranty	-128,198
	(0.296)
Constant	1.088e+06*
	(0.0692)
Observations	56
R-squared	0.139

**p<0.10; **p<0.05*

The following regression ($F_i = \beta_0 + \beta_1 P_i + \beta_2 S_i + \beta_3 Q_i + u_i$) was used to answer the question of whether financing affected unit scaling. Additionally, it was used to determine if certain product types or the spread of geographies in which a firm operates correlated with whether the firm provides financing. Recall that these are potentially important relationships as discussed in the introductory chapter.

Table 4. The Role of Finance

	Financing
Categories of Products	**0.123***
	(0.0559)
Unit Sales	-4.03e-08
	(0.657)
Number of States	-0.00372
	(0.708)
Constant	0.0972
	(0.541)
Observations	56
R-squared	0.083

**p<0.10; **p<0.05*

The following regression ($G_i = \beta_0 + \beta_1 P_i + \beta_2 S_i + \beta_3 Q_i + u_i$) was used to answer whether the existence of the grid affected overall unit sales, the types of products sold in those areas, and the number of states the firm sold products in.

Table 5. The Role of the Grid

	In Grid
Categories of Products	**-0.212****
	(0.0255)
Unit Sales	-4.57e-08
	(0.731)
Number of States	**0.0275***
	(0.0621)
Constant	2.168**
	(0)
Observations	56
R-squared	0.123

**p<0.10; **p<0.05*

The following regression ($P_i = \beta_0 + \beta_1 S_i + \beta_2 G_i + \beta_3 Q_i + u_i$) was used to determine whether the categories of products provided by a firm correlated with whether the firm was distributing products in areas with the grid, in a certain number of states, or was associated with overall unit sales for the firm. Recall from the discussion that certain product types may be easier to sell due to their size and may thus also affect their ability to be sold in more states or areas with or without the grid.

Table 6. Product Categories, Scale & Spread

	Categories of Products
In Grid	**-0.435****
	(0.0255)
Unit Sales	**-3.37e-07***
	(0.0713)
Number of States	**0.0470****
	(0.0250)
Constant	2.914**
	(1.11e-10)
Observations	56
R-squared	0.189

**p<0.10; **p<0.05*

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 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.

Several 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 requires 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.

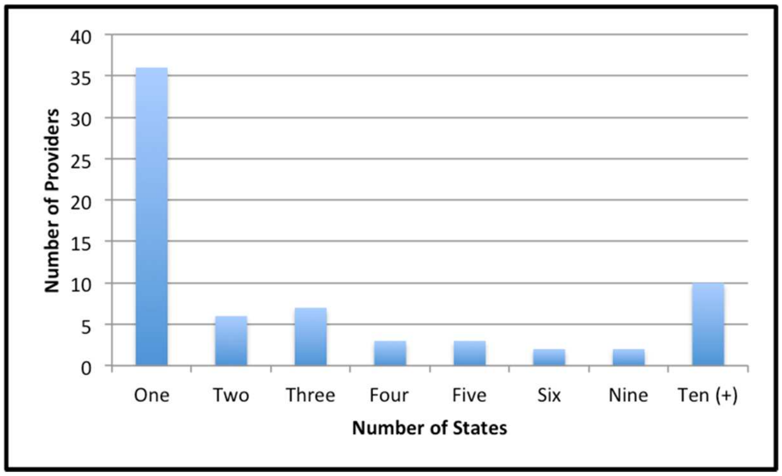


Figure 11. This graph depicts the distribution of the number of states the firms surveyed operate in. Overwhelmingly a large number of respondents only distribute products in one state.

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. 11). 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.

2.5. Conclusion

While further 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 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 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.

CHAPTER III: FINANCING FOR WHOM BY WHOM? COMPLEXITIES OF ADVANCING ENERGY ACCESS IN INDIA

3.1 Introduction

This study asks the question, what is the role of financing in the diffusion of off-grid solar technologies in India: the end-user, the firm, or both? The sub-questions explored here include: what elements of financing are helping or hindering expansion of off-grid solar technologies? What kinds of financing are required for different kinds of off-grid solar technology businesses to succeed? And what might be the role of government-supported financing and how might it be used effectively for either the end-user or the firm? This research is based upon surveys and interviews with customers across four Indian states, and financial institutions, off-grid solar companies and experts from across the country.

The discourse on financing access to energy for the rural poor is puzzling, given realities from the field. During the early stages of their deployment, the high upfront costs associated with solar technologies kept the focus on the required government-backed financial assistance in the form of end-user subsidies. This form of financing was consistent with government-supported subsidies for a variety of consumer goods and fuels, such as kerosene, in countries like India. Over time, the cost of manufacturing solar technologies has decreased and the incomes of hundreds of millions of rural poor have risen. These changes have supported breakthroughs in financing innovations provided by emerging off-grid solar energy enterprises that put these technologies within reach of the rural poor. While venture capital firms have seized on the promise of these firms to deliver energy access, development banks have been slow and governments reluctant to fund the firm because: 1) they still consider end-user financing to be the main barrier preventing solar technologies from scaling; and 2) they are too risk-averse or do not see themselves playing the role of venture capital investor. This dichotomy on financing has led government policies to focus on programs for end-user financing. Indeed, the relatively higher upfront cost of the technology has prevented its large-scale diffusion; however, field observations and experiments of business models employing innovative financial tools in places like India should help explain where the emphasis should lie in the financing off-grid solar technologies moving forward.

In India, traditional end-user financing for energy access has largely come from the government. Under its National Solar Mission, the Indian government established a program to subsidize solar home lighting systems (SHS). The Indian Renewable Energy Development Agency (IREDA) through the National Bank for Agriculture and Rural Development (NABARD) implements the program. Only individuals, Self Help Groups (SHGs), Joint Liability Groups (JLGs) Non-Governmental Organizations (NGOs) and farmers' clubs are eligible for the subsidies. Forty percent of the cost of a SHS is subsidized and the remaining 60% of the cost is eligible for a soft loan through a registered bank. The Reserve Bank of India regulates all interest rates and margins for which the beneficiary is liable over the five-year loan repayment period. During those five years, the supplier of the technology (which is also authorized by the government) is required to provide after-sales support and maintenance service to the customer. The steps to apply for the subsidy are as follows: 1) have an account with a registered commercial or regional bank; 2) approach a vendor of solar home lighting systems and agree to purchase a product; 3) submit all documents to the bank; 4) the bank verifies all documents and goes for a site survey to the home of the applicant; 5) the bank submits documentation to NABARD for release of the subsidy to the bank; 6) NABARD releases the subsidy to bank; and 7) the bank approves the loan and the customer receives the product from the vendor. This process is cumbersome; more recently, there have also been significant delays in the releasing of subsidies by NABARD.

Both academic literature on off-grid energy access primarily focus on traditional end-user finance, such as government subsidies as described above. Recently gray literature has started to uncover the financing needs of energy access firms as being one of the barriers to off-grid technology diffusion (UN 2015; BNEF 2016). Due to emerging evidence about the lack of effectiveness of the government subsidies, this study will explore the realities of funding for both the end user and the firm operating in this sector. In particular, it examines alternative approaches to government financing to help address both the ability and purchasing decision of end users to pay for off-grid solar technologies.

3.2 Literature Review and Methodology

3.2.1 *Literature Survey*

To adequately discuss financing for off-grid solar technologies in India, one must examine the politics and policies of supplying energy in India, the complexities around financing off-grid solar energy access, and how innovations in financing energy access are surmounting the challenges that plague the sector.

3.2.1.1 The Politics and Policies of Energy Supply in India

India has a vast and complicated history of electrification policies (Modi 2005). Of particular importance to this study, the 2006 Rural Electrification Policy established a "minimum supply" [16] of 1 kilowatt-hour (kWh) per household per day (364 kWh/household/year) "as a necessity by 2012" (MOP 2006). The Policy additionally provided assurance of reliable power supply at reasonable rates and access to electricity for all households by 2009. Unfortunately, these goals were not achieved, because of lack of adequate

[16] The minimum supply is calculated as the "lifeline requirement" corresponding to the all India monthly per capita consumption of kerosene (0.61 liters) and electricity (6.35 kWh) for lighting.

investment in the energy infrastructure, coupled with subsidies that had a crippling effect on the State Electricity Boards.[17]

The well-meaning pro-poor policies designed to expand energy access resulted in a system of untargeted producer and consumer subsides, which in turn resulted in the power sector's inability to generate enough revenue for continued investment in infrastructure and management expertise (Modi 2005). Failure to meet the original goals ultimately culminated in a resetting of the goals and continued expansion of the grid under the new Rajiv Gandhi Village Electrification Program (RGVEP), which was part of the National Common Minimum program of the ruling coalition at the time (United Progressive Alliance). Through the RGVEP, the then ruling government claimed to have met its target of electrifying 100,000 villages and providing free electricity to 175,000 households below the poverty line by 2012.

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. As mentioned before, 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 considered

[17] In India, the states manage their own generation, transmission, and distribution of electricity, which makes power planning particularly difficult to implement. Private power purchase agreements must be made separately with each state if one state or entity is to purchase power that crosses through multiple territories.

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 (REC 2005). The National Democratic Alliance (NDA) elected government that swept into power in May 2014 has redoubled the previous government's electrification efforts to achieve universal electrification by 2019, supported by both centralized and decentralized energy distribution systems. Of course, there will need to be enough power generated to ensure that the electricity supplied is adequate and reliable.

The politics of energy pricing and subsidies in India has a long history. Specifically, "a standard collective action problem prevents politicians from making difficult decisions concerning electricity pricing" Joseph (2010). So bad is the situation that a third of the country's electricity each year is not billed, and much of the lack of billing may be attributed to electoral politics (Min 2014). Today subsidized electricity and access at large is part of the nation's vote bank[18] politics. One example of this phenomenon is India's longstanding provision of subsidized electricity to farmers for irrigating their fields, a practice that led rural electrification efforts in the post-independence era. As nearly half of a farmer's annual income can go into diesel for irrigation pumping, subsidies to provide nearly free electricity was seen as a means to

[18] Vote bank: consists of a loyal bloc of voters from a single community (often based on caste, religion or culture), who consistently support a certain candidate or political party in democratic elections.

alleviate an otherwise prohibitive financial burden in return for political allegiance. To quantify "nearly free," according to Cust et al., "typically grid tariffs for poor rural households range from Rs.0-10 ($0.16)/month for the poorest households[19] and Rs.0-130 ($2.05)/month for remaining domestic customers" (2007). To further complicate the matter for a financially strained system, where collection is undertaken, metering can often be faulty, and the frequency of collection may be just as erratic as the electricity supply. This system of subsidization and inefficient financial collection threatens India's already overburdened energy infrastructure.

Electoral politics makes it nearly impossible for any political party to drastically change a system of subsidies that has been locked into place over decades. Furthermore, politicians have often meddled in electrification policies at the state level, which has led to uneven progress of electrification across the country. Take for example the rise of the Aam Aadmi Party (AAP) in Delhi, which won with an overwhelming majority of seats in the Legislative Assembly in 2014 on the promise of reductions in electricity prices. Another example comes from research conducted by Min and Golden (2014), which analyzed four decades of annual data from the power corporation of Uttar Pradesh, India's most populous and politically important state. Just before

[19] The central government funded Kutir Jyoti program aims to provide free basic connections for all BPL households. For non-BPL households, grid connections can be effectively free given poor rates of bill collection in many regions.

state assembly elections in 2002 and 2007, tremendous line losses occurred in certain localities where the incumbent party may have directed power at flat and unbilled rates (essentially discounted or free electricity) to gain an upper hand. It could be argued, as pointed out by the struggles of off-grid solar enterprises operating in the state, that such practices create an ecosystem in which the population does not care to pay for electricity, no matter the cost, when they have known it to be free of charge. This government behavior violates one of Douglas Barnes' four principles of electrification, which specifically includes keeping politics separate from electrification projects (2007).[20]

Finally, the availability of subsidized kerosene creates a further distortion. In this regard, rationing, a concept that was introduced in India during the 1940's at the time of the Bengal Famine, continues to pose a political challenge. The Public Distribution System (PDS) set up by the government provides basic consumption goods (primarily food grains but also kerosene) through local distributors (called "Fair Price Shops") at a fixed government subsidized rates to all families classified as being below the poverty line (BPL) – families earning less than $1/day. Households must carry a ration card in order to

---

[20] Barnes' five principles of electrification include: sustained government commitment, effective prioritization and planning (includes establishing a rural electrification body, coordinating with other rural development goals, limiting political interference, and reducing construction and operating costs), sustainable financing (includes developing effective subsidies), and having a customer focus by effective distribution companies.

obtain these goods at subsidized rates from those shops. For example, each family might be able to receive a monthly supply of three to four liters of kerosene for their lighting and cooking needs for free or at a reduced rate. It is an uphill battle to get people to forego these subsidies once they are above the poverty line, and there may be lack of adequate reporting in income in a "race to the bottom" to be able to get on the register for BPL benefits, particularly for cooking fuels (IE 2015). It is estimated that as of 2012, the government spent approximately 7% of the GDP subsidizing fuels (Guay 2012).

Kerosene was subsidized with the intention that it would be used as a cooking fuel. However recent findings reveal that kerosene is largely being used as a lighting fuel across the country, with some states such as Bihar topping the charts at 73% of rural households using the fuel solely for lighting (Singh 2015). Central subsidies for both electricity and kerosene can be augmented with state subsidies, and tend to price out viable decentralized renewable energy alternatives (such as solar home lighting systems), which are attempting to enter the large base of the pyramid market. Thus, rationing in favor of a particular energy option unintentionally inhibits the generation of adequate demand for these alternatives.[21]

[21] Heavy critique of kerosene-specific subsidies for lighting has prompted the government to recently launch the "Direct Benefit Transfer" program. This nascent program provides a direct cash transfer to each below poverty household for energy. By remaining technology agnostic it may encourage demand for alternative forms of energy perhaps favoring solar home lighting solutions over kerosene.

3.2.1.2 Changing Dynamics: Financing Off-Grid Solar Energy Access

To evaluate the changing dynamics within financing for energy access one needs to examine: 1) the role of customers' changing ability and decision to pay for off-grid technologies; 2) the declining costs of technologies; and 3) the financing needs of energy access firms today.

Pode (2013) argues that "the high upfront cost of SHS and the absence of payment flexibility is deterring the penetration [of the technology] into larger market of lower-income group rural population." However, studies specific to innovations not related to physical products, such as new financing models, claim that success is more likely when innovations are adapted to the user's cash cycle and economic situation (Monroy 2008, Bardouille 2012). Another study by Urmee and Harries (2009) that evaluated numerous renewable energy implementers across the Asia Pacific region, including India, suggests that the "lack of suitable financing mechanisms" is the most significant barrier to the uptake of solar home lighting systems. Furthermore, the study concluded that low income is "no longer perceived to be the primary, or even a major, barrier to the uptake of solar home lighting systems."

Other signs that the business of doing solar in India is less dependent on end-user income are demonstrated through a study that concludes that most providers of off-grid solar technologies in India use micro-finance institutions as a distribution channel for their products, not as a provider of credit (Harish

2013). While the same study states that the “presence of willing banking partners was crucial to entering a new region,” anecdotal evidence coupled with survey results show that the majority of off-grid solar enterprises are not using bank financing for the sales of their products. The story here may be that the role of banks may be critical in regions where populations have limited exposure to or awareness about off-grid solar technologies, such that it influences their decision to purchase. Perhaps, beyond a certain stage of technology penetration in an area, a firm can conduct sales with greater ease with the population residing in that area without the help of banks because the local population is familiar with the technology and its associated benefits. This would support Rogers (2003) theory of diffusion of innovations in which the experience of early adopters creates awareness amongst the local population and affects the overall rate of adoption (and, in this case, the decision to pay) for the innovation.

The findings of other researchers discussed above are also supported by a recent study of willingness to pay conducted by Urpelainen and Yoon (2015) of 750 households in rural areas of the north Indian state of Uttar Pradesh. The study found that households with high levels of awareness (or, knowing someone who has a solar home lighting system) have an increased willingness to pay for such systems. In addition, the study found that households who had access to the grid or high levels of income also had a higher willingness to pay. Overall, the study concluded that there was a Rs. 3000 ($50) gap between the respondents' willingness to pay and the actual cost of a high quality 40-Watt solar home lighting system in the market. This gap is arguably marginal; given the availability of financing innovations employed by a firm, it could easily be bridged to facilitate the purchase of such systems on a larger scale.

The sharp decline in the cost of solar photovoltaic panels driven by manufacturing in China (Aanesen 2012) coupled with domestic government policies such as the National Solar Mission have supported "the emergence of new solar lighting firms targeting rural customers" (Harish 2013). These firms are capable of innovating business models that make access to energy through previously expensive solar technologies much more affordable. Reduced costs for the PV modules have been amplified by improved demand side efficiency; LED-based lighting is a good example. Harish et al. calculate that a 3 compact fluorescent light system powered with a 40 Watt panel and a 40 Ah battery is 20% more expensive than a system that produces as much light but has 3 LED bulbs that are powered by a 20 Watt panel and a 22 Ah battery (2013). Their study is based on the cost of a high quality LED solar home lighting system in the market being Rs. 9,900 ($165), and when amortized over a period of five years at an annual interest rate of 12%, the monthly installments amount to Rs. 180 ($3). This cost is less than the combined subsidized and supplemental (unsubsidized) monthly cost of kerosene for the lowest ten deciles of household income in rural areas in India. Another study by the Lawrence Berkley National Laboratory (Phadke 2015) explains that declining costs of solar PV, the advent of LED lighting and improvements in lithium-ion battery technologies have enabled dramatic performance gains and price declines in the pico-solar market (see Figure 1).

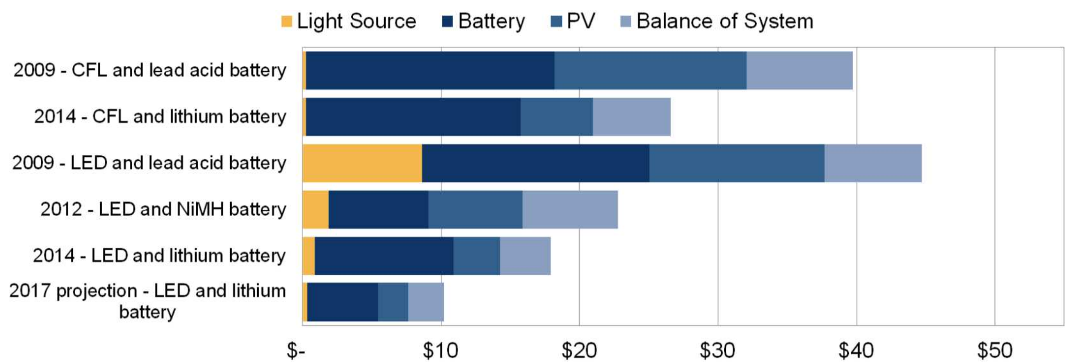


Figure 1. Retail price of pic-solar off-grid products that provide 120 lumens of lighting service for four hours per day (Phadke 2015).

