HOUSEHOLD SOLAR ADOPTION: A SYSTEMATIC REVIEW

by

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Executive Summary

We face a substantial energy crisis with billions of humans lacking access to electricity and clean cooking options around the world. In these households, family members are exposed to poor air quality from burning fuels like kerosene for light or biomass for cooking needs. Furthermore, these behavioral choices cause environmental harms ranging from local forest degradation and air pollution to global warming.

Many organizations, international agencies, and private firms are currently involved in providing off-grid solar solutions to the energy access crisis. Unfortunately, development in this sector has been asymmetric and growth is seen in only a handful of countries worldwide. The 2016 Poor People's Energy Outlook notes that "governments and the international community still lack the tools and approaches necessary to deliver on this important objective"- ending energy poverty. This noted lack of information sharing forms the motivation for this systematic review. I identified a need to explore the complex factors surrounding distributed solar models to define efficient programs that accurately address the challenges to disseminating solar technology in rural, off-grid, low-income communities. I have conducted a systematic review to assess the documented enabling market factors on household adoption of solar products in off-grid settings.

The first section of this report outlines the process of conducting a systematic review of the peer-reviewed literature on off-grid solar technology in low- and middle-income countries. A systematic review is "based on a clearly formulated question, identifies relevant studies, appraises their quality and summarizes the evidence by use of explicit methodology". I outline the requirements for the systematic review process and the benefits of utilizing this framework in my project.

In the second section of this report, I describe my methods for working through the systematic review framework. I conducted a search in three journal databases, using a defined set of keywords to collect the articles that were included in this review. These articles were analyzed and kept for final analysis based on a series of inclusion and exclusion criteria.

I assessed the 43 remaining papers to determine their defining enabling environment characteristics. Of the final set of papers, 32 covered solar home systems, 6 mentioned solar hot water heaters, 3 discussed solar cookers, and 4 covered solar lanterns. The majority of papers discussed a fee-for-service and energy service company (ESCO) model. Seven papers noted a household form of ownership and the remaining papers mentioned a variety of these options. The country locations vary widely with 6 from India, 5 from China, 4 from Bangladesh and South Africa, 3 from Papua New Guinea, and many others

including Argentina, Botswana, Burkina Faso, East Timor, El Salvador, Fiji, Ghana, Greece, Kenya, Laos, Lebanon, Lesotho, Malawi, Mongolia, Morocco, Nepal, Philippines, Sri Lanka, and Zambia. Of the total papers, 85% of them were published since 2010.

Finally, I reviewed the selected enabling environment factors within each paper and analyze the themes found. I highlight the factors within three groupings that are found to be critical to the success of off-grid solar projects. At the household level, the cost of technology and quality of a product have the potential to greatly impact the success of a program. Customer support and ongoing maintenance increase the initiative's sustainability and impact as customers continue using solar technologies in their daily lives. For programs, trainings and financing mechanisms provide customers with new platforms to address their energy needs and maintain agency over their household purchasing choices. Finally, regional market growth is encouraged when governments facilitate product testing and high quality standards.

This complex and interconnected system of factors can either drive increases in households transitioning from harmful fuel usage to renewable energy or discourage communities from adopting the equipment under consideration. The themes listed throughout the report are important criteria to individually address but they are also part of a potentially enabling environment. In individual studies, programs did not succeed or fail because of any one particular factor. Each of these topics should be addressed in future planning with an understanding of the complex and varied enabling environment network. Addressed together and with location-specific cultural contexts in mind, these factors may increase the ability of projects to overcome energy poverty using off-grid solar.

Introduction

We face a substantial energy crisis with billions of humans lacking access to electricity and clean cooking options around the world. In these households, family members are exposed to poor air quality from burning fuels like kerosene for light or biomass for cooking needs (Jeuland & Pattanayak, 2012). The astounding scope of the global energy poverty challenge has motivated many organizations to provide solar energy solutions to lighting, heating, and cooking needs in off-grid settings. However, poorly designed or executed projects can potentially harm communities lacking access to reliable energy. This review aims to identify and analyze the enabling environment scenarios that lead to adoption of small-scale solar systems in a household setting.