The same study analyzed the declining costs of solar home lighting systems with super-efficient appliances (a television, a radio, mobile charging, and a fan) to be sold as one package. The price declined between 2009 and 2014, for systems providing identical level of service, thanks to technological innovation

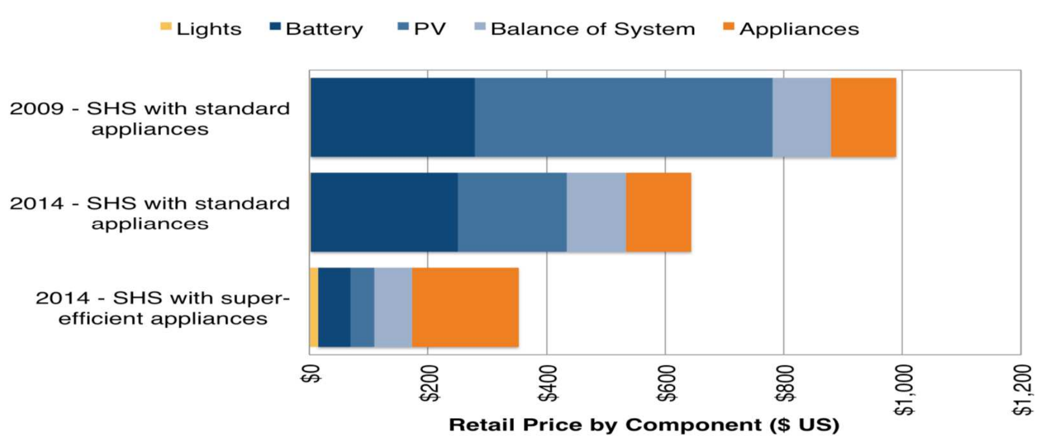


Figure 2. Retail purchase price for three solar home systems that provide identical levels of service (4 hours of 600 lumens of lighting, 4 hours of operating a 19-inch color TV, 6 hours of operating a small portable radio, and one charge per day of a basic mobile phone (Phadke 2015).

and reduced costs of manufacturing by over 60% (see Figure 2). These findings suggest that the combined impacts of high costs of kerosene, erratic electricity supply through the grid, and advancements in technological innovation supported by innovations in financing models overcome low household income as a barrier for the uptake of off-grid solar technologies in India.

To leverage the declining costs of technology and the greater ability and propensity of customers to pay for those technologies firms are coming up with innovative finance models to successfully conduct their business. However, these firms require capital for operations and to scale up their businesses. In 2011, the International Energy Agency (IEA) asserted that financing for "off-grid electrification of low energy expenditure households was the most challenging" type of finance to raise. According to the UN Foundation, accessing the "right kind and amount of capital at the right time remains one of the key bottlenecks to scaling-up decentralized energy solutions" (2015). Collective global funding requests for the sector amounted to over USD $1 billion in 2015.

In light of the shifting discourse, it is important to acknowledge that the challenge to the adoption and diffusion of off-grid solar technologies is not simply the low income of the end user, contrary to what so much of the literature argues (Balachandra 2011, IEA 2011, Wong 2012, Pode 2013). This paper will show that the more important factor for the diffusion of off-grid solar is the innovative types of financing introduced by entrepreneurs that make end users' access to energy provided by such technologies more flexible and affordable. The paper then suggests that the firms who utilize these innovative models urgently require financing to help scale up their businesses.

3.2.1.3 Innovations in Energy Access Finance

The burst of entrepreneurial activity around the business of off-grid solar technology distribution in India has led to a variety of experiments in financing. Use of microfinance is perhaps the most tried example, but a number of other innovations are also relevant to the energy access market. These innovations, which are discussed below, include: solar technology rentals, use of remittances to pay for energy services, pay-as-you-go (PAYG) financing and crowdfunding.

Studies on microfinance reveal that access to modern energy is greatly enhanced when people have access to loans in order to pay for the technologies (Hilman 2007, Rao 2009). Microfinance loans differ from traditional lending, in that they do not require access to formal banking institutions, as described above, and may also be subject to different conditions of repayment and interests. Microfinance has been proven to be a successful mechanism to improve livelihoods and eradicate poverty by providing people with small, manageable loans to support income-generating activities. Providing loans specifically for energy technologies that can be used for income-generating activities or increasing productivity is one of primary ways in which microfinance is playing a role in helping expand energy access around the world. However, while conceivably a useful financial tool, in India, only 9% of the firms distributing off-grid solar technologies are leveraging the power of microfinance (Singh 2016).

Another example of innovation in energy access financing tried specifically for solar lantern technology is a rental model. Chaurey and Kandpal (2009) compare the ownership versus fee-for-service/rental models of dissemination set up by The Energy & Resources Institute (TERI). However, their results conclude that a central charging station model (rental model) is not viable even with 100% capital subsidy support "if the households were to compare renting vs. owning the solar lantern." In the rental model the households would end up paying a daily rental that is more than the effective daily cost of owning the solar lantern. If the goal of an energy poor household is to be energy independent, such technologies must lead to ownership where financially possible, not continued dependence.

Remittances may also have a role to play in financing energy access. According to the World Bank, India has remained one of the largest recipients of remittances for several years (Gupta 2015). While the use of remittances for energy has not yet been documented in India, efforts to channel remittances specifically towards energy technologies in Haiti (Akkari 2013) do suggest that successes in using this large volume of capital to fuel the expansion of energy access technologies, such as solar, could be replicated in India.

Experiments in financing for energy access that leverage mobile technology and the internet are more promising and transformative for the sector. Pay-As-You-Go (PAYG) is a concept that is familiar to most people in both the developed and developing world due to cell phone usage. A report by Arc Finance describes the "idea of paying for something in advance, only when needed, and in increments that match one's cash flow," as "easy, flexible, and appealing to the energy poor" (ArcFinance 2014). PAYG models highlight that the challenge of financing energy access technologies is not simply affordability, but also flexibility of payment mechanisms. This flexibility mirrors how people pay for electricity through the grid: a monthly electricity bill that is flexible according to how much energy a household consumes, unencumbered by the total upfront costs of the energy generation and distribution infrastructure. The energy poor in India increasingly have access to mobile phone technology, which allows them to use PAYG for access to energy that is tailored to their needs. Micro-grids and solar home lighting systems, coupled with mobile phones in an interaction termed Machine-to-Machine (M2M) technology, afford the opportunity for people to use PAYG financing for off-grid energy access (Nique 2013). Nique estimates that the “energy addressable market” of people living without electricity access but having mobile phones in India is approximately 85 million people (2013).

In India, companies such as SIMPA Networks, OMC Power and Gram Power are pairing these methods of weekly tariff collection with their solar technologies to provide electricity services. In the case of SIMPA Networks, customers make a small down payment on the SHS provided by the company, and their weekly payments go towards eventual ownership of the product. They are essentially paying down the entire cost of the system over time. Should they choose not to continue service, the product remains the property of the company.

Barriers exist for the advancement of PAYG SHS technology in India. First, mature mobile money markets are required to support PAYG financing; these markets are not as developed in India, where regulations have until recently restricted mobile money transfers. In addition, quality metering technology and the right kind of business model (either partnering with a cellular service provider or developing one’s own technology) are also important factors associated with PAYG financing (ArcFinance 2014). Nonetheless, this financing innovation promises to accelerate access to energy for millions more, and to do so without the need for subsidies to the end user to purchase off-grid solar technologies.

Another nascent financing innovation for the energy access sector, “crowdfunding,” describes “the practice of raising funds in small increments from large numbers of non-institutional sources” (ArcFinance 2014). It generally requires an online platform that can be promoted using social media campaigns, thereby leveraging the social networks of the non-institutional sources to contribute towards the advertised early-stage companies or projects. A few major enterprises have emerged that host these platforms for raising funds such as Kiva, Indiegogo and Kickstarter. In India there are only a few online crowdfunding platforms: Rangde and Wishberry. Another organization, Milaap, combines microfinance with crowdfunding by facilitating crowdfunding of microloans for a variety of organizations. These platforms have started to be used for financing off-grid solar technologies in India.

As India’s online retail market booms, the opportunity to capitalize on online crowdfunding could be quite significant. However, barriers remain: regulations of the Security and Exchange Board of India (SEBI) do not allow returns on investment for any funds raised from the public, unless the company goes “through the complicated and costly procedure of listing on a stock exchange” (Lopicich 2015). Many early-stage companies that are currently operating in the energy access space are far from being able to be listed publicly. Thus, investors are largely those who are interested in philanthropic giving, and those who contribute micro-loans using Milaap’s platform would have to be flexible about return timelines and understand that they will not receive interest on their payments. Or in the case of Wishberry, investors would only be given access to gifts provided by the hosts of the campaign as an incentive. Regardless, the potential for raising funds for energy access through crowdfunding could be enormous. By some estimates (Guay 2012), it is a $90 billion opportunity. For a country like India, which attracted $55 billion in remittance flows in 2010, the possibility to use some of those funds for energy access through crowdfunding platforms would make a substantial impact.

3.2.2 Methodology

This study utilized various forms of inquiry to capture players both in the formal and informal markets. It is supported by original fieldwork involving site visits to customers of several different off-grid solar technology firms in various states and villages. Methods include a structured telephone interviews of operators of government authorized solar retail shops known as "Akshay Urja" shops, semi-structured in-person interviews with representatives of various off-grid solar technology firms operating both in the formal and informal market, semi-structured interviews with the customers in villages who are utilizing off-grid solar technologies, and semi-structured interviews with financial institutions. In addition, the study draws on the results from a structured online survey of 69 off-grid solar enterprises operating in India (Singh 2016), which has been discussed at greater length in the previous chapter.

3.2.2.1 Structured Telephone Interviews

With the help of research firm Outline India, between May and July 2014, 170 government-authorized retailers of off-grid solar technologies from across the country were called to ask about their solar business. Respondents were given no incentive to participate and were told that the questions were being asked for research on how such technologies are distributed in the country. Region appropriate language was utilized when asking the questions, with the help of translators. The complete list of registered retailers and their corresponding contact information was procured from the Ministry of New & Renewable Energy website. The registered telephone numbers were called 4 times before the shop was deemed inactive. Respondents were asked how many of which types of off-grid solar products they sold on average per month. The categories that they were given to choose from included solar lanterns, solar home lighting systems, solar water heaters and solar streetlights. The respondents were also asked how many of these products per month were reported to have requirement for maintenance by their customers. Finally, respondents were given the opportunity to elaborate on factors that may be affecting the ability of their firm to succeed.

3.2.2.2 Semi-structured Interviews

A total of 74 customers of nine different off-grid solar technology firms were interviewed during the course of this study. Most interviews were conducted in 2014, although this study also draws upon field visits the author conducted with two firms in late 2007 and early 2008. Primarily, respondents were from the states of West Bengal, Bihar, Uttar Pradesh, Rajasthan and Karnataka. The interviews were designed to assess: 1) the demographics of the customer base of off-grid solar technology firms; 2) how and if the purchase of the technology was financed; 3) servicing and maintenance issues; 4) fuel switching; 5) quality and satisfaction; and 6) livelihood improvement or augmentation.

Figure 3. A map of states visited by the author for field surveys.

In addition, in-person semi-structured interviews were conducted with representatives from 19 different off-grid solar technology firms. The purpose of these interviews was to understand in greater detail the business plans of the firms operating in this market, the challenges faced, and the opportunities leveraged as these firms have grown in size and customer base. Among the topics explored was the role of financing in distribution of their products, the partnerships the firms had with financial institutions, if any, and the role of government in helping or hindering the expansion of their business.

Entrepreneurs operating in the informal market for off-grid solar products seldom find mention in academic literature, despite having a large presence throughout the country. These businesses manage to sell significant volumes of off-grid solar lighting products, which they purchase wholesale, and assemble in affordable customized packages for their clientele. Little has been written about their business models, or how much money they are able to generate through sales. These entrepreneurs 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. This study interviewed 10 solar entrepreneurs operating in this informal space from the states of West Bengal, Bihar and Uttar Pradesh. Discussions focused on the entrepreneurs' monthly sales for various products; customer product preference and methods of payment; maintenance issues; the educational background of the entrepreneur; and factors that may affect their business, such as the arrival of the central electric grid in previously un-electrified areas.

Six financial institutions of various sizes and types participating in the energy access market were also surveyed about the finance gap in meeting the energy access challenge in the country. These included the startups Milaap and Wishberry, which offer online micro-lending and crowdsourcing solutions respectively, as well as representatives from the Self Employed Women's Association (SEWA), the Small Scale Infrastructure Development Fund (S3IDF), Micro-energy Credits, and a rural branch of the Union Bank of India.

3.2.3 Data Limitations

3.2.3.1 Structured and Semi-Structured Interviews

The main objective of this study is to challenge the traditional notion of lack of adequate government funded end-user financing as a barrier to the diffusion of off-grid solar technologies in India by exploring emergent financing models that make access to energy through those technologies affordable and reliable. Gathering sensitive information - regarding household income from people in rural India, or sales data from private entrepreneurs - is difficult. All such data, no matter the source, or by whatever means gathered, should always be questioned. People are hesitant to accurately report financial information, such as household incomes, because they may not want to be investigated by government authorities or lose their privilege to subsidized goods under government welfare programs. This study attempted to address this limitation by asking whether people paid for a product using cash or through a bank loan and how many installments they paid. These factors could be better proxies to analyze the financial aspects of the off-grid solar business in a particular geography. It is also possible that the firms and entrepreneurs surveyed were not entirely truthful about the sales figures (although they had no incentive to inflate their figures.)

Finally, socio-economic context, cultures, and business environments vary across a landscape as vast as India. Thus, it is important to gather as much information as possible from across the country to test any hypotheses regarding financing of energy access technologies in India at large. This study compensated for this potential data limitation by conducting customer surveys from diverse geographies including the states of Bihar, Rajasthan, West Bengal and Karnataka. It must be noted that the sample size of the customer surveys is not sufficient to draw statistically significant conclusions. Nonetheless, the data provide valuable insights into the on-the-ground realities of financing off-grid solar technologies in India.

3.2.4 Method of Analysis

A mixed method approach was employed for this study to synthesize and analyze the different types of data from the surveys, interviews, and experiments. A combination of process tracing, content analysis, quasi-statistics, constant comparison, and analytic induction were utilized to identify the emerging patterns of the study.

3.3 Results and Discussion

Energy access financing cannot be explored through a single lens or with any one methodology alone. Using the various methods discussed above, many different stakeholders, such as financial institutions, off-grid solar entrepreneurs, and customers, were engaged to gain a better understanding of what role financing plays in the diffusion of off-grid solar technologies in India. To answer this question, the following sections unpack the results of the methods of inquiry employed by this study. First, interviews with customers sheds light on what types of financing tools are currently used to purchase two different types of solar products in four different states. Second, insight into customers' ability and decision to pay is explored through interviews with informal solar sales agents and analysis of micro-grid tariffs from across north India. Finally, the case for greater emphasis on financing for the firm versus the customer is made by examining a government –supported off-grid solar technology deployment program as opposed to the types of financing innovations used by private companies and individuals to facilitate sales.

3.3.1 Customer Financing Realities from the Field

This section explores end user perspectives on financing by examining the results of semi-structured interviews from four different states in India (West Bengal, Bihar, Rajasthan and Karnataka) of various kinds of technologies and enterprises.

3.3.1.1 Bihar

In July 2014, a randomly chosen, semi-structured survey was conducted of customers of Green Light Planet (GLP), a solar lantern manufacturer and distributor, in several villages in the Vaishali District, Hajipur block of the state of Bihar. The villages visited included Chowsian, Parveja, Gangajal Tola and Badhuraiya. A total of 14 households were visited in the area. On average, each of the households surveyed had 4 different solar lantern products sold by the company. Ninety percent of all homes in Chowsian village and 50% of the homes in Parveja village had the company's products at the time the survey was conducted. Seventy-nine percent of the respondents had more than one product, with the highest number bought by one household being 12 products.

GLP's business plan in the region is based on the concept of direct marketing, the use of door-to-door salesmen who are incentivized to make sales using a system of monetary incentives. Customers are not provided any form of financing and must usually purchase the product through up-front cash payment. Though not encouraged by the parent corporation, at the discretion of the sales agent (who is locally known), customers can choose to set up a short structured timeline for completing payments. Customers are guaranteed after-sales support and maintenance during the included warranty period received with the product.

All the respondents were male between the ages of 17 and 60 years. The average household size in the area made up of joint families is 13 people. Every home had children that were enrolled in formal education. Nearly all households surveyed were involved with agriculture either as a major source of income or a supplemental one. Some of the other occupations represented include: poultry farming, dairy/animal husbandry, convenience store operation, kerosene retailer, railways employee, and a tutoring center.

All the homes visited, as well as those located near them, were made of formal construction material. Some homes were in the process of expansion. People in the area were growing onions, which at the time of the visit were highly valued across India due to shortage and price inflation. It was noted that several people in these villages were now able to sell their excess kerosene that was substituted with solar lanterns. All homes visited had access to the electric grid. The majority of homes reported having 12 hours of electricity access through the grid every day. Some noted that the grid had been more stable in the last six months.

On finance, respondents were asked whether they found the pricing of the company's products to be appropriately priced. 64% of the respondents stated that they initially thought the price of the company's products (ranging from $10 - $40) was too high. However, after acquiring the product and realizing the savings, they said that the pricing was appropriate. All of them paid using cash and 50% of them paid in a single installment while 36% paid in two installments. The remainder paid in 3-4 installments. Those that paid in multiple installments had generally done so because they found the product cost to be expensive or questioned the quality of the product and the resulting savings they would accrue over time by switching from kerosene. Recalling Harish (2013) and Urpelainen and Yoon (2015), these results support the argument that small off-grid solar products such as lanterns have easily become cost competitive for the low-income rural households. Further analysis of this business model (see Chapter IV) reveals that village level entrepreneur networks may facilitate large volumes of sales quickly and easily without relying on formal financing mechanisms, to which so many Indians living in rural India lack access.

3.3.1.2 West Bengal

In July 2014, 27 households were visited spread across the villages of Nagendrapur, Harod, Bagnan, Bangalpur, Uttar Sundaraganj (G-plot), and Govindapur Bhojobalipur, predominantly in the districts of the 24 South Parganas and Howrah in the eastern state of West Bengal. All of them were customers of the Kolkata-based private company Onergy, a private company, which distributes solar lanterns, solar home lighting systems, and establishes micro-grids for remote communities in the region. The solar lanterns distributed by Onergy are made by Green Light Planet and are usually sold without any customer financing options. Solar home lighting systems encountered during the field visits varied from 40 to 200 Watt systems with LED-based bulbs, charging ports for mobile phones, and in some cases televisions and fans. These SHS are sold to customers either without financing options, or with local bank financing that allows the customer to take advantage of government subsidies. Onergy's micro-grid customers who were visited had three lights and a mobile phone charging port. Onergy establishes micro-grids with the help of grants from foundations that carry the risk for communities or individuals who wish to own and operate their own micro-grids. Some individuals are able to take on a bank loan to set up a micro-grid for their communities, and set up their own payment structure for tariffs (they charge local customers who need electricity) in order to pay back the loan.

Respondents in all the villages of the 24 South Parganas district lacked access to central grid electricity; the six households visited in Howrah district, on the other hand, did have access to the central grid. This connectivity differential is probably because Howrah district contains a major urbanized beltway in the state, whereas the 24 South Parganas are at the fringes of the state in a mangrove forest swamp region known as the Sundarbans. Forty-eight percent of the respondents were female; the age of the respondents ranged from 17 years to 57 years old. Occupations of the respondents varied but largely consisted of subsistence agriculture and small-scale fishing. Most of the sites were individual homes, but a few of the products were used in small shops, an NGO, and a remote post office. The average household size consisted of six people. Nearly all the homes visited in the 24 South Parganas were made of earthen construction material while those in Howrah district were made of modern construction material.

On affordability, 64% of the respondents who purchased solar home lighting systems thought the pricing was appropriate, while 30% thought it was too high. Nearly 90% of these respondents, whether they thought the system was appropriately priced or too expensive, would recommend purchasing solar home lighting systems to others. On financing, 30% of the respondents who purchased solar home lighting systems paid in cash for the whole system, while 70% used bank loans and were able to take advantage of government subsidies. These figures did not appear to be correlated with whether the respondents considered the systems appropriately priced or too expensive. The respondents who used bank loans were organized by a local NGO, and had their applications collectively submitted to the local rural bank in order to expedite the process. This suggests that institutions outside of the off-grid solar enterprise may be able to facilitate the use of a rather complicated government subsidy regime with greater efficiency and scale than the enterprise itself. Given the complex nature of accessing government supported end-user subsidies for off-grid solar technologies in the country, and the shifting realities of people's ability and decision to pay, the CEO of Onergy suggested that while government subsidies were important for his business early on, they may have served their purpose and may no longer be required for conducting sales. Instead he argued that the technology was sufficiently socialized amongst the people in the regions he operates to not require subsidies for customers as an incentive.

3.3.1.3 Karnataka

In April 2008, a randomized semi-structured interview was conducted of 15 households in Sugatur village of Kolar district in the southern state of Karnataka. The respondents were decision-makers within their households, with one-third of respondents being women. All households owned solar home lighting systems distributed by SELCO, an established off-grid solar energy enterprise based in Bangalore, Karnataka. The solar home lighting systems they owned ranged from having four to eight bulbs, with some systems also including additional capacity for charging of cellular phones or other small appliances.

Sugatur is the *gram panchayat* headquarters for local area villages; thus, it is easily accessible by road. The median household income in Sugatur as reported by SELCO was Rs. 40,000 ($856) annually at the time of the visit. The primary occupation is agriculture and sericulture (silkworm farming), however, many people interviewed were operating small restaurants or provision stores as a primary occupation. The average household size was eight members, but several of the homes visited during the field visit had small families of just four people, and several did not have children. One hundred percent of the homes visited were formally constructed, and it appeared that that the majority of the homes in the village were of similar quality. Finally, Sugatur village is considered 100% electrified, and all the homes visited had access to grid electricity.

When questioned on pricing, financing and willingness to pay, all respondents said they would be willing to buy another system as needed given the experienced benefits. Approximately 73% of the respondents said they would be willing to pay for it using a loan. The remaining did not wish to use a loan, and many had paid for the first system using cash. Some people reported that they were about to purchase their second system during the time of the field visit. Some respondents claimed to receive a small discount on a third system if they purchased two systems. The cost of a solar home lighting system from SELCO at the time the survey was conducted started at $125 and increased based on the need of the customer. Most of SELCO's products are customized based on the need and affordability of the customer. The price list keeps on changing, but the Manager of Innovations at SELCO stated the following on affordability of their systems: "anybody who can afford to pay Rs.100-150 (approximately USD1.60 - 2.50) per month for five years can afford a single light system which lasts more than 15 years with one battery replacement. Similarly, somebody who can pay Rs.250 ($4) per month for five years can afford a 4 light system lasting for a similar time period." Customers can access small credit loans and take advantage of government subsidies from a variety of banks with which SELCO has formed partnerships. According to SELCO, the interest rates vary depending on the source, but are between 10 – 13%. Customers make a down payment of between 10 – 25% and pay the remaining balance over a period of three to five years.

These findings reflect the fact that SELCO, an industry veteran in the off-grid solar lighting space in India, has worked hard to build the financial ecosystem needed to support sales of its products. SELCO has done this in a number of ways: 1) by experimenting with tailoring products according to the needs of individual customers such that products are matched with potential customers' ability to pay and 2) by managing the relationship between customers and banks so that the former can have access to financing. This effort has meant that SELCO has focused on the needs of people in the state of Karnataka alone, and not been able to (nor wanted to) scale beyond one state, as so many of the emerging off-grid solar enterprises in the country wish to do. It is important to note that the CEO of SELCO said that government subsidies have not had the desired effect of helping the ecosystem of off-grid solar technologies to grow.

3.3.1.4 Rajasthan

The final case this study draws from is the most unusual. In February 2006, each of the 52 homes in Dabkan village of Alwar District in the northwestern

Indian state of Rajasthan were given (free of charge), some of the first[22] LED-based solar home lighting systems in the country by the company Grameen Surya Bijlee. Yet no supply chains for replacement parts was established and no after-sales maintenance or warranty was provided to the community. Furthermore, at the time, there were no government standards or specifications for LED-based solar lighting technologies. The home lighting systems in Dabkan each consisted of one 10-watt solar photovoltaic panel, one 12-volt battery, and two 15 or 22-light LED bulbs. In November 2007, surveys were conducted in 18 households – or 35% of all households in Dabkan. The large majority of respondents were decision-makers within their households, and 89% fell within the labor-contributing age range of 18 to 49. Twenty-eight percent of respondents were women.

Dabkan is accessible by dirt road from the nearest rural nodal town, Tehla, three kilometers away. It is 55 kilometers southwest of the city of Alwar, and 105 kilometers northeast of the capital of Jaipur. Because Dabkan is set within a government-designated forest area, grid electricity is prohibited from reaching the area. As reported by the local school teacher, median household income at the time the survey was conducted was $25 per month or $300 per year. This did not include the effective income generated by subsistence agriculture production, nor the collection of fuel wood and dung for home

[22] Since the time this survey was conducted, LED lighting has become more commonplace in India. At the time the survey was conducted, LED bulbs had to be imported into the country.

energy use. In Dabkan, monetary income is primarily derived from milk sales from animal husbandry. Many young males also pursue seasonal work outside of the village, typically in nearby mines, where they earn $1.60 – 2.50 per day. The average household size is seven members, of whom an average of three are under the age of 12. On average, in each household, two members attend school. Roughly 60% of homes were formally constructed, while the remaining 40% were informally constructed using earthen compounds and thatch.

Because the households were given the systems free of charge, customers were instead probed about their willingness to pay for such systems. It is important to add that the lack of proper supply chains for replacement parts and after-sales maintenance meant that nearly all the SHSs in Dabkan required some level of servicing. To assess whether households would be willing to pay for such systems, given the benefits they had experienced[23], varied questions were asked of each household, depending on which was contextually appropriate. In each case, respondents were asked whether they would be willing to take out a bank loan of between $50 - 100 – assuming one would be available – to make such a purchase. Questions included the following:

---

[23] As a result of having the solar home lighting systems, households cited that children were able to benefit in their studies and overall household productivity after sunset was increased. In addition, households reported decreased indoor air pollution as a result of reduced burning of kerosene. Reductions in consumption of kerosene from fuel switching (kerosene to solar energy) were as high as 5 liters a month per household bringing down total household consumption on average to just 2 liters per month.

(1) If you did not already have this system, would you wish to pay to have one?
(2) To acquire a new light bulb or solar panel, would you be willing to pay for it?
(3) If you could gain additional uses, would you be willing to pay for an upgrade (more bulbs)?

In 81% of households the answer was yes – they would be willing to pay for the system or improvements. In the remaining households, inability to pay back the loan – because of exceptionally low income – was cited as the reason for unwillingness to pay. In several homes, respondents were asked to give the maximum amount of a loan that they would be willing to take to pay for the system or improvements. Typically, the answer to this question was $100.

The findings of this case, which surveyed perhaps the poorest income group in the country, suggest that even amongst the absolute destitute, there is a willingness to pay for off-grid solar lighting products, especially when alternatives do not exist and people understand the value of the technology as cited by Urpelainen and Yoon (2015). However, for such a low-income group, access to a financing mechanism that makes payments easy and affordable would be required. Perhaps the emergent models that have arisen since the time this survey was conducted - such as PAYG - would be appropriate for such an income group to be able to have eventual asset ownership of off-grid solar technologies (should they wish), or to make easy and affordable payments based on their needs.

3.3.2 Insights into Customers' Ability and Decisions to Pay

In the following sections we explore the ability and decisions of customers to be able to pay for off-grid solar technologies. Much can be gleaned from the interviews of informal sales agents of off-grid solar technologies, who may be present in greater numbers across rural India, embedded in local communities, and conducting business without involving formal financial institutions. Sales data collected from these agents suggests that many end users have the ability to pay for such technologies. Finally, a snapshot of micro-grid tariffs from across North India further adds to the discussion on affordability and decisions of end users to pay for a certain base level of service.

3.3.2.1 Informal Solar Sales Agents

Semi-structured interviews of nine off-grid solar entrepreneurs (operating in the informal market but within the market ecosystems of enterprises in the formal market) were conducted. Eight of these were in the state of West Bengal, operating in the same market ecosystem as Onergy; one was in the state of Bihar, operating in the same market ecosystem as Green Light Planet. General questions were asked about their business, including their annual or monthly sales, financing, maintenance support provided, and their customers. Eighty-nine percent of the entrepreneurs had received technical training on solar or electrical engineering, and 56% of them could conduct assembly of products on site (specifically solar lanterns, or small DC appliances).

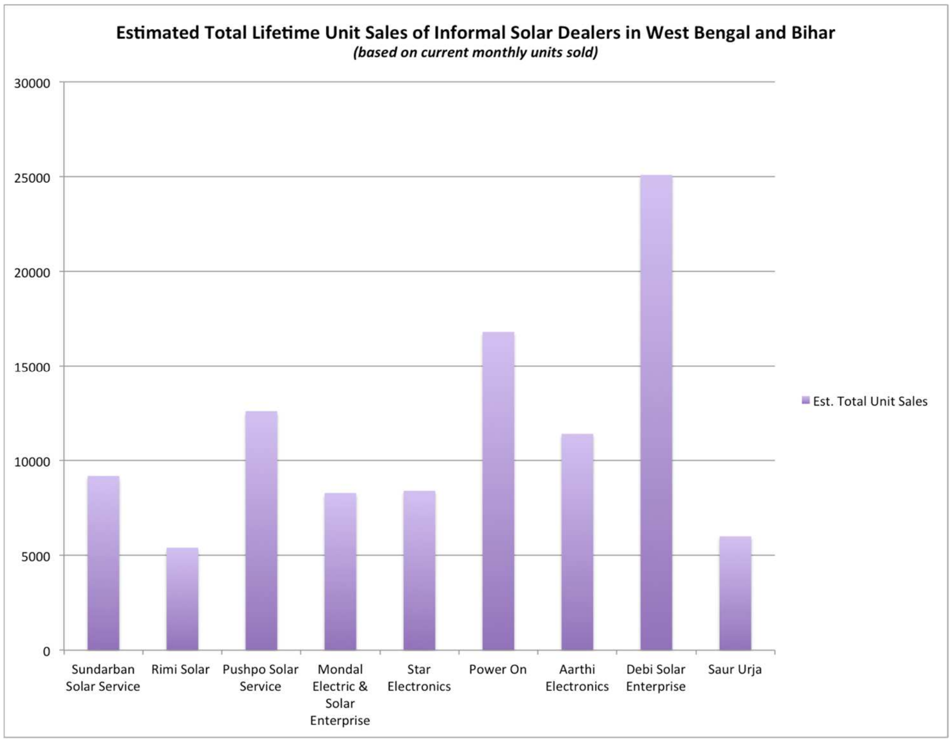


Figure 4. This figure depicts the estimated total lifetime sales of SHS and solar lanterns per informal solar sales agent encountered in the field in West Bengal and Bihar. Data is based on estimated monthly sales data during July 2015.

All the agents reported that their customers paid in full one-time installments of cash, and all of them provided after-sales support and upheld the manufacturer's warranty provisions. This is a notable demonstration of end users' ability to pay, as the sales of some of these agents – of whom there be hundreds across the country - can be as high as 200 solar home lighting units sold per month, at a retail price of $500 per unit. Figure 4 depicts the estimated total lifetime (averaging 6 years of operation) unit sales (including solar home lighting systems and solar lanterns) of these informal sales agents. Sales data used for these life-time calculations is from around the time the interviews were conducted, suggesting that monthly or annual sales figures in the past before the arrival of the central electric grid in many of these areas was likely much higher. These findings further support the argument that the landscape of financing solar energy access in India is complex. Furthermore, it suggests that we must move away from a paradigm that sees lack of sufficient government-supported financing for the end user as a barrier to the diffusion of these technologies, and towards a paradigm that seeks to support business innovations that allow even the poorest people to make easy and affordable payments for technologies, which are fast coming within their reach. One way to support this potentially large group of informal sales agents is to have solar engineering courses available at the 6,000 Industrial Training Institutes that are owned and operated by the government. This would essentially train an army of solar engineers, who could create localized business models to sell off-grid solar technologies according to customers' needs, and ensure the existence of after-sales support and maintenance which such technology requires.

3.3.2.2 Lessons from Micro-Grid Tariffs across North India

Micro-grids have been changing the face of energy delivery in rural India. They are often seen as a more effective and efficient way to provide a small community access to electricity, and to do so more affordably for the end user.

Several enterprises have arisen across the country capitalizing on this technology. Some of the important factors to consider when evaluating micro-grid projects are the establishment of tariffs, security of the equipment, and management of the system either by an enterprise, an entrepreneur, or a community. The long-term financial viability of any micro-grid project is determined by the amount of money generated to sustain operations through the collection of tariffs from the end users. This study interviewed a variety of off-grid solar enterprises that are operating micro-grids in India. A sample of base tariffs (providing roughly the same quantity and quality of service) from across enterprises operating in five north Indian states is depicted in Figure 5. The monthly rates range from a low of USD $0.83 to a high of $4.50.

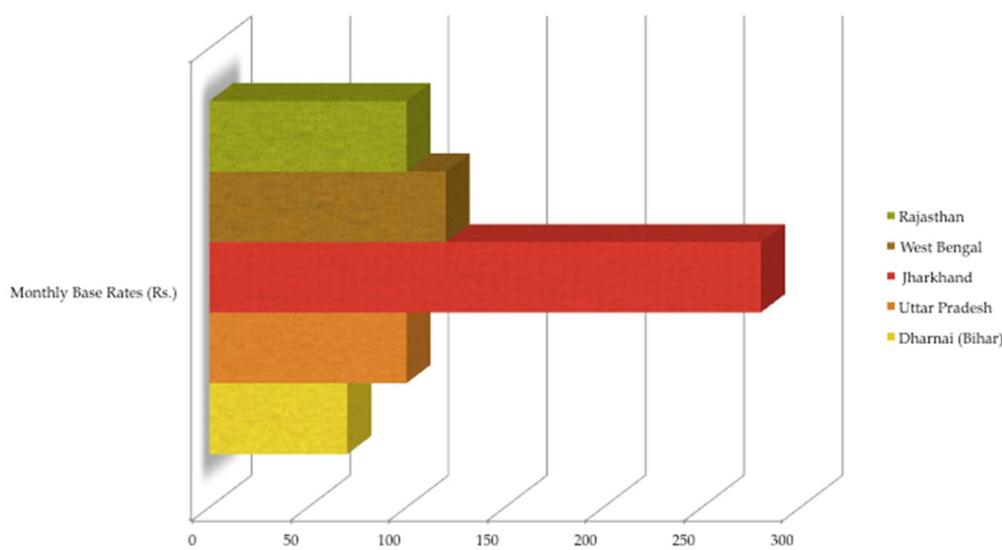


Figure 5. Sampling of monthly base tariffs for micro-grid projects across north India.

These results indicate that, even with monthly tariffs for electricity provision through micro-grids, people are willing to pay substantial amounts for the same level of service. Rather than the issue being about their ability to pay, perhaps it has more to do with how that service is packaged and the local circumstance. For example, the micro-grid in question in Bihar has an extremely low tariff that was agreed to by the community despite a willingness to pay determined by a pre-project survey of the community that was 2-3 times the established amount. The micro-grid in Jharkhand is for a community that knows that it will never gain access to electricity, as it is illegally squatting on property owned by the Indian Railways Corporation. Thus the decision to to pay of those end users is significantly higher than those in other regions. An employee of Gram Power, a micro-grid company based in Jaipur, Rajasthan recounted that a community that once had access to electricity through the centralized grid but lost the service due to lack of payments several years ago was willing to pay up to $8.30 a month per household to gain access to electricity again.

Representatives of Pune-based Gram Oorja and Auroville-based Sunlit Futures argue that the initial capital for establishing a micro-grid are too high for a community in parts of rural India, and may require a wealthy investor to bear the one-time cost. However, after the system is in place, tariffs can be arranged such that the community is willing and able to pay for the system, its replacement parts and a staff person to operate and manage it. These factors, especially the tariffs, can be left up to the community - and may result in higher payments than one might expect.

Finally, representatives of micro-grid company, Mera Gao Power, noted that based on their experience with rural communities in the state of Uttar Pradesh, there is a big difference between "decision to pay" and "ability to pay." Mera Gao Power representatives claim that they have regularly encountered customers who refused to pay for monthly services when they knowingly could afford it (as evidenced by consumer goods they chose to purchase[24]). All this anecdotal evidence from the field reveals that the pricing of a base level of service for micro-grids across the country is dependent on complex localized situations. These insights suggest that firms are innovating business models to ensure that end users in a variety of geographies, and from across the economic spectrum, can get access to electricity services through solar micro grids in a manner that matches decisions and ability to pay, and that such firms are still able to recuperate their costs.