The market for off-grid solar products as solutions to this crisis is growing (Lighting Global, 2016). Around the world, certain products are considered "mainstream" and "highly effective for enabling access to basic electricity services" (Lighting Global, 2016). However, the market development has been asymmetric and the boom is seen in only a handful of countries worldwide (Lighting Global, 2016). Experts at Practical Action conclude that "governments and the international community still lack the tools and approaches necessary to deliver on this important objective"- ending energy poverty (Practical Action, 2016). Even with dropping technology costs and an increased focus on the sector, "current approaches do not meaningfully consider the realities of energy-poor people or the technologies most suited to addressing their needs" (Practical Action, 2016).

There are many articles, reports, and reviews that discuss energy access, improved cookstoves, biogas, electrification, and solar solutions for households. However, these sources tend to focus on improvements to the physical technology and software, feasibility studies of implementing technical solutions in low-income countries, specific projects or locations, or large-scale electrification programs (Sovacool, 2014). The decision by households to adopt a new technology and for firms and NGOs to promote the same technology are influenced by a complex array of factors, especially given the uncertainties associated with new technologies (Pattanayak & Pfaff, 2009; Lewis et al., 2015). The adoption and diffusion of such "renewable" technologies depend on institutions, incentives, and behaviors, yet we have little or no systematic evidence on implementation successes on the ground (Pattanayak et al., 2016). As discussed in environmental health literature, a combination of political will, community involvement, shared responsibility at national and local levels of government, and a balance between public and private sector actors provide a fertile enabling environment for impactful interventions (World Bank, 2008). Given the multitude of ongoing projects, agencies, and private

businesses implementing solar models to reduce energy poverty, there is a great need to explore what leads to a successful program.

Thus, the goal of my project is to identify features of programs that accurately address the challenges to disseminating solar technology in rural, off-grid, low-income communities. A strong understanding of the complex factors surrounding distributed solar models would lead to more efficient programs that accurately address the fiscal challenges to disseminating solar technology in rural, off-grid, or low-income communities. Following recent systematic reviews for household cooking behaviors (Lewis and Pattanayak, 2012; Puzzolo et al., 2016), I systematically reviewed the enabling factors on household adoption of solar products in off-grid rural, low-income settings. Specifically, the enabling environment in this study includes themes such as financing, market development, program structure, and technology standards.

Theoretical Framework

This systematic review seeks to answer the following research questions:

1) How do the identified enabling environment factors interact within the context of solar energy programs to influence household-level solar adoption in low-income countries?

2) What lessons can be learned from the literature for scaling-up solar programs?

In his article on barriers to renewable power in the US, Sovacool (2009) outlines the concept of socio-technical systems- "a term that encompasses the technological, social, political, regulatory, and cultural aspects of electricity supply and use." In a recent paper, Sovacool et al. (2011a) applied this thinking to Papua New Guinea and solar energy. His theory "argues that for any energy technology to succeed-that is, to be accepted by consumers- a 'seamless web' of factors must be aligned" (Sovacool et al., 2011a).

Lewis and Pattanayak (2012) conducted a systematic review of drivers of household adoption of clean cooking solutions by specifically examining the role of market prices, socio-economics, and socio-demographics. More recently, Puzzolo et al. (2016) conducted an exhaustive systematic review on the adoption of clean fuels in a household setting and specifically focused on an outlined web of factors in their research. These reviews influenced my decision to consider the entire enabling environment. This complex web of factors has recently been depicted in Rosenthal et al. (2017). I have adapted their framework to fit the off-grid solar environment, as shown in Figure 1.