3.3.3 Financing for Whom by Whom: Innovative Companies and Entrepreneurs

Extensive fieldwork and analysis of the off-grid solar enterprises in India by the author reveals a pattern that is of significance to the debate on financing

[24] One specific example is a customer who chose to pay approximately Rs. 80 ($1.30) for a bag of chips but did not want to pay Rs. 25 ($0.42) for the week of service he received through the micro-grid.

for the sector. Broadly speaking, the complexities of financing for off-grid solar technologies in the country are such that a lack of government-supported end-user financing is less of a barrier than in previous decades, and - while the poorest of the poor may still not be able to afford an off-the-shelf purchase of SHS - emergent business models and technologies have made it possible for many to be able to afford and pay for the services provided by off-grid solar technologies. However, firms employing such models require financing to scale up their businesses specifically on improvements of "delivery, installation, and ongoing maintenance" (UN 2016). Aside from reductions in costs associated with innovations in the technologies themselves, what helps to bring these technologies within reach of the end user are companies and entrepreneurs with innovative business models that make financing for the end user easy and reliable. This prompts the question, should the financing discussion focus on traditional government financing for the end-user, or on financial and policy support for the agent with the innovative model to make access to the technology more affordable for the end-user, or both?

3.3.3.1 The Akshay Urja Case

We will start this discussion by examining the case of the government-authorized retail network of "Akshay Urja" shops. The Ministry for New & Renewable Energy launched the Akshay Urja program in 1995 as government owned retail outlets for the sale, repair, and awareness building of off-grid solar technologies. Recognizing the burden of operating such shops, by 2002 the government provided incentives for private entrepreneurs to establish these shops. Paltry monetary incentives[25] for meeting monthly sales targets, as well as compensation for utility costs of running the shops, were some of the perks for private entrepreneurs to want to become a government-authorized retailer of solar energy technologies. Government financed end-user subsidies for the technologies and an erratic if present electricity supply guaranteed the success of anyone entering this business. As a result, at least 170 individuals opened such shops across the country. Many years later, government subsidies for the end user have not always been disbursed in time, and electricity supply has expanded across the country. Without further appropriate incentives to drive innovation to compete in the changing market, these entrepreneurs - who often had other business interests - simply closed their shops.

[25] Entrepreneurs are provided with $83/month for manpower and utilities as well as a flat $83/month for a monthly minimum turnover of $833/month in the first year of the shop's operation and the same incentive for minimum turnover of $1666/month starting the second year of the shop's operation. In addition a soft loan at an interest rate of 7% to a maximum of 85% of the cost of the establishment of the shop along with a one time publicity grant of $833 is available to the entrepreneur.

Figure 6. Map depicting Akshay Urja shops across the country. Green markers indicate shops that were open and responded to the survey, orange markers represent shops that gave partial responses to survey questions, and red markers indicate shops that were closed

Results from the telephonic survey conducted show that out of 174 shops, approximately 53 were still in the business of selling solar technologies (see Figure 6). Most of these shops are clustered in a few states, where electricity access is still unreliable (although even that may not remain true for long.) A breakdown of their sales and maintenance data reveals that while the shop owners managed to make significant sales, they received few requests or reports from customers of need for servicing and maintenance (see Figure 7).

Lacking an at-home servicing policy, and being based in district headquarter towns (far from potential customers, who would be required to bring their technologies to the shop for maintenance) may explain this anomaly. Furthermore it demonstrates a lack of commitment by the firm to provide quality after-sales servicing and maintenance, which – by contrast – is a common characteristic of other private companies driven by competition and less reliant on government subsidy regimes discussed below.

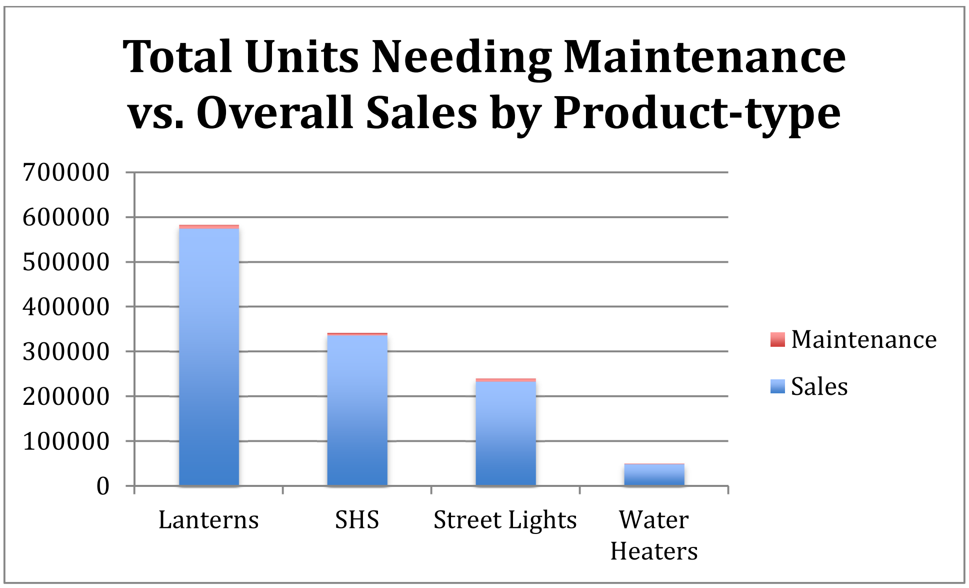


Figure 7. A comparison of sales versus maintenance of overall sales by product-type of Akshay Urja shops still in operation across India.

Many of the shop owners lamented that the arrival of the electric grid in their region was decreasing the demand for their products, and that continued government subsidies for end-user financing were required to make sales. While this may be true for a certain segment of the population, particularly middle-income residents of peri-urban areas, it contradicts the decisions of poorer customers in areas further away from the district headquarters, a market segment clearly being catered to by innovative companies. Furthermore, it contradicts the fact that the majority of firms in this sector are selling off-grid solar technology products in areas where the grid is present (Singh 2016).

The case of Akshay Urja shops is interesting, in that the government had the right idea of creating a retail network of standardized quality products for sale across the country. In doing so, it created an ecosystem that increased awareness of solar energy technologies in the population. Unfortunately, it fell short of providing incentives to individual franchisees to find ways to make off-grid solar technologies more accessible and affordable on their own, especially in the face of increased competition from the grid. Carefully managed, the entrepreneurs in the network could have shared information on best practices for enhancing sales. As a result of these shortcomings, however, the entrepreneurs were not able to wean themselves off government-supported end-user subsides, nor to take advantage of plummeting prices of SPVs to continue sales.

3.3.4.2 Companies

As discussed earlier, companies that utilize PAYG technologies can bring electricity access to millions more of the energy poor, who may not want to pay for the upfront costs of solar technology (or might want to make payments towards eventual asset ownership, as is the model of SHS provided by SIMPA

Networks). But these companies need money to be able to scale up their businesses. Though in 2015, PAYG companies specifically raised $160 million in financing they will require more. To broaden the ecosystem of investment crowdfunding may disrupt the traditional power of venture capital financing, by putting control in the hands of a larger pool of people, and avoiding the need to work with risk-averse state-run banks. Doing so may support the rise of other disruptive companies that wish to pilot projects or create new technologies to help expand energy access. A supporting example is the case of a successful crowdfunding campaign conducted on the platform provided by the company Wishberry. Over 45 days, with contributions from 89 private individuals, an entrepreneur managed to raise twice the amount she needed to purchase two 3 KW micro-hydro unit turbines to help electrify 50 remote households in the northeastern state of Arunachal Pradesh.

Finally, for customers who require financial assistance, and need or want to continue to take advantage of purchasing off-grid solar technologies such as SHS off-the-shelf, the rise of models of companies such as Micro-Energy Credits should be supported. Micro-Energy Credits plays the role of intermediary between banks and potential customers and facilitates access to solar loans. At the time of the interview, in just four years of operating in India, Micro-Energy Credits had facilitated loans for 124,700 SHS and 10,000 lanterns thanks to partnerships with local banks. The company relied on a strategy of bundling the transactions it facilitated for carbon credits as a source of revenue. While the fate of the carbon market has been dubious in the recent past, renewed emphasis on a new global deal on climate change this year in Paris may make such models profitable once more. Micro-Energy Credits facilitates awareness of the technologies and accelerates solar loan transactions, thereby reducing the burden on solar technology firms such as SELCO, which otherwise often need to match customers with banks and serve as an intermediary between the two - at significant cost to the firm itself.

3.3.3.3 Entrepreneurs

The role of individual entrepreneurs, who are locally embedded in the communities that lack access to reliable (or any) electricity, towards diffusing and maintaining off-grid solar technologies is important. These entrepreneurs can provide innovative financing options for the end-user in order to increase sales. Numerous off-grid solar enterprises in the country are leveraging these entrepreneurs in order to be able to conduct business. The ability of a firm to

Figure 8. Advertisement of SHS packages for sale with discounts in Bangarmau, Uttar Pradesh.

create a franchise network that is owned and operated by an independent agent also relies on financing. Such is the model of a successful company Orb Energy. Orb's extensive franchisee network across southern India facilitates a large number of sales of products from solar water heaters to SHS. Individuals who wish to go into the solar business take a loan out from a bank in order to open an Orb shop, and become exclusive dealers of Orb's products. A system of commissions on sales and incentives for meeting sales targets keeps the entrepreneur interested in continuing to sell Orb's solar products.

In the realm of micro-grids, entrepreneurs are slightly wealthier individuals (pre-existing entrepreneurs in rural areas) who wish to take on an affordable loan to set up a solar micro-grid. That individual can then set up a tariff structure and provide access to electricity to last-mile households, where it might be difficult for firms based in urban areas to reach. Such a case was witnessed in the Sundarbans region of West Bengal. Similarly, informal sales agents can utilize the power of bulk purchasing to assemble SHS packages that might be more affordable to the local communities than the products offered by firms operating in the formal market. Take for example the entrepreneur encountered in Bangarmau, Uttar Pradesh, who was advertising deep discounts on sales of 20W or 40W SHS with two LED bulbs and a clean cook stove for $80 or $117 respectively (see Figure 8).

In conclusion, locally embedded entrepreneurs that can overcome the perceived barrier of end-user financing through use of innovative business models to diffuse off-grid solar technologies should be the focus of government and multilateral development assistance. Furthermore, policies that facilitate standardization of quality technologies and access to training on repair and maintenance will strengthen these important members of the off-grid solar energy ecosystem.

3.4 Conclusions and Policy Implications

This study suggests that government-supported end-user financing as currently structured may not be the most effective means in accelerating the diffusion of off-grid solar technologies in the country. This form of end-user financing is limited by the fact that a large segment of the population that requires off-grid solar technologies does not have access to the formal banking sector. Furthermore, firms that wish to pass the savings of subsidized solar products on to their customers face bureaucratic hurdles, resulting in loss of time and revenue.

By examining the experiences of both, the firms and the end users, this study further suggests that the focus of financing for the diffusion of off-grid solar technologies should shift from the end-user to the firm and entrepreneur. For firms, financing is required to pilot projects, build up inventory, and expand their base of customers to reach a point of financial self-sufficiency. For the customer, while financial constraints are at times a reality, often the factors affecting the decision to pay are more important than the ability to pay. Contrary to widespread assumptions, many people have the ability to pay for these technologies. Innovative financial models of off-grid firms should thus address customers' decision to pay. The decision to pay is influenced by experience with a product, association with a sales agent or company, and/or exposure to technology through others in the community. Innovative financing tools can both make products more affordable (addressing the end users' ability to pay) and more accessible (addressing their decision to pay).

The government's new policies to expand solar energy to 100GW in the country's energy mix by 2022 and provide universal energy access by 2018 are admirable goals, but must realize the limits of the existing subsidy regime which may be used to meet these targets. The existing governmental policy directives (and corresponding allocation of resources towards the diffusion of off-grid solar technologies) fail to drive the required financial innovation in the business of making solar energy technologies more affordable and accessible. Government efforts are not matched by the capacities of the banks to be able to transact loans for customers. This mismatch is further complicated by lack of awareness of the technology for both the customers and the bank branch managers. Failure to increase awareness of the technology for all stakeholders will result in missing the opportunities presented by other government policies, such as: 1) the financial inclusion initiative that is providing access to formal banking for millions of first-time users; and 2) the direct benefit transfer program to channel subsidies for energy, leaving the choice of how (and on what technology) to spend the money up to the customer.

Instead of only allocating funds to *subsidize* financing for off-grid solar technologies, the Indian government should create an additional fund to support business innovation for the technologies that can be used by existing companies, start-ups, or individual entrepreneurs. The recently launched $8 million PACESetter Fund, established jointly by the United States and the Government of India, may serve as a good pilot to explore the impact of such a fund, because it will finance the firms with the most innovative business models to scale access to energy through off-grid technologies such as solar. The success of such initiatives can be tracked over time by measuring the growth of such firms in the number of customers they serve, or by measuring the decrease in number of people nationally who are dependent on government subsidies for fuels such as kerosene, the main competitor for off-grid solar technologies.

Finally, the current government has indicated the desire to capitalize on Indian diaspora living abroad, and the need to increase foreign investments into the country to help meet development targets. Thus, improving the business environment to support emergent forms of financing could leverage foreign actors to help scale up and realize the true potential of emergent innovations, such as crowdfunding and PAYG technologies. Specifically, the government should remove bottlenecks for conducting transactions through mobile payments, allow foreign contributions for energy companies, and allow small investors to receive interests for loans specifically for crowdfunding efforts for energy access.

CHAPTER IV: NETWORKS AND THE DIFFUSION OF OFF-GRID SOLAR TECHNOLOGIES

4.1 Introduction

Achieving universal access to modern energy has become enshrined in the new U.N. Sustainable Development Goals (UN 2015) because of its related effects on human development (Sovacool 2012). Doing so with low-carbon technologies is paramount, given the need for deep decarbonization in a climate-constrained global carbon budget (Meinshausen 2009, Wilson 2009, Casillas 2011). Off-grid solar technologies provide a potential mechanism for meeting the twin goals of establishing universal energy access and low-carbon technology diffusion. This paper contributes to scholarship about what factors affect the scaling up, or not, of off-grid solar technologies in India, the largest single market of people without modern electricity access (Singh 2016).

Beyond the technical characteristics (Byrne 2011), authors cite various barriers to the diffusion of these technologies, particularly for the last mile customer (Balachandra 2011, Palit 2011, Chaurey 2012, Palit 2013). Through the lens of innovation and diffusion theories, this specific case study unpacks in detail how a firm can achieve success in unit scaling and overcome some of the barriers identified by scholars and practitioners.

Schumpeter (1934) highlighted the role of the entrepreneur in driving innovation: being the agent who disrupts the existing system, and generates new wealth through new combinations of existing materials and processes. Agbemabiese (2012) argues that beyond the individual, "it is generally the case that multiple interacting actors, institutions and functions are involved in the process" of transforming an invention (a material or process created by an entrepreneur) into an innovation that is diffused to a broader audience. Barnett (1990) would add that "the analysis of the diffusion of energy technologies [the focus of this study] should at least try to identify the key actors in the process and to understand the environment in which they operate: an environment formed by their objectives, their resources, the technology available to them and the market they face." Research about the successes and failures of innovations suggests that, fundamentally, an innovation must meet the user's needs (Sechrest 1998); the understanding of specific needs of technology users is thus critical (Ockwell 2012). Finally, the processes that facilitate the creation of knowledge or "learning" for a firm are powerful drivers of innovation, and form a critical part of the energy technology innovation system (ETIS) (Gallagher 2012).

Suurs (2009) categorizes the actors in a technology innovation system as either enactors (those responsible for the creation of a specific technology or process) or selectors (those who choose from a variety of technological options to address a particular problem). The role of the energy access firm as either an enactor or a selector would therefore have an impact on its ability to diffuse off-grid solar technologies. Rogers (2003) emphasized that perceptions of technology, as well as locally present indigenous knowledge systems, can play a large role in the diffusion and acceptance of technologies. In addition to a technology's attributes that can influence its "rate of adoption," there are other culturally dependent factors, including the nature of communication channels diffusing the innovation", the role of and respect for early adopters in communities, as well as the amount of social capital and associational activity within those communities (Aker 2007). Specifically, Rogers states that diffusion happens through certain channels (interpersonal or mass media), over time (influenced by the rates of adoption, the innovation-decision process, and the innovativeness of the individual), and facilitated by certain people (pre-existing opinion leaders in a community, or change agents arriving from outside the community).

The role of networks, specifically social (Valente 1996) or communication networks (Caird 2008, McEachern 2008), in some of the emergent business models for distributing off-grid solar technologies is critical to the diffusion of such innovations (Ramirez 2014). Rogers defines a communication network as "interconnected individuals who are linked by patterned flows of information" (2003). Specifically, it is the opinion leader's "interpersonal networks that allow him or her to serve as a social model whose innovative behavior is imitated by many other members of the systems." Energy innovations that utilize such networks would be categorized by Tawney

(2013) as part of the process that explicitly targets the poor as end-users of the resulting solutions, or "pro-poor energy innovations."

The problem of inadequate investment in pro-poor energy, a major barrier to scaling energy access, has been compounded by the fact that the energy sector suffers more broadly from chronically low investment in innovation (Gallagher, Holdren, & Sagar 2006). Supporting firms and ecosystems that birth scalable pro-poor energy innovations is critical to achieving universal energy access for all. This case study provides a closer look at an innovative pro-poor off-grid solar energy enterprise in India that has scaled in units of products sold, which yields insights into elements of successful business models and the ecosystems required to support such firms.

4.2 Results

Green Light Planet is a private enterprise that manufactures and sells off-grid solar energy technologies across India. The company's products, predominantly a variety of solar lanterns[26] with or without mobile phone charging capability (see Table 1), are branded as "Sun King" products, so that they can be sold through partners as well as directly by GLP. GLP's pathway to growth started with a combination of early stage technology development and trials and learning for the corporation, coupled with capital infusions (see

---

[26] Shortly after the survey was conducted, GLP expanded its line of products and entered a new market segment by introducing a solar home lighting system.

Figure 1). The scaling of GLP's business is best understood by examining the evolution and architecture of its innovation related to deployment.

4.2.1 Deployment Model Innovation

GLP is one of the few companies in India utilizing village level entrepreneur networks (VLE) that facilitate the sales of their products to the "last mile." Bairiganjan and Sanyal (2013) describe a VLE as a "local village based individual who acts as the last mile to reach consumers, thus improve access for the low-income population to diverse products by taking on market innovations at the grass roots level." Also called the "direct marketing concept" or "direct sales model," it relies heavily on these grassroots sales agents who leverage the communication networks described by Rogers (2003) for the diffusion of innovations. There are no shops from which sales are made; rather, the agents sell directly to members in their community.

For GLP, the direct sales model faced initial challenges such as appropriate partner selection, difficulty in establishing a supply chain and cultural as well as financial barriers that affected staffing in certain geographies, but emerged successful over time. In June 2009, GLP started out partnering with the education-focused NGO Pratham in Orissa, with Pratham tutors serving as sales agents of the Sun King Eco lantern. By October, however, 90% of the staff were fired, because funding from Pratham stopped. GLP also learned that the model did not work in states like Karnataka, causing operations in that state to cease. The failure in Karnataka may have been due to cultural factors, such as the unwillingness of people to perform door-to-door sales. Bihar, the state in which this model has thrived, took three years to mature.

Table 1. List of Sun King Products' Prices and Specifications

Product Type	Retail Price	Solar Power	Daily Run-Time[1]	Brightness[2]	Mobile Phone Charger
Eco	$17.99	500 mW>	30 hours	25 lumens (2 x kerosene)	No
Solo	$24.99	700 mW>	24 hours	50 lumens (5 x kerosene)	No
Mobile	$29.99	1.5W>	36 hours	75 lumens (8 x kerosene)	1 x USB charger
Pro2	$49.99	3.3W>	36 hours	150 lumens (15 x kerosene)	2 x USB charger

1. Sun King uses Lithium-ferro phosphate batteries that last 5 years.
2. Max lumens depending on setting chosen and the approximate brightness as compared to kerosene lamp.

Timeline of Growth of Green Light Planet

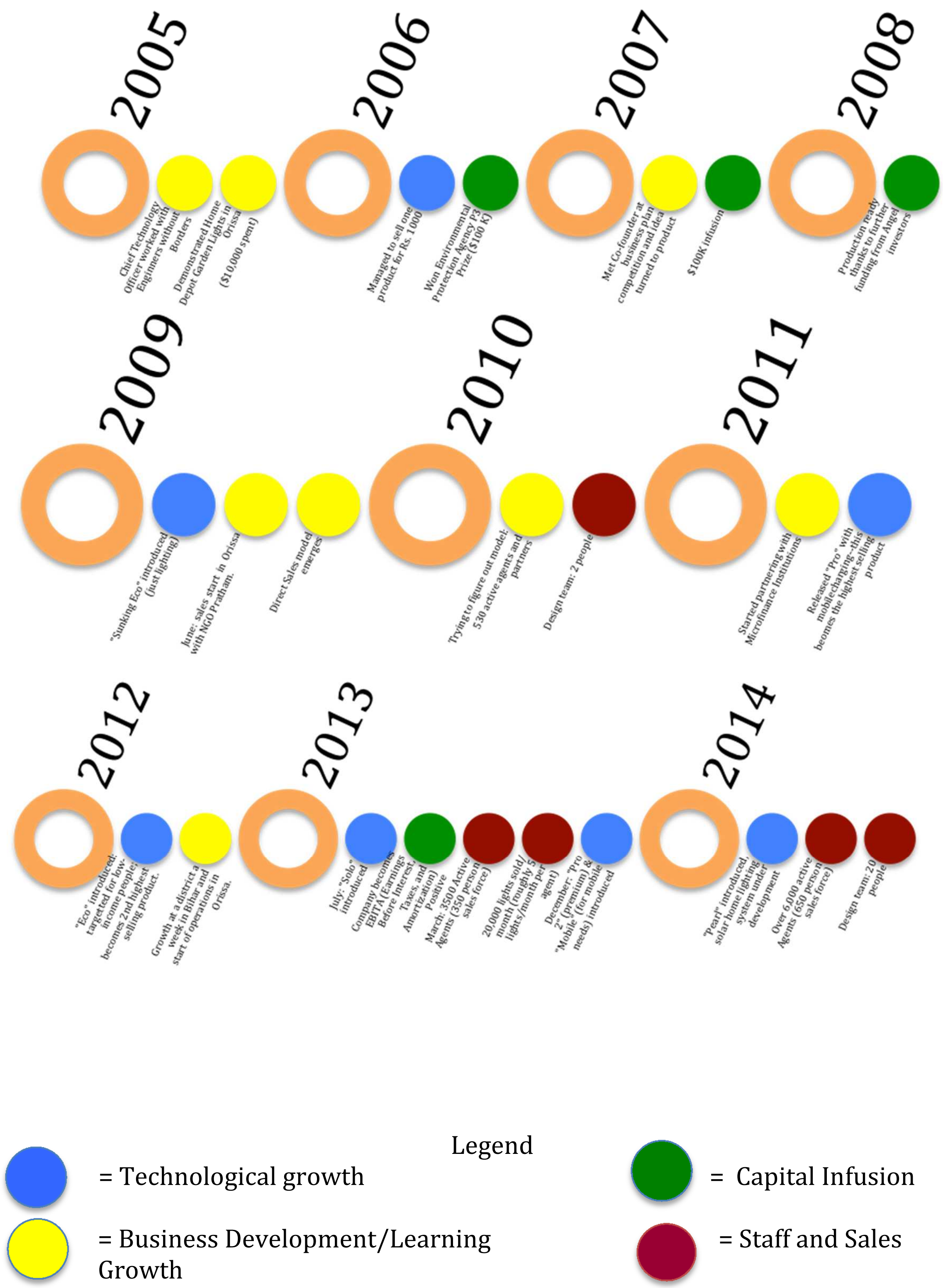


Figure 1. Timeline of Growth of Green Light Planet

4.2.1.1 Organizational Chart

In the direct sales model, GLP organizes its staff into the following categories:

- a **Zonal Business Manager** (ZBM) is incharge of a particular state
- several **Regional Sales Managers** (RSM) look after a few districts each and report to the ZBM
- each **District Sales Manager** (DSM) is responsible for the management of sales in his district and report directly to the RSM.
- Up to eight **Team Leaders** (TL) are responsible for the management of sales in several villages and report directly to the DSM incharge of the area.
- Each TL manages up to 16 **Sales Business Associates** (SBA) who are responsible for sales in their own villages.

The role of this extensive, organized network in facilitating sales is evidenced by the increase in revenue through sales in the state of Bihar from

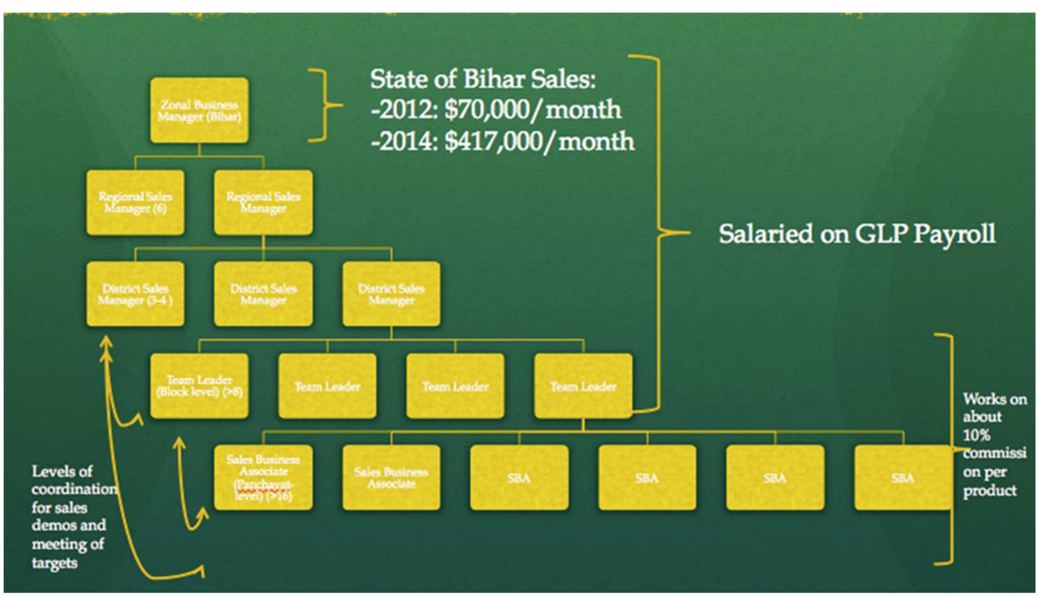


Figure 3. Direct Marketing Organizational Chart (example from Bihar).

$70,000/month in 2012 to $417,000/month in 2014 (see Figure 2). This growth could be attributed to the fact that the number of District Sales Managers (DSMs), Team Leaders (TLs) and Sales Business Associates (SBAs) have dramatically increased in that two year period[27].

Every staff category is salaried on the GLP payroll, except the SBAs, who work on 10% commission per product sold. There is constant communication and coordination for sales, demonstrations, and meeting of targets between the DSMs, TLs, and SBAs. There is a monthly review meeting between the DSM, RSM and ZM. All TLs meet with the DSM in the district once a week, and a RSM may meet with the DSM 3-4 times a month. Furthermore, GLP facilitates the cross-pollination of ideas between its staff in India and East Africa through exchanges. The constant sharing of information through this network probably allows for greater diffusion of GLP's technology.

[27] This case study is confined to GLP's organizational structure in the state of Bihar, as described above. However, it is already evolving in other parts of the country. The future of sales for GLP hinges on the introduction of a "super agent," which replaces the role of the TL. The super agent is not salaried by GLP, which removes another fixed cost for the company thereby increasing profitability. In the past nine months this super agent model has already expanded to 100 districts in the states of Uttar Pradesh, Rajasthan, Jharkand and the Northeastern states.

4.2.1.2 Supply Chain

A supply chain is defined by Mentzer et al. (2001) as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.” Establishing a well functioning supply chain for the distribution and maintenance of technologies is critical for the success of any off-grid solar energy enterprise. GLP keeps one stock point for all its products per district. The district needs to generate monthly sales of $6,667 in order for GLP to establish a stock point and transporter in the locality. The stock point maintains 12 days of stock for each product. To find a good distributor/stock keeper, GLP undertakes a market survey in the region to determine who is stocking products for reputed companies. Stock keepers have a 3.75% margin on sales which is capped at $250/month. The stock keeper hires a transporter, and allocates approximately $70 for transport, including fuel charges.

A Team Leader is responsible for buying inventory from GLP from the stock point and selling it to the SBA. SBAs are far from stock points so they rely on the Team Leaders to purchase products for them. This arrangement reduces the transportation costs for the SBA as well. The SBA purchases two pieces of each product from the TL.

4.2.1.3 Sales Business Associate (SBA)

The primary role of the SBA is to motivate the customer to purchase GLP products. Nearly all of them do their job part time, choosing to focus on sales either in the morning or evening hours. One of the SBAs interviewed during the study, has been with GLP for almost two years. He also serves as a lab technician for a pharmaceutical company, while his family operates an after-school tutoring center and engages in agriculture. Another SBA interviewed is an influential man in his village, who has been with GLP for nearly a year, and is known to be one of the company's most successful SBAs. In addition to his duties as an SBA, he operates a poultry farm.

Recalling the importance of knowing the user's needs when trying to diffuse an innovation (Ockwell 2012), field interviews confirmed that SBAs must have a detailed understanding of why a customer is not purchasing products, and where there is unmet demand for electricity from the grid. For example, a potential customer may consider GLP's products too expensive when compared to alternative products available in the market. Or, the number of small business owners in a village may be higher than in another, driving up the demand for off-grid solar products in that location. Some villages may also have a more erratic electricity supply than others, making the residents there more interested in subsituting grid power with solar energy.

In addition, SBAs must know the paying capacity of their clients, which is useful for GLP to establish price points for their various products. One of the SBA's stated that his customers are "too poor" to be able to afford the products. Coupled with the fact that he is selling to his relatives and friends, he has gotten in the habit of taking payments from the customers in installments instead of full payments. Acting as a micro-lender has resulted in debt accumulation, which he was tracking in a little book he presented at the time of the field visit. A bit frustrated with the situation, he stated, "this is the business of tying the noose of debt around people's necks."

Finally, SBAs may have overlapping territories, or two or more SBAs may reside in the same territory but sell to people in neighboring villages or hamlets. Being in close proximity highlights the continued role of communication networks in the diffusion of innovations, as it facilitates knowledge sharing between SBAs in how and where to make sales, in addition to driving competition to meet individual monthly sales targets.

Direct sales is a difficult job. It takes approximately 30-40 minutes for a SBA to convince the customer, and requires 3-4 visits on average. The sales pitch typically starts with the health challenges of using kerosene, and a cost-benefit analysis of switching from kerosene to a solar lantern. For example, on average a person in Bihar might spend Rs. 10 ($0.17) a day on kerosene. Similarly, a person might spend Rs. 150 ($2.50) a month for approximately 3 hours a day of access to a diesel generator-based plug point connection (presumably for mobile charging).

Table 2. Monthly Debt Acquired by Team GLP Staff

Debtor	Monthly Debt (USD)
Team Leader	$833-$1667
Sales Business Associate	$167-$334

The GLP model is also unique because it shifts the risk of completing sales from the parent corporation to its network of sales agents. All SBAs have targets for monthly sales that are set for them by District Sales Managers and facilitated with the help of Team Leaders. Both SBAs and TLs are under immense pressure to meet monthly sales targets. To meet these targets, TLs take on high inventory loans from GLP and pass these loans on to SBAs (see Table 2) . This way, GLP gets the product off its shelf and into the homes of customers much faster than a traditional solar company, whose stock may sit in warehouses, stockpoints, or with a dealer for a much longer time. The desire to get rid of inventory debt drives sales. Though this model results in relatively high sales, the pressure to meet targets (and to carry debt) results in a low retention rate of 50-60% for SBAs in the GLP network.

Table 3. Sample Sales of SBAs in Vaishali District, Bihar

SBA	Avg. Monthly Products Sold	Highest Monthly Sale
SBA 1	21	40
SBA 2	25	65

Sales vary from region to region, with some SBAs managing to sell up to 80 pieces a month. The average monthly products and highest ever sales per month for the two SBAs interviewed for this study are listed in Table 3. There is grid-based electricity access in the district that was surveyed, so sales for an SBA have never reached as high as 80 products a month.

4.2.1.4 Team Leader

A good Team Leader has prior experience in marketing and distribution. One of the Team Leaders interviewed during the field visit to Baishali district in Bihar previously worked with Aircell, a cellular network provider, for two years in a marketing position. Working full-time dealing with his SBAs, he must reach out to at least two of them a day to ensure that they are meeting their sales targets. Through all his combined SBAs, a Team Leader should average $167 in sales a day. In June of 2014, prior to the field visit, the TL interviewed executed $6,667 in sales with the help of his 21 SBAs.

4.2.1.5 Commission and Incentive Structures

As mentioned before, SBAs are not on the GLP payroll. The company has set up an incentive and per-product sales commission structure (see Table 4) to keep SBAs motivated.

Table 4. Commission Structure for SBAs

Product	Maximum Retail Price (Rs.)[28]	SBA Commission	Billed to SBA
Solo	900	80	820
Eco	600	60	540
Mobile	1600	125	1475
Pro 2	2300	175	2125

Incentives, or sales "boosters" for SBAs are established on the basis of the number of products an SBA sells every month. The figure below shows the required number of products sold (in blue) along with the corresponding boosters received listed on the right. Boosters are essentially Sun King products given to SBAs to keep for themselves, or to sell at full retail value giving them 100% of the proceeds from the sale. In addition, SBAs may receive things like irons, sewing machines, and other household appliances equaling the value of certain Sun King products as boosters.

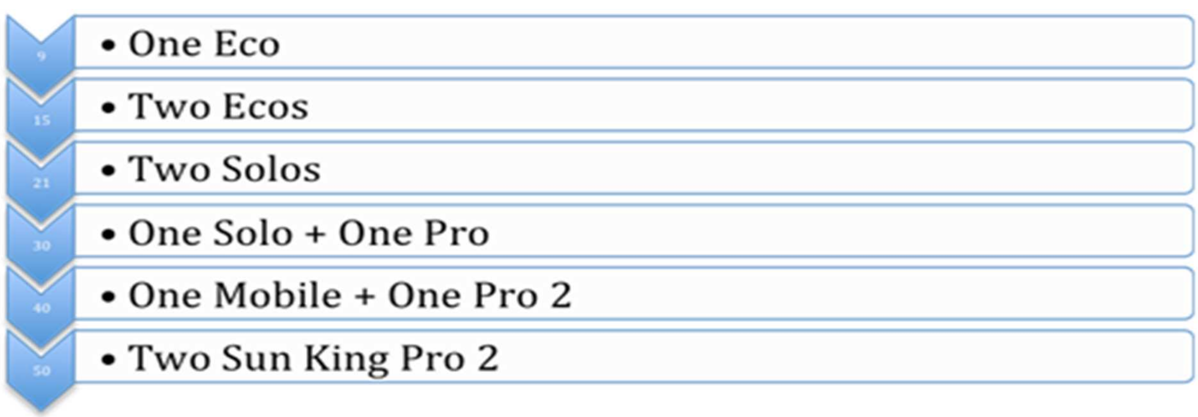


Figure 3. Boosters Received from Achieving Target Sales

[28] 1 US Dollar = approximately 60 Indian Rupees at the time the survey was conducted.

To motivate Team Leaders, GLP has devised a four-tiered promotion and incentive structure for them. This includes a mix of salary increases, target driven monthly sales incentives and benefits (see Table 5). Occasionally TLs have also been rewarded with international travel to solar conferences.

Table 5. Team Leader Stucture of Promotions and Incentives

Level	Monthly Salary (Rs.)	Boost
Team Leader 1	10,000	Sales Incentive of Rs. 5-7,000/month
Team Leader 2	10,000	Sales Incentive + Rs. 250/month (to cover mobile costs, etc.)
Team Leader 3	10,000	Monthly Sales incentive + Rs. 500/month (to cover mobile costs, etc.)
Team Leader 4	17,000	Monthly Sales incentive + Rs. 500/month (to cover mobile costs, etc.)

4.2.2 Sales Strategy

A variety of levers are used to drive the sales of Sun King products in the ecosystem in which GLP operates. These levers include marketing tools, such as brand building and product demonstrations, and targeted sales and customer relationship building. The Regional Sales Managers (RSMs) are encouraged to come up with innovative localized marketing techniques. The RSM of Vaishali district has taken it upon himself to come up with unique marketing strategies, including a ring-tone for his staff's phones that is essentially a sales jingle for Sun King products.

4.2.2.1 Brand Building

All Sun King SBAs and TLs wear a bright yellow t-shirt and a cap with the logo so that villagers can recognize the Sun King brand. Leaflets for all products are carried with the GLP staff and taken for door-to-door sales pitches. The leaflet includes the contact information for the local SBA or TL for the customer to contact when they are ready to buy a product (see picture below). Posters of Sun King products are also placed at high-traffic areas such as chai stalls, general stores in villages, or at the village chief's house.

In Vaishali district of Bihar, the RSM has employed another unique strategy to build the brand and enhance sales locally. Termed a "van activity," it involves a large Sun King banner draped around a van with a repeated audio announcement about the benefits of solar lighting. This van moves through 5-7 villages and generates one product sold daily over the course of the two-week activity. An SBA follows up with those customers who may have expressed interest during the time the van was moving through their locality. This activity, another that falls within Rogers' theory of communication networks facilitating the diffusion of innovations, is most effective when conducted prior to the arrival of a sales team to an area.

Another brand building strategy employed by the local RSM is called "Halla Bol." Every Saturday, 8 GLP Team Leaders from a region travel through the region on motorcycles wearing Sun King branded shirts, blaring their horns and chanting slogans. This activity is not only a marketing ploy, it also allows TLs from different areas to interact with each other and share information on how to best facilitate sales.