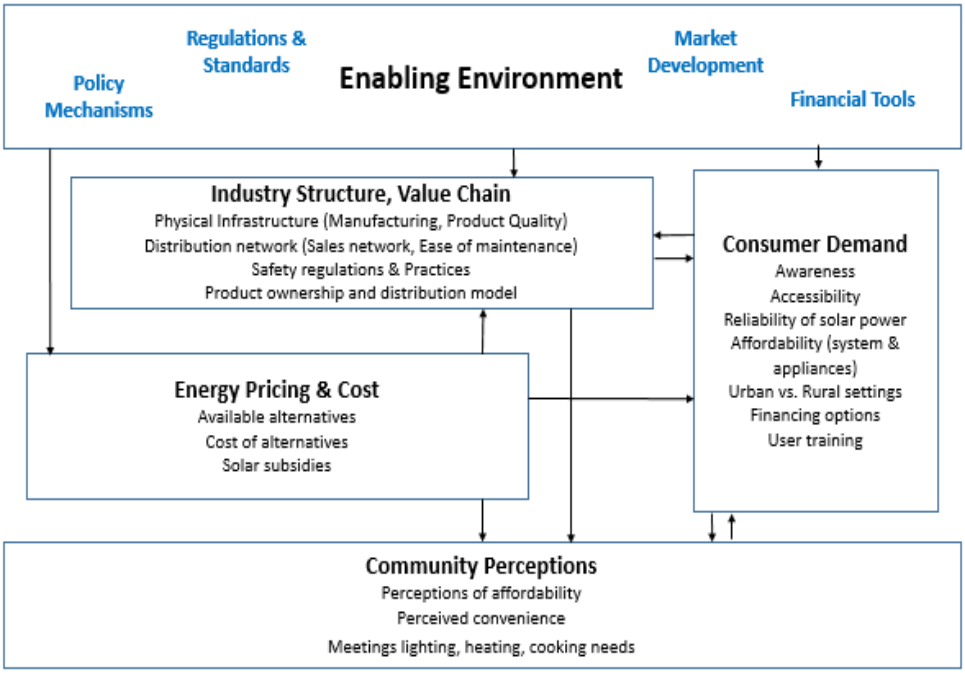

Figure 1 – Solar Product Adoption Concept Model

Systematic Review

To address these research questions, I completed a systematic review of the selected existing literature on solar energy in low- and middle-income countries. A systematic review is "based on a clearly formulated question, identifies relevant studies, appraises their quality and summarizes the evidence by use of explicit methodology" (Khan et al., 2003). In an international development context, Snilstveit et al. (2012) suggest a move from the tradition of asking 'what works' in a "narrow and 'rigid'" manner. Instead, they suggest a need to "utilize existing research and support the development of evidence-informed policies…[synthesizing] evidence across a broad range of questions asked by policy-makers and practitioners in the field" (Snilstveit et al., 2012). This concept is applied to the off-grid solar sector in this systematic review process.

Khan, et al. (2003) describe the review process as having five steps:

(1) framing questions for a review,

(2) identifying relevant work,

(3) assessing the quality of studies,

(4) summarizing the evidence, and

(5) interpreting the findings.

This review utilizes all five components to assess current literature on off-grid solar solutions in the

developing world. Each step is outlined in sections below and was given careful consideration and planning. The research scope was outlined to identify relevant, peer-reviewed works that cover a multitude of aspects surrounding the off-grid solar context. Relevant work was collected through a series of searches in Econ Lit, Web of Science, and PAIS International. Further, these works were carefully coded and selected based on title and abstract readings in EndNote. The quality of the studies was assessed using a constructed priority survey. Finally, the evidence from the final 43 articles was summarized, using a coding matrix in Excel and interpreted in this Masters Project.

Methods

Scope of Review

The main scope of this review centers on solar technology employed in an off-grid setting. To provide a snapshot of global solar uses, I have chosen to examine solar home systems, solar lanterns, solar hot water heaters, and solar cooking products. Solar home systems include products with a panel, 1-5 light bulbs, a battery, charge controller, and potentially a radio or TV. Solar lanterns are much smaller products that simply charge one light bulb for mobile use. Solar hot water heaters capture heat from the sun and pass it on to water for household consumption. These are typically used in households as alternatives to electric or gas water heaters. Solar cooking utilizes a similar principle to reflect direct sunlight to a cooking vessel.