4.2.2.2 Product Demonstrations

In the daily product demonstrations an SBA, a TL, and the DSM move together through a village after sunset with switched on Sun King lights hanging around their necks. This draws the attention of the villagers and starts the conversations about the products. Each demonstration activity generates immediate sales and totals approximately 25% of GLP's sales in Bihar. Most people take leaflets and the SBA follows up with those who showed interest in the product but refrained from purchasing at the time of the demo in the next few days.

GLP staff also target shop owners with Sun King products because they are frequented by many villagers. An SBA might leave a Sun King product at the shop over night with their contact information. A potential customer may then inquire about the lit solar lantern and follow up with the SBA. By leaving a product free of charge with the shop owner for a few days, GLP manages to create awareness and trust in the product. If the shop owner is satisfied with the product s/he may choose to purchase it instead of risking having it being taken away by GLP staff.

4.2.2.3 Targeted Sales

Targeting locations without access to reliable electricity access or approaching businesses that have large lighting needs helps ensure sales. For example, a small poultry farm may require 40-45 Sun King lights, whereas a brick factory could replace its liquefied petroleum powered lanterns with Sun King products and recuperate the investment in 3 months. Areas identified as having extremely unreliable or no electricity access present an opportunity to conduct sales, by using a general store in the area as a marketing and sales point.

4.2.3 Competition

Nationally, GLP competes with many kinds of alternatives to its products. In Bihar, the main competitors for GLP in the market identified by GLP staff are D.Light Design, Bhaskar Solar, G-light, and Sun Max (see Table 6). Products from Sun Max are no longer being sold in the Vaishali district of Bihar. The product offered by G-light resembles the Sun King Eco offered by GLP. Regional Sales Manager for GLP, Mr. Bijay Tiwari, states that while G-Light retailers tell the customers their products can be used to charge cell phones, the cell phone batteries are not capable of handling such a charge. Ultimately customers find their cell phone performance compromised. As for Bhaskar Solar, their primary product in the region is a solar home lighting system, which is a much bigger and more expensive product for which villagers must approach their Gram Panchayat (village governing body) for financing.

Table 6. GLP Competitors in the Region

Brand	Product	Price ($)	Sales Channel
D.Light	Kiran lantern	$8.50-30	Retail through Vasudha Kendra (government common service center)
Bhaskar Solar	Solar Home Lighting System	>$150	Procured through Gram Panchayat Fund
G-Light	Eco-like Lantern	$15	Retail
Sun Max	Lanterns	$30-40	Retail through Kirana Shops (Convenience Store)

The main competitor most like GLP in the region and nationally is D.Light Design. Though not the focus of this paper, it should be noted that D.Light operates on a completely different business model than GLP, choosing primarily to focus on retailing through partners. In Bihar, D.Light sells its products through the government's "common service centers" (CSC) known as Vasudha Kendra. CSCs serve as a hub for a variety of "high quality and cost-effective video, voice and data content and services, in the areas of e-governance, education, health, telemedicine, entertainment as well as other private services[29]."

[29] Source: http://Vasudhakendra.com/about

The graph below shows the annual sales of both GLP and D.Light nationally. The two companies dominate the private solar lantern market in terms of total volumes sold and brand recognized.

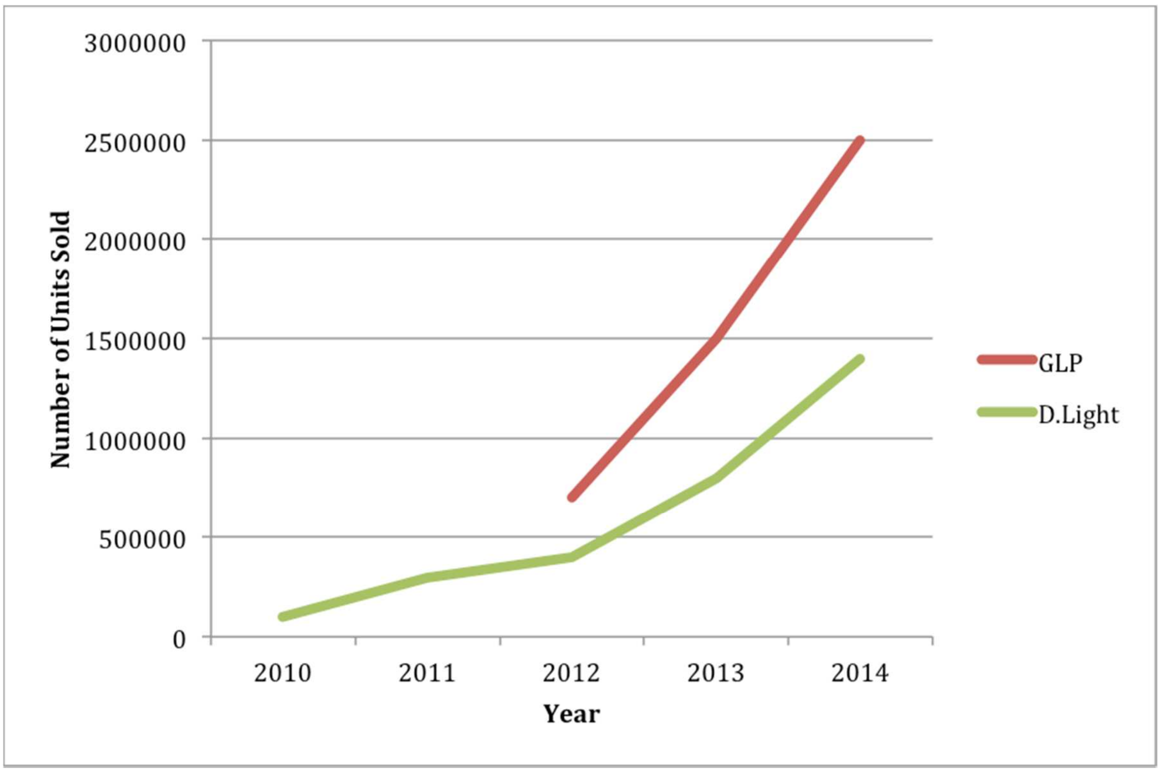


Figure 4. Annual Unit Sales of GLP and D.Light in India

4.2.4 Customer Relations

It is important to note the role of building good relationships with customers in order to establish trust in the brand and enhance sales. Trust, Rogers points out, is critical in the adoption of innovations in a target community, and something that takes time and key individuals to establish. The GLP model relies on SBAs, who are embedded in their local communities, and therefore must meet product-servicing requirements as and when they arise. SBAs keep going back to check on customers, which improves confidence and boosts

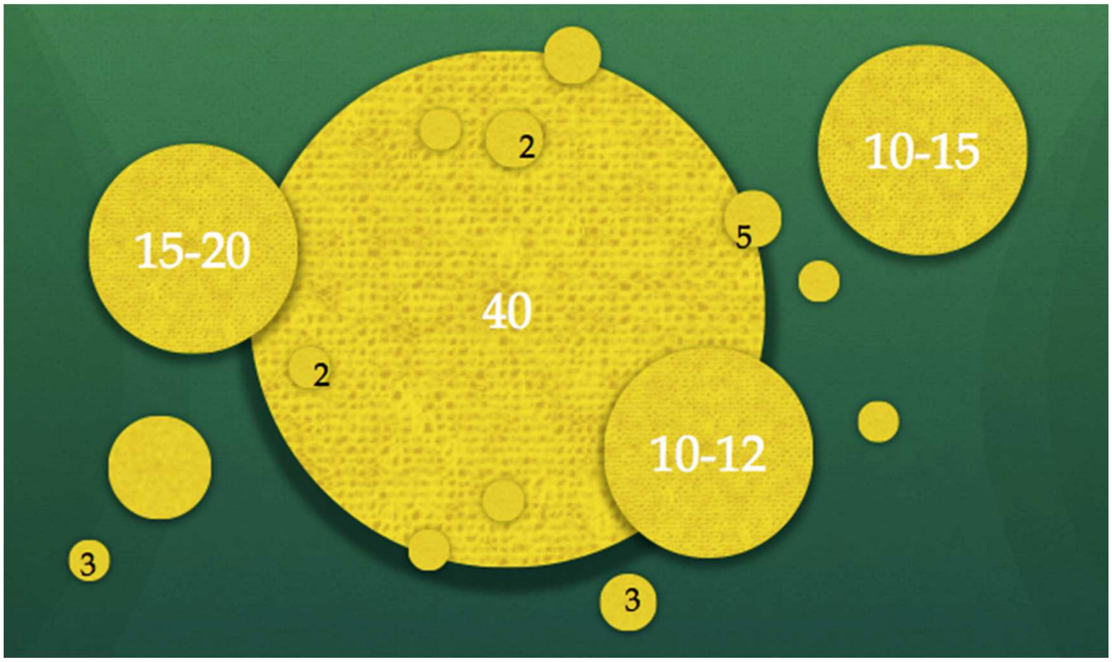


Figure 5. Each bubble in this figure represents a customer of Green Light Planet. The numbers correspond with the number of people whom s/he was able to convince to also purchase a Green Light Planet Product.

sales through word of mouth amongst the villagers. Villagers are often subjected to "fly-by-night" sales agents who offer faulty products of all kinds, so convincing them to purchase a product can be a lengthy and challenging process. Continually asking them about their Sun King products and being visible in the community builds trust.

A closer examination of how these products are diffusing reveals that by targeting the elected head of the village, or another person in the community with high social capital, as the first customer, a lot more products can be sold in the community thereafter. This suggests that GLP products are diffusing locally along the lines of the network theories discussed above. One village chief interviewed said that in the beginning he would have the lantern turned on and placed outside his house during the evenings. People stopping by would inquire about the product. Around 30% of the respondents stated that they taken their own or gifted new Sun King products to friends and relatives in other villages. Figure 5 further reveals the power of social capital in diffusing these products: each bubble represents a customer and each number associated with a bubble represents the number of other people that customer managed to convince to purchase a GLP product using their social capital. It was reported that caste may also be a factor in the diffusion of products locally. Caste loyalties are strong in the region, and perhaps some groups are facilitating the uptake of Sun King products in their communities better than others.

4.2.5 Maintenance and Servicing

An important part of maintaining good customer relations is providing quality maintenance and after-sales servicing. Quality of maintenance and after-sales service support is one of the most important factors affecting the success of an off-grid solar energy enterprise. Every GLP staff member encountered during the field visit in 2014 seemed to agree that servicing in the area needed improvement. Before the arrival of the Service Center in the nearby city of Patna, GLP used to simply replace any products facing maintenance issues with brand new ones. The main maintenance problems witnessed by customers in the area are to do with batteries entering a state of "deep discharge" from overuse, and mobile charge port malfunction (perhaps due to loose wiring and the quality of the pin used to charge mobile phones).

Once the customer hands over the product to GLP staff, the entire process of repairing and returning should only take 20 days. However, the field visit revealed that one of the biggest challenges faced by GLP's direct marketing business model was delay in the maintenance and repair of products. This delay comes from a few specific parts of the process. Delays in the transportation of broken products to and from a stock point may be one of the biggest problems. The distributor is responsible for this as he is responsible for choosing the transportation courier. In addition, the distributor may wait for a certain number of broken products to collect at the stock point before sending them all together as part of the same consignment to the service center. The sales team may also be responsible for delays by failing to pick up the products from the customers in a timely manner to pass over to the distributor. The figure below depicts the process of repairing Sun King products from customer to service center. Elements written in red font in the figure represent areas where delay may be introduced into the process.

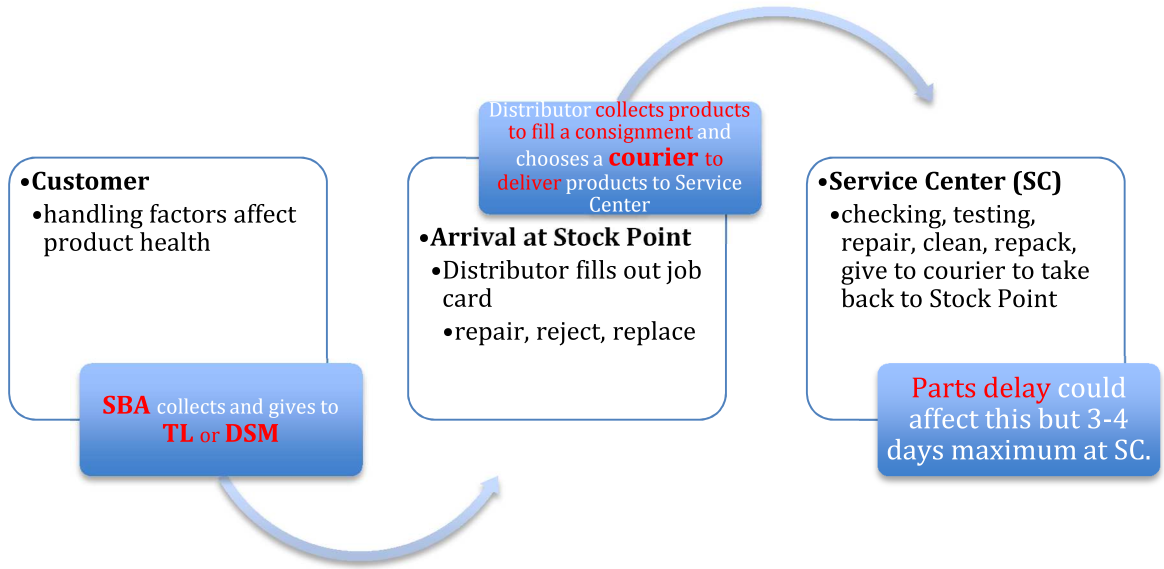


Figure 6. Delays in GLP Product Servicing Chain Process

4.3 Conclusion

The business innovation of GLP, which relies on shifting the risk of conducting sales from the parent corporation to a network of reliable sales agents, has given the company an edge in the distribution of off-grid solar technologies in India. By relying on the social capital of the locally embedded sales agents, the company is able to capitalize on the trust required for the adoption of its technology for the last mile customer. The constant communication between the dendritic network representing the company's organizational leadership facilitates the flow of learning on how to conduct and continually improve sales. For taking on the risk of making sales leveraging their social capital within communities, and doing so with strict targets and timelines, SBAs and Team Leaders are rewarded by the company through a system of incentives. GLP leverages most of the social and communication networks defined by scholars in order to meet the twin goals of low-carbon technology diffusion as well as expanding (limited) access to modern energy.

4.4 Methods

This paper presents an in-depth case study of how unit scaling can be achieved for pro-poor energy innovation. It is part of a broader research endeavor aimed at understanding which firm-level factors affect the scaling-up (or not) of off-grid solar technologies in India (Singh 2016). Methodologies drawn from for this study include both quantitative and qualitative analysis. This analysis revealed that the most successful firm identified, by unit, was Green Light Planet. While one case study cannot conclusively prove anything, there is intrinsic value in a detailed analysis of what appears to be one of the most successful cases. To explore in detail factors that may be affecting the firm's ability to achieve scale, in-depth qualitative analysis was required. Using the methodologies employed in this paper, further research should explore other firms using business models similar to or different from the direct marketing approach of GLP. A compilation of such cases would enhance the understanding of the role of networks in the diffusion of off-grid solar technologies in India.

The main tool used for qualitative inquiry were semi-structured interviews conducted with various employees of the company, including the CEO, the head of the Service Center in Patna, the acting District Manager responsible for

Vaishali District, a Team Leader and two Sales Business Associates. The purpose of these interviews was to understand in greater detail the evolution of GLP's business plan, and the challenges faced and opportunities leveraged as the firm grew in size and customer base. In addition, a structured survey was conducted of 15 Green Light Planet customers in several villages of Vaishali district in the eastern state of Bihar in July 2014 (see Figure 7). The interviews were designed to assess: 1) the demographics of the customer base of off-grid solar technology firms; 2) finance and the technology; 3) servicing and maintenance issues; 4) fuel switching; 5) quality and satisfaction; and 6) livelihood improvement or augmentation. The purpose of these surveys were to verify responses of GLP staff, as well as identify the challenges and opportunities post-deployment of the company's business model.

The author also participated in a few sales attempts with a local sales agent of Green Light Planet, to better understand the sales strategy, and to witness the interaction between potential customers and the company. To identify and analyze the role of social networks in GLP's business model, a combination of observation, process tracing, content analysis, quasi-statistics, constant comparison, and analytic induction were utilized. When examining the impact of each customer helping diffuse the technology further (see Figure 5), due to limited data and simply to provide a snapshot, an improvised visual graphic was created in lieu of the graph theory methods used in traditional actor centrality and prestige-based social network analysis (Wasserman 1994).

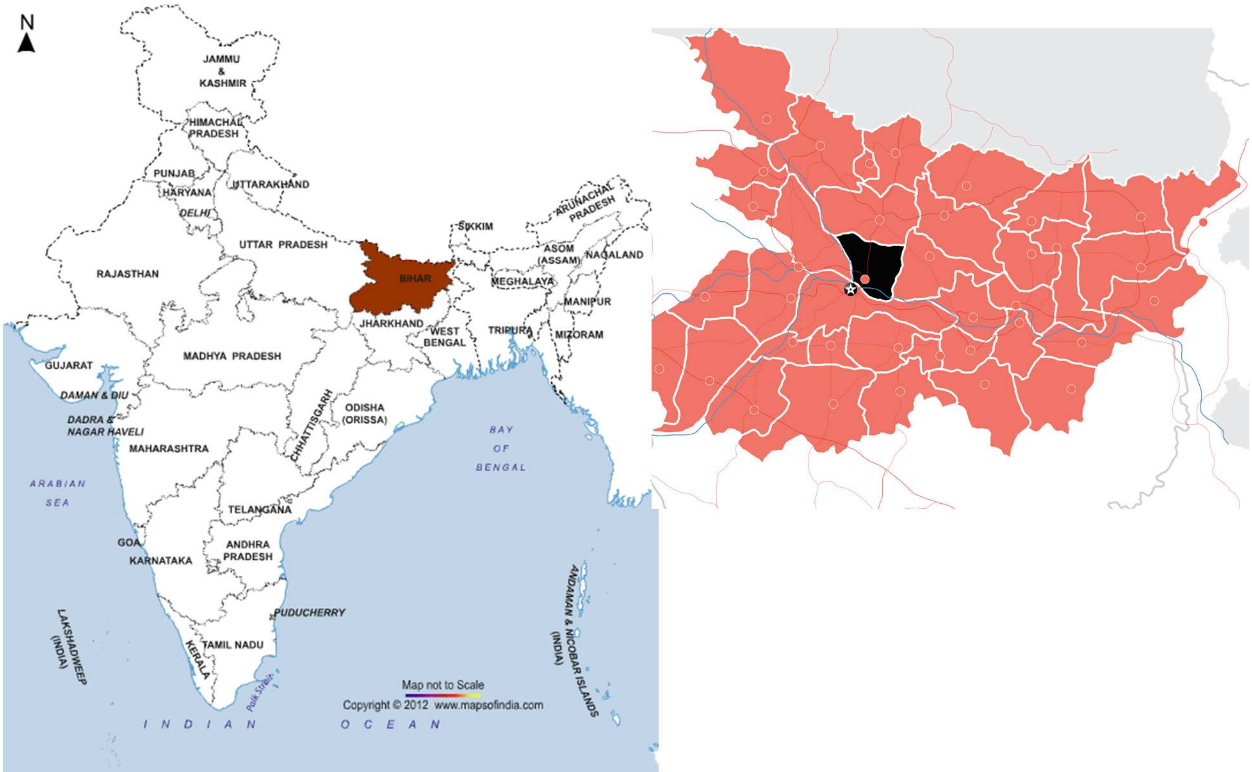


Figure 7. The map on the left depicts the location of the state of Bihar in India while the map on the right depicts the Vaishali district in the state of Bihar.

CHAPTER V: CONCLUSION

5.1 Key Findings

This dissertation has largely answered the question of which firm-level factors affect the scaling-up (or not) of off-grid solar technologies in India. These factors can be categorized as technological, financial, and social. Based on these factors, this study suggests that the biggest barriers to the diffusion of these technologies include: 1) poor supply chains that limit the reach of firms who wish to sell off-grid solar technologies in areas with large populations who lack access to electricity; and 2) limited financial inclusion for the very people who may need to take advantage of government subsidies through formal bank accounts to purchase off-grid solar technologies. Consequently, the biggest incentives for the diffusion of these technologies include: 1) the ease of purchasing products or solar energy services (through financial innovations) from the firm by the customer as well as having the assurance of it being serviced in a timely manner should anything fail; and 2) commission based sales that facilitate the sale of products to the last mile customer by networks of entrepreneurs.

5.1.1 Technological Factors

The technological factors affecting the scaling-up of off-grid solar technologies include: 1) modularity in product design; 2) focus on limited number of product types; and 3) the existence of the centralized electricity grid in the area where the firm conducted sales. The first two technological factors are consistent with Wilson's (2009) hypothesis that low-carbon technologies achieve unit scale when there is a certain level of homogeneity and standardization of product design. A closer look at the firms leading the pack in terms of sales reveals that they are largely selling compact[30] products. Conversations with entrepreneurs during the course of this study revealed that innovations in battery technology and the transformation of the market from CFL to LED bulbs have increased the efficiency of these compact products, making them capable of providing more energy at lower costs.

Recall that the study also intended to explore the role of product multi-functionality in unit scaling of off-grid solar technologies. This study concludes that while multi-functionality of an off-grid solar product does not affect the overall unit scaling for the firm, products providing energy services beyond lighting have become the norm. The results of this study indicate that use of solar energy for charging appliances such as mobile phones is perhaps as, if not more, important for the customer than the lighting service provided by the technology. Experts concur that the demand for aspirational appliances such as fans and televisions (that are increasingly low-watt and thus super-efficient) will drive the diffusion of solar technologies. These conclusions are consistent with prior scholarship on the importance of aspirational products and consumer behavior for the base of the pyramid market (Prahalad 2010)

[30] Refers to products that are homogenous and modular.

and the role that appliances such as mobile phones already play in improving rural livelihoods (Aker 2010).

The most surprising factor that did not affect the scaling of off-grid solar technologies was its relationship with the existing electricity grid. This finding is at odds with existing reports that suggest a reduced role for off-grid technologies in the face of an advancing centralized grid system (Bazilian 2013, Caine 2014, Lomborg 2015). The fact that the market of off-grid solar technologies in India is not limited by the grid is an indicator that until the reliability of the grid is addressed, people will always want to supplement their existing electricity access with solar – or that despite the access, customers may be opting for the energy security and long-term savings a technology such as solar home lighting systems can provide.

Another grid-related and important finding of this study is 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). Chapter II explains that one reason this may be affecting the scaling-up of off-grid technologies to those who are truly beyond the grid is that the firms operating in truly off-grid areas find it more difficult to carry the lessons they learn on technology diffusion from one region to the next (due to the different socio-cultural, political and economic factors present locally).

Finally, some of the technological factors analyzed, such as the presence of an R&D or marketing budget, had no noticeable impact on the diffusion of off-grid solar technologies. Other techno-social factors include the provision of warranty and after-sales support, which is a critical need and cost of off-grid solar technologies post-deployment (Kumar 2009, Carrasco 2013), and has become a norm amongst distributors in the formal market. While this is good news for the industry at large, another study has identified that there is a large market of "unbranded" low-cost products that do not have established supply chains for maintenance and after-sales service (BNEF 2016). These products may number in the millions globally, and - should they perform poorly - could adversely affect a user's experience with solar technologies, thereby decreasing their willingness to pay for quality solar products in the future.

5.1.2 Financial Factors

One of the main questions this study sought to ask was, what is the role of financing in the scaling-up of off-grid solar technologies? This study suggests that end-user financing is not the primary factor affecting scaling-up of off-grid solar technologies; rather financing models that support innovative firms focused on the reliability and accessibility of their products result in greater scaling. This conclusion shifts the argument away from lack of adequate government-supported financing for the end-user as a barrier for the diffusion of off-grid solar technologies.

Contrary to existing scholarship on financing that places low income of customers as one of the primary barriers to the diffusion of off-grid solar technologies (Harish 2013, Palit 2013, Pode 2013), this study finds that factors affecting the decision to pay are more important than the ability to pay. To purchase these technologies cheaply, banking facilities and a robust network of MFIs could provide millions of end-users with access to government subsidies and credit, respectively. However, this study finds that most firms operating in the formal as well as informal market are making direct cash sales[31] and not participating in the government subsidy program. Experts add that while some off-grid solar firms may be partnering with MFIs, the utility of MFIs for the firms lies in their extensive distribution networks rather than their credit lending abilities.

By examining the experiences of firms, end-users, and financial institutions, Chapter III explains that these sales are presumably being conducted by use of innovative financing models that make products more affordable, for example through PAYG (addressing the users' ability to pay) and more accessible, for

[31] These findings are consistent with a recent global off-grid solar market report that states that customers around the world are choosing to pay by cash (BNEF 2016).

.

example through reliable distribution channels for sales and after-sales support (addressing their decision to pay). Thus this study suggests that the role of financing in the diffusion of off-grid solar technologies should be to support the companies that make these products not only affordable, but also more accessible[32].

5.1.3 Social Factors

The social factor affecting the scaling-up of off-grid solar technologies is the presence and use of strong distribution networks. In Chapter IV, this factor is explored in-depth through a case study of Green Light Planet, the most successful firm in terms of unit scaling across the country. The analysis of the business model of Green Light Planet confirms Rogers' (2003) claims that innovations diffuse fastest through strong networks led by early adopters in a community. These findings are also consistent with existing scholarship (Caird 2008, McEachern 2008, Ramirez 2014) that places an emphasis on communication networks as the driving factor for the diffusion of energy technologies.

Beyond the fact that GLP's technology is modular and easy to pay for, the key innovation for its extensive diffusion lies in the use of networks of locally-embedded sales agents. These entrepreneurs are incentivized to take on small

[32] Off-grid solar firms using PAYG financing that makes products more affordable and accessible, raised $160 million in private venture capital in 2015 (BNEF 2016).

loans to stock GLP inventory, and utilize their own social capital to conduct sales. This fundamentally shifts the burden of establishing capital-intensive sales outlets to a vast network of independent part-time sales agents. Having extensive reach and a recognized brand across the country sets the stage for GLP to introduce, perhaps successfully and at scale, larger off-grid solar technologies such as solar home lighting systems.

5.2 Policy Implications

From a policy perspective, this research is timely for a number of reasons. Since the start of this dissertation process in 2011, dramatic shifts have taken place in India's political arena. The super-majority of the new National Democratic Alliance (NDA) government, led by Prime Minister Narendra Modi, is making overtures to establish universal electrification by 2019, and to increase the share of solar energy in the national fuel mix from 20 GW by 2022 to 100 GW by 2022. At the United Nations Framework Convention on Climate Change meeting in Paris (COP 21), India launched the International Solar Alliance (ISA), a proposal for an international institution that will help facilitate the diffusion of solar technologies (including off-grid) across countries in the tropics. Thus, the political commitment from the government for the diffusion of off-grid solar technology diffusion is apparent. In this setting, there are policy implications associated with the technological, financial, and social factors affecting the diffusion of off-grid solar technologies that were found by this study.

The technological factors discussed above, such as product design, product type, and the rise of low-watt super-efficient appliances, could benefit from government support for off-grid solar technology manufacturing within India. Many of the firms, including the most successful ones, currently have their manufacturing bases in southern China. Increased domestic manufacturing could create the conditions for competition between companies, thereby bringing down the costs of the technology further. If more solar manufacturers existed in India, the import and transportation costs would also be reduced, as the materials would not have to travel from foreign markets. Prospects for technology innovation might also increase if more of the manufacturers and distributors of solar technologies were in the same ecosystem. The Indian government's "Make in India" initiative could be leveraged to create special off-grid solar manufacturing and design parks. There are currently no manufacturing hubs for the off-grid sector. Given that this study found that the existence of the grid is not a limiting factor for the diffusion of off-grid solar technologies, there is an obvious need for the government to provide incentives for manufacturing in this sector. The states needing off-grid solar technologies for electrification the most (such as the Northeastern states) could offer companies tax advantages to manufacture the products in the state. Finally, quality testing and assurance for products is particularly important for off-grid solar technologies, as some informal retailers noted that the wholesale solar photovoltaic panels they purchased were not always reliable. Given the possible reach of “unbranded products”, which are the least scrutinized, having access to local testing facilities would ensure that informal sales agents are providing quality products to their customers.

One of the biggest policy implications of this study is that the government should change the way it supports end-user financing for off-grid solar technologies. As discussed above, this study suggests that end-user financing is not a barrier to the scaling-up of off-grid solar technologies in India. This is supported by the fact that the majority of the firms operating in the formal as well as informal market are not participating in the cumbersome procedures for their customers to receive government subsidies for solar; rather millions of customers are paying for their products through cash. Should the government plan to continue to finance base of the pyramid end-users’ energy consumption through existing mechanisms, it should rapidly scale up its program to open up bank accounts for these customers. The recently launched Jan Dhan Yojana (JDY) or “the People’s Money Scheme,” can increase access to formal banking for millions of first-time customers. Access to formal banking for millions of customers could dramatically expand the market of potential customers for more expensive products that might need end-user subsidies or loans, such as solar home lighting systems. To take advantage of these changes, banks would need to hire a dedicated energy loan officer at most of their rural bank branches, so as to ensure that subsidy programs are supported by the technical staff required to execute loans. The expansion of the previous government's Direct Benefit Transfer scheme, which channels subsidies for energy directly to the customers' bank accounts while leaving the choice of how (and on what technology) to spend the money up to the customer, would be another way for customers to have the choice to purchase more off-grid solar technologies.

The finance solutions discussed above may be as long-term as they are cumbersome. To facilitate the innovation in finance required to make solar technology more accessible and affordable in the near-term, better options exist. The government should remove bottlenecks for conducting transactions through mobile payments, allowing foreign contributions towards energy projects, as well as the ability for small investors to receive interests for loans specifically for crowdfunding efforts for energy access. Improving the business environment to support such emergent forms of financing could leverage foreign actors to help scale up and realize the true potential of emergent innovations, such as crowdfunding and PAYG technologies.

To support the growth of firms that use innovative financing tools to drive the diffusion of off-grid solar technologies, ecosystems that support entrepreneurship and business innovation in both the formal and informal market should be created. Recalling that one of the findings of this study was the surprising number of informal sales agents operating in this market, the "Skill India" initiative could be harnessed to fund formalized quality training for this group. An army of solar engineers who could build and repair off-grid solar technologies at any one of India's 6,000 Industrial Training Institutes (ITIs) could be one important outcome of such an initiative.

For the formal market, the government should leverage its "Start-Up India" initiative to create a series of off-grid solar innovation challenges. A network of public and private off-grid technology-specific incubators and accelerators could anchor these challenges. During the course of this research, the author only came across two formal incubators for off-grid solar technology businesses in the country. Increasing the network of business incubators and accelerators would be useful for supporting budding off-grid solar energy entrepreneurs. At these incubators, entrepreneurs could gain access to financing through the newly launched PACESetter Fund or the New Ventures India public-private fund. The Clean Energy Access Network (CLEAN), a network of energy access enterprises from across India, can also be leveraged to share best practices and facilitate learning between these start-ups.

5.3 Limitations

A number of limitations emerged during the course of this study. First, generalizability is a concern; it is difficult given the disparate nature and large number of providers and technologies. Millions of customers are spread across 28 states, with vastly different socio-cultural, political and economic geographies, and may be affected by the presence or absence of third party stakeholders (such as NGOs, financial institutions, local government bodies, etc.,) who could support or prevent the diffusion of the technologies. Finally, it was difficult to collect raw data with reliable figures from both customers and the firms distributing the technologies. These stakeholders can provide, at best, an estimate of figures required to understand the factors affecting the diffusion of these technologies in the local context.

The challenges outlined above lead to inexact facts and figures between analogous studies on energy access. This dissertation fully acknowledges these limitations, and finds that much of the data collected for this study in 2014 is reflected by the facts and figures of the off-grid solar technology market reported by some studies since 2014 (TCG 2015, BNEF 2016).

Figure 1. This map represents the number of places the author sourced his data from in order to inform his research. Black lines indicate areas travelled to.

In addition to data limitations, methodological limitations that influence this study include the sample size, method of inquiry, access to information, and language barriers. While the total number of off-grid solar technology firms in India could number as many as 200, this study formally managed to capture information from 69 firms. Most of the detailed research about each of those firms was conducted online, which may have limited the access to a number of firms the author could have reached. Sometimes the phrasing of the question had to be altered, or new questions emerged after data collection had started. In addition, there were language barriers to being able to converse with customers and firms who did not speak or read in Hindi or English. To compensate for these limitations, the author relied on a variety of methods of inquiry including structured in-person, online, and telephonic interviews), in some cases with the help of translators, and did so from a variety of different sources across India (see Figure 1). The extensive reach of this study through various forms of inquiry is an attempt to overcome the methodological limitations of conducting research on this subject.

5.4 Future Research

Future work should focus more intently on the firm and the environment in which it is based. Growth timelines such as the one created for GLP in Chapter IV (see Figure 1) need to be mapped out for other firms, and examined for periods of growth of the firm in number of products sold or staff hired, against the backdrop of State and Central government policies. Not much is known about the reason an enterprise locates in a particular state versus the size of the off-grid market in that state. No direct links have been made linking business model types to certain states. A more thorough analysis of the geography of participation of these enterprises vis-à-vis their business models and local off-grid market size would further the understanding of the diffusion of solar lighting products in India. Such research could also illuminate the barriers and opportunities for government involvement for this sector.

Further research on the post-deployment effectiveness of PAYG technologies and technologies deployed with the help of crowdfund financing would shed light on the customer's decision versus ability to pay argument. The "Energy Diaries" project launched by Arc Finance, which tracks daily household energy consumption patterns, will further the understanding of how people choose to prioritize payments for access to energy services.

The human-technology interaction of communities getting power through micro-grids needs further study. Based on field visits, challenges with the deployment of this solution - currently championed by the development community - became apparent. Entrepreneurs explained that they face the challenge of theft of electricity from their infrastructure, suggesting that the problem of electricity theft is not limited to stealing from the larger government-owned transmission and distribution network. Government structures for the deployment and management of micro-grids can incentivize the misuse of such systems. One entrepreneur in West Bengal may have been charging different rates to his neighbors for the same quality and quantity of service. Electricity provision could thus be used to strengthen power structures in a country where discrimination based on caste and religion is pervasive.

Another area that requires further study is the role and impact of informal solar sales agents. According to the director of the Ashden Energy Collective, the numbers on how many solar products may be in homes across the country may be grossly underestimated in formal surveys because of the un-captured but outsized role of sales from the informal entrepreneurs. A mapping of the informal sector is critical to understanding the reach of this technology that has been distributed in India since the late 1970s. Undertaking this mapping exercise may also uncover if there is a market for broken solar products, an important issue given the toxicity of e-waste.

Finally, as solar energy technology moves into the mainstream, more studies need to be conducted to look at the impact of the availability of super-efficient low cost appliances such as televisions and fans on the sales of solar photovoltaic panels. As discussed in the study, the combined impacts of low-cost solar PV and more efficient batteries has resulted in more access to energy services such as mobile phone charging through existing PV capacity, and thus lowered costs. If today's market has few players who sell off-grid solar products without the capacity to charge a mobile phone, perhaps in a few years, the same will be true of other low-watt appliances. Tracking these changes in the market would further our understanding of how these low-carbon technologies do (or do not) achieve scale.

REFERENCE LIST

Aanesen, A., S. Heck, D. Pinner (2012). Solar power: darkest before dawn. McKinsey on sustainability and resource productivity, McKinsey & Company.

Agbemabiese, L., Jabavu Nkomo, Youba Sokona (2012). "Enabling innovations in energy access: An African perspective." Energy Policy **47**: 38-47.

AGECC (2010). Energy for a Sustainable Future: Summary Report and Recommendations. A. G. o. E. C. Change. New York, United Nations**:** 1-26.

Aker, J. C. (2007). "Social Networks and Household Welfare in Tanzania: Working Together to Get out of Poverty." Social Science Research Network: 1-33.

Aker, J. C., Isaac M. Mbiti (2010). "Mobile Phones and Economic Development in Africa." Journal of Economic Perspectives **24**(3): 207-232.

Akkari, Y., Niki Armacost (2013). Using Remittances to Finance Clean Energy: Inspiring the Haitian Diaspora to Combat Climate Change. New York, Arc Finance**:** 1-15.

ArcFinance (2014). Crowdfunding in the Energy Access Space. REMMP Briefing Note. A. Finance. New York, Arc Finance**:** 1-8.

ArcFinance (2014). Pay-As-You-Go Technologies in Consumer Energy Finance. REMMP Briefing Note. A. Finance. New York, Arc Finance**:** 1-6.

Asheim, B. T., Meric S. Gertler (2005). The Geography of Innovation. Oxford Handbook on Innovation. F. e. al. Oxford, Oxford University Press**:** 291-317.

Bairiganjan, S., Ray Cheung, Ella Aglipay Delio, David Fuente, Saurabh Lall, and Santosh Singh (2010). Power to the People: Investing in Clean Energy for the Base of the Pyramid in India. Washington, D.C., World Resources Institute and IFMR**:** 74.

Bairiganjan, S., Sanjoy Sanyal (2013). The Last 50 Mile: Using LVE Networks for Increasing Clean Energy Access. Hyderabad, New Ventures India**:** 1-49.

Balachandra, P. (2011). "Modern energy access to all in rural India: An integrated implementation strategy." Energy Policy **39**: 7803-7814.

Bardouille, P. (2012). From gap to opportunity: Business models for scaling up energy access. Washington, D.C., International Finance Corporation

Barnes, D., Gerald Foley (2004). Rural Electrification in the Developing World: A Summary of Lessons from Successful Programs. Washington, D.C. , World Bank and UNDP**:** 1-17.

Barnes, D. F. (2007). Meeting the Challenge of Rural Electrification. The Challenge of Rural Electrification. Washington, D.C., Resources for the Future**:** 313-327.

Barnett, A. (1990). "The diffusion of energy technology in the rural areas of developing countries: a synthesis of recent experience." World Development **18**(4): 539-553.

Bazilian, M., H. de Coninck, M. Radka, S. Nakhooda, W. Byd, I MacGill, R. Bradley (2008). Considering technology within the UN climate change negotiations. Amsterdam, Energy Research Centre of the Netherlands.

Bazilian, M., Patrick Nussbaumer, Erik Haites, Michael Levi, Mark Howells, and Kandeh K. Yumkella (2010). "Understanding the Scale of Investment for Universal Energy Access." Geopolitics of Energy **32**(10 & 11): 21-42.

Bazilian, M., Roger Pielke Jr. (2013). "Making Energy Access Meaningful." Issues in Science & Technology **29**(4).

Bhalla, M. S. (2000). Transmission and Distribution Losses (Power). National Conference on Regulation in infrastructure Services: progress and way forward, New Delhi, TERI.

Birol, F. (2011). Energy for All: Financing Access for the Poor. Paris, International Energy Agency.

BNEF (2016). Off-Grid Solar Market Trends Report 2016. Off-Grid Solar Market Trends Report. Washington, D.C. , Bloomberg New Energy Finance and the World Bank Group**:** 1-108.

Byrne, R., Smith, A., Watson, J. and Ockwell, D. (2011). Energy Pathways in Low-Carbon Development: From Technology Transfer to Socio-Technical Transformation. STEPS Working Paper 46. Brighton, STEPS Centre**:** 1-81.

Caine, M., Jason Lloyd, Max Luke, Lisa Margonelli, Todd Moss, Ted Nordhaus, Roger Pilke Jr., Mikael Roman, Joyashree Roy, Daniel Sarewitz, Michael Shellenberger, Kartikeya Singh, Alex Trembath (2014). Our High Energy Planet. A Climate Pragmatism Project. Washington, D.C., Breathrough Institute and Consortium for Science, Policy, & Outcomes**:** 1-28.

Caird, S., Roy, R., Herring, H. (2008). "Improving the energy performance of UK households: results from surveys of consumer adotpion and use of low- and zero-carbon technologies." Energy Efficiency **1**: 149-166.

Carrasco, L. M., L. Narvarte, E. Lorenzo (2013). "Operational costs of a 13,000 solar home systems rural electrification programme." Renewable and Sustainable Energy Review **20**: 1-7.

Casillas, C. E., and Daniel M. Kammen (2011). "The delivery of low-cost, low-carbon rural energy services." Energy Policy **39**: 4520-4528.

CEEW (2013). Developing Effective Networks for Energy Access: An Analysis. New Delhi, Council on Energy Environment & Water**:** 1-58.

Chaurey, A., et al. (2012). "New partnerships and business models for facilitating energy access." Energy Policy **47**: 48-55.

Chaurey, A., Tara Chandra Kandpal (2010). "Assessment and evaluation of PV based decentralized rural electrification." Renewable and Sustainable Energy Reviews **14**(8): 2266-2278.

Cust, J., Anoop Singh, Karsten Neuhoff (2007). Rural Electrification in India: Economic and Institutional aspects of Renewables. Cambridge, UK, Electricity Policy Research Group**:** 1-37.

Davidsen, A. a. K. P., Jarnail Singh, Jay Shiv, Paul Walker, Sarah Parrish, Subaskar Sitasabeshan (2015). The Business Case for Off-grid Energy in India. New Delhi, The Climate Group**:** 1-108.

Dehejia, V. (2012). The Cookstove Conundrum. The New York Times. New York.

Economist (2013) Out of the trees: A murderous attack highlights neglect in India's "outland". The Economist

EIA (2012). China Analysis. E. I. Administration. Washington, D.C. , Government of the United States of America**:** 1-27.

Forsyth, T. (2005). "Enhancing climate technology transfer through greater public-private cooperation: Lessons from Thailand and the Philippines." Natural Resources Forum **29**(2): 165-176.

Gallagher, K. S. (2014). The Globalization of Clean Energy Technology: Lessons from China. Cambridge, MA, MIT Press.

Gallagher, K. S., Arnulf Grubler, Laura Kuhl, Gregory F. Nemet, Charlie Wilson (2012). "The Energy Technology Innovation System." Annual Review of Environment and Resources **37**: 137-162.

Gallagher, K. S., John Holdren, and Ambuj Sagar (2006). "Energy technology innovation." Annual Review of Environment and Resources **31**(1): 193-237.

Gregory, M. (2006) India Struggles with Power Theft. BBC World News

Guay, J. (2012). The $90 Billion Opportunity In Crowd-funded Energy Access. Climate Progress. San Francisco, Think Progress. **2015**.

Guay, J. (2012) Eight19 and the Un-grid. What's with the Climate?

Gupta, P. (2015). Remittances to India - Resilient to Domestic and External Shocks. People Move: A blog about migration, remittances and development. Washington, D.C. , World Bank. **2015**.

Harish, S. M., et al. (2013). "Adoption of solar home lighting systems in India: What we might learn from Karnataka? ." Energy Policy **62**: 697-706.

Harish, S. M., Kaveri K. lychettira, Shuba V. Raghavan, Milind Kandlikar (2013). "Adoption of solar home lighting systems in India: What might we learn from Karnataka." Energy Policy.

Harish, S. M., Shuba Raghavan, Milind Kandlikar, Gireesh Shrimali (2013). "Assessing the impact of the transition to Light Emitting Diodes based solar lighting systems in India." Energy for Sustainable Development **17**: 363-370.

Harish, S. M., Subha V. Raghavan (2011). "Redesigning the national solar mission for rural India." Economic & Political Weekly **46**(23): 51-58.

Hilman, H., Jyoti Gidwani, Ellen Morris, Prem Sagar Subedi, Sonali Chwodhary (2007). Using Microfinance to Expand Access to Energy Services: The Emerging Experience in Asia of Self-Employed Women's Association Bank (SEWA), Sarvodaya Economic Enterpise Developent Services (SEEDS), Nirdhan Utthan Bank Limited (NUBL), and AMRET. T. S. Network. Washington, D.C., The Seep Network**:** 1-124.

Hosier, R. H., J. Dowd (1987). "Household Fuel Choice in Zimbabwe: An Emperical Test of the Energy Ladder Hypothesis." Resources and Energy **13**(9): 347-361.

IE (2015). Ration card fraud: HC notice to Center, Delhi government. The Indian Express. New Delhi.

IEA (2010). Energy Poverty: how to make modern energy access universal? World Energy Outlook 2010: Special Early Excerpt for UNGA Assembly on the MDGs. Paris, International Energy Agency.

IEA (2011). Energy for All: Financing Access for the Poor. World Energy Outlook. Paris, OECD/IEA**:** 1-52.

IEA (2015). India Energy Outlook. Paris, International Energy Agency**:** 1 - 191.

IRENA (2012). Renewable Energy Jobs & Access. Masdar City, UAE, International Renewable Energy Agency**:** 1-80.

IRENA (2015). Off-Grid Renewable Energy Systems: Status and Methodological Issues. Abu Dhabi, International Renewable Energy Agency**:** 1-36.

Joseph, K. L. (2010). "The politics of power: Electricity reform in India." Energy Policy **38**: 503-511.

Kamalapur, G. D., R.Y. Udaykumar (2011). "Rural electrification in India and feasibilty of photovoltaic solar home systems." International Journal of Electrical Power & Energy Systems **33**(3): 594-599.

Kammen, D. (2004). Renewable Energy, Taxonomic Overview. Encyclobedia of Energy. C. Cleveland, Elsevier**:** 385-412.

King, G., Robert O. Keohane, Sidney Verba (1994). Designing Social Inquiry: Scientific Inference in Qualitative Research. Princeton, Princeton University Press.

Kumar, A., et al. (2009). "Approach for standardization of off-grid electrification projects." Renewable and Sustainable Energy Reviews **13**(8): 1946-1956.

Lahimer, A. A., M.A. Alghoul, Fadhil Yousif, T.M. Razykov, N. Amin, K. Sopian (2013). "Research and development aspects on decentralized electrification options for rural household." Renewable and Sustainable Energy Reviews **24**: 314-324.

Lomborg, B. (2015). "Climate Aid Gone Wrong: A Case Study." Retrieved May 26, 2016, 2016, from http://www.huffingtonpost.com/bjorn-lomborg/climate-aid-gone-wrong-a_b_8747616.html.

Lopicich, B. (2015). Off-grd energy powered by the crowd. Sustainable Markets. London, International Institute for Environment and Development. **2015**.

Lovins, A. a. L. H. L. (1982). Brittle Power: Energy Strategy for National Security. Andover, MA, Brick House Publishing.

Lundvall, B.-A. (1992). National systems of Innovation: Towards a Theory of innovation and interactive learning. London, Pinter.

Martinot, E., A. Cabraal, S. Mathur (2001). "World Bank/GEF solar home system projects: experiences and lessons learned 1993-2000." Renewable and Sustainable Energy Reviews **5**: 39-57.

McEachern, M., Hanson, S. (2008). "Socio-geographic perception in the diffusion of innovation: solar energy technology in Sri Lanka." Energy Policy **36**: 2578-2590.

Meinshausen, M., Meinshausen, Nicolai, Hare, William, Raper, Sarah C.B., Frieler, Katja, Knutti, Reto, Frame, David J., Allen, Myles R. (2009). "Greenhouse-gas emission targets for limiting global warming to 2 degrees C. ." Nature **458**: 1158-1162.

Memmott, M. (2012) Massive Failure: 670 Million in India Lose Power; Grid Collapses for Second Day. NPR News

Mentzer, J., William DeWitt, James Keebler, Soonhong Min, Nancy W. Nix, Carlo D. Smith, Zach Zacharia (2001). "Defining Supply Chain Management " Journal of Supply Chain Management **22**(2): 1-25.

Min, B., Miriam Golden (2014). "Electoral cycles in electricity losses in India." Energy Policy **65**: 619-625.

MNRE (2010). Human Resource Development Strategies for Indian Renewable Energy Sector: Final Report. M. o. N. R. Energy. New Delhi, MNRE and CII**:** 1-66.

Modi, V. (2005). Improving Electricity Services in Rural India. CGSD Working Paper No. 30. CGSD. New York, Center on Globalization and Sustainable Development, Columbia University**:** 1-73.

Modi, V. (2005). Improving Electricity Services in Rural India. CGSD Working Paper No. 30. CGSD. New York Center on Globalization and Sustainable Development, Columbia University**:** 1-73.

Monroy, C. R., A.S.S. Hernandez (2008). "Strengthening financial innovation in energy supply projects for rural communities in developing countries " International Journal of Sustainable Development & World Ecology **15**: 471-483.

MOP (2006). Rural Electrification Policy. M. o. Power. New Dehli, Government of India**:** 1-17.

Navani, J. P., N. K. Sharma, Sonal Sapra (2012). "Technical and Non-Technical Losses in Power System and Its Economic Consequence in Indian Economy." International Journal of Electronics and Computer Science Engineering **1**(2): 5.

Nelson, R. (1993). National Innovation Systems: A Comparative Analysis. New York, NY, Oxford University Press.

Nique, M., Firas Arab (2013). Sustainable Energy & Water Access through M2M Connectivity. GSMA Mobile Enabled Community Services. GSMA, GSMA**:** 1-24.

Ockwell, D., Alexandra Mallett (2012). Introduction. Low-carbon Technology Transfer: From Rhetoric to Reality. Abingdon, Routledge**:** 3-19.

Phadke, Amol, Arne Jacobson, Won Young Park, Ga Rick Lee, Peter Alstone, Amit Khare (2015). "Powering a Home with Just 25 Watts of Solar PV: Super-Efficient Appliances Can Enable Expanded Off-Grid Energy Service Using Small Solar Power Systems." Berkeley, Lawrence Berkeley National Laboratory: 7 - 12.

Palit, D. (2013). "Solar energy programs for rural electrification: experiences and lessons from South Asia." Energy for Sustainable Development **17**(3): 270-279.

Palit, D., Akanksha Chaurey (2011). "Off-grid rural electrification experiences from South Asia: status and best practice." Energy for Sustainable Development **15**(3): 266-276.

Palit, D., Benjamin K. Sovacool, Christopher Cooper, David Zoppo, Jay Eidsness, Meredith Crafton, Katie Johnson, Shannon Clarke (2013). "The trials and tribulations of the Village Energy Security Programme (VESP)." Energy Policy Journal.

Palit, D., Benjamin Sovacool, Christopher Cooper, David Zoppo, Jay Eidsness, Meredith Crafton, Katie Johnson, Shannon Clarke (2013). "The trials and tribulations of the Village Energy Security Programme (VESP)." Energy Policy **57**: 407-417.

Paulsson, E. (2009). "A review of the CDM literature: From fine-tuning to scrutiny? ." International Environmental Agreements: Politics, Law and Economics **9**(1): 63-80.

Pode, R. (2013). "Financing LED solar home systems in developing countries." Renewable and Sustainable Energy Reviews **25**: 596-629.

Prahalad, C. K. (2010). The Fortune At the Bottom of the Pyramid: Eradicating Poverty Through Profits. Philadelphia, Wharton School Publishing.

Prahlad, C. K. (2010). The Fortune at the Bottom of the Pyramid. Upper Saddle River, New Jersey, Pearson Education, Inc.

Raman, P., et al. (2012). "Opportunities and challenges in setting up solar photovoltaic based micro grids for electrification in rural areas of India." Renewable and Sustainable Energy Reviews **16**(5): 3320-3325.

Ramirez, S., Puneet Dwivedi, Adrian Ghilardi, Robert Bailis (2014). "Diffusion of non-traditional cookstoves across western Honduras: A social network analysis." Energy Policy **66**: 379-389.

Ranganathan, M. (2003). "Participatory approach for linking rural energy transitions and developmental needs in Uttar Pradesh, India." Boiling Point: 15-17.

Rao, P. S. C., Miller, J.B., Wang, Y.D., Byrne, J.B. (2009). "Energy-microfinance intervention for below poverty line households in India." Energy Policy **37**: 1694-1712.

REC (2005). Guidelines for formulation of projects under Rajiv Gandhi Grameen Vidyutikaran Yojana: scheme for Rural Electricity Infrastructure & Household Electrification for grid sypply systems (Part B) for "Electrified Villages" in States with 100% village electrification level (P: RHhE - B). M. o. Power. New Delhi, REC**:** 1-77.

Reddy, A. K. N., B. S. Reddy (1994). "Substitution of Energy Carriers for Cooking in Bangalore." Energy **19**(5): 561-571.

Rogers, E. (2003). Diffusion of Innovations. New York, The Free Press.

Sagar, A., J. P. Holdren (2002). "Assessing the global energy innovation system: some key issues." Energy Policy **30**: 465-469.

Sanyal, S. (2014). "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.

Sathaye, J., O. Lucon, A. Rahman (2011). Renewable energy in the context of sustainable development. IPCC special report on renewable energy sources and climate change mitigation. R. P.-M. O. Edenhofer, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadnes, C. von Stechow. Cambridge, Cambridge Univeristy Press**:** 707-790.

Schumpeter, J. (1934). The Theory of Economic Development. Cambridge, MA, Harvard University Press.

Sechrest, L., Michelle Stewart, Timothy Stickle (1998). Factors Affecting the Adoption and Impact of CGIAR Innovations: A Synthesis of Findings. Washington, DC, CGIAR**:** 1-56.

Sife, A. S., Elizabeth Kiondo, and Joyce G. Lyimo-Macha (2010). "Contribution of Mobile Phones to Rural Livelihoods and Poverty Reduction in Morogoro Region, Tanzania." Electronic Journal on Information Systems in Developing Countries **42**(3): 1-15.

Singh, K. (2007). "In India's Sea of Darkness: An Unsustainable Island of Decentralized Energy Production." Consilience: The Journal of Sustainable Development **1**(1): 5.

Singh, K. (2011). "India's Emissions in a Climate Constrained World." Energy Policy Journal **39**(6): 3476-3482.

Singh, K. (2016). "Business innovation and diffusion of off-grid solar technologies in India." Energy for Sustainable Development **30**: 1-13.

Singh, M. K. (2015) NSSO: 73% of rural Bihar use kerosene for lighting. Times of India

Singh, R. K. (2013) NTPC Coal Imports said to Double on Shortage: Corporate India. Bloomberg News

Sovacool, B. (2012). "The political economy of energy poverty: A review of key challenges." Energy for Sustainable Development **16**(3): 272-282.

Suurs, R. A. A. (2009). Motors of Sustainable Innovation: Towards a theory on the dynamics of technological innovation systems. Utrecht, Utrecht University

Tawney, L., Mackay Miller, Morgan Bazilian (2013). "Innovation for sustainable energy from a pro-poor perspective." Climate Policy **15**(1): 146-162.

TCG (2015). The Business Case for Off-grid Energy in India. New Delhi, The Climate Group: 1-108.

Telegraph (2010). India has more mobile phones than toilets: UN Report. World News, India, The Telegraph.

Thakkar, M. a. S. J. (2014). Review of subsidy plan for off-grid solar applications. Economic Times. New Delhi, Times of India.

UN (2015). Investing for Energy Access: 2015 Directory of Investment and Funding Opportunities. UN Foundation, Washington, D.C.: 1-174.

UN (2015). Transforming our World: The 2030 Agenda for Sustainable Developent. New York, United Nations: 1-29.

Urban, F., Rene M.J. Benders, and Henri C. Moll (2009). "Energy for Rural India." Applied Energy **86**: S47-S57.

Urmee, T., David Harries (2009). "A survey of solar PV program implementers in Asia and the Pacific region." Energy for Sustainable Development **13**: 24-32.

Urpelainen, J., Semee Yoon (2015). "Solar home systems for rural India: Survey evidence on awareness and willingness to pay from Uttar Pradesh." Energy for Sustainable Development(24): 70-78.

Valente, T. W. (1996). "Social network thresholds in the diffusion of innovations." Social Networks **18**: 69-89.

Wasserman, S., Katherine Faust (1994). Social Network Analysis: Methods and Applications. New York, Cambridge University Press.

Wilson, C. (2009). Meta-analysis of unit and industry level scaling dynamics in energy technologies and climate change mitigation scenarios. . Interim Report. Laxenburg, Austria, IIASA: 1-119.

Wong, S. (2012). "Overcoming obstacles against effective solar lighting interventions in South Asia." Energy Policy **40**: 110-120.

WRI (2010). Power to the People: Investing in Clean Energy for the Base of the Pyramid in India. Washington, D.C., World Resources Institute, IFMR Research, New Ventures: 74.