This systematic review focuses on the off-grid, household setting in low-income countries. This particular scope allows me to analyze a specific type of development outcome that has been sought by multiple agencies and businesses- bringing electricity to poor households that have yet to receive grid-level electrical connections. In examining this setting, I have excluded a number of article types and program evaluations based on their fit within the scope outlined below. Additional research with alternative scopes could provide different understandings of an enabling environment.

The most critical piece of this review concerns the off-grid specification. Households that do not have a grid connection to meet their electricity needs have the most to gain from appropriate and thoughtful solar development initiatives. In these settings, households are also typically low-income and have a multitude of concurrent needs. A stable, consistent supply of energy could fulfill basic lighting, heating, and cooking needs for a family. To better understand the challenges that face implementers seeking to bring solar energy to these communities, articles that mention off-grid locations or villages technically served by a grid but with less-than adequate power supply have been included in this review. For the

solar hot water heating section, a household may choose to opt out of grid electricity for hot water heating solutions only. In this case, previous connection to the grid will not exclude an article from being included in this review.

Because the choice to adopt each mentioned technology tends to occur at a household or individual level, articles that did not focus on this particular level of operation were excluded from the study. This review does not include commercial business solar installations, programs that deal directly with schools, or any other non-household entity.

Articles had to meet all of the above criteria and provide further comment on adoption and the general success of a program or initiative to be included in the study. Included papers have a robust discussion of efforts led by a government entity, nonprofit organization, for-profit business, or any other agent to increase the availability of solar technology in a given area. In a majority of the final 49 papers, this discussion included a sample population, description of the program and the connectivity of the community, challenges to successful implementation of the program, and indicators that led to successful technology adoption.

Finally, all papers must be peer-reviewed to be included in this process. By selecting three journal databases, I have limited the amount of grey literature papers that will be returned in the search process.

Table 1 – Inclusion and Exclusion Criteria

Inclusion Criteria	Type and scale of intervention: All analyses of solar dissemination in a large scale, household setting will be included in this review. Medium-scale regional interventions and national-scale policy interventions as well as smaller case studies, if representative of larger programs, will be included as well.
	Type of intervention setting: Interventions that take place in low- and middle-income countries, or resource-poor areas of other countries, as defined by the World Bank (2017), will be included in this review.
	Type of studies: Case studies and policy analyses that examine a suitable environment for solar adoption only if (i) based on empirical evidence and (ii) include enough description of solar financing, market context, regulations, policy and/or programmatic features.
	Type of study outcomes: Studies included in this review will also measure and report on relevant outcomes on the positive, negative, or neutral effects of the enabling environment for solar adoption.
Exclusion Criteria	Studies that focus on solar installations for commercial or industrial use, e.g. hospitals, schools, solar water pumps, etc.
	Studies superficially reporting on experience from several countries, with lack of in-depth analysis and poor description of the wider solar context

Methods & Search

To determine the relevant articles to include in this review, I selected three databases to search- EconLit, Web of Science, and PAIS International. Each database pulls from a large number of peer-reviewed journals. These three were chosen to reflect environmental economic studies, technical science analyses, and international papers that might not have been included in the first two search engines. I consulted with a library staff member as well as seasoned systematic reviewers at Duke and academic research colleagues to determine the appropriate databases.

I developed a list of search terms to narrow the returned results in each database. A complete list of the syntax can be found in Table 2. Terms were grouped to ensure that papers meeting the above scope requirements would be returned. Extensive testing was performed to identify the appropriate terms and groups in each database. The search terms include topics like "micro grid" which were added to be as inclusive as possible at this stage in the review. The search only covered years since 2000 and was conducted in 2016. An update was performed in January 2017 to capture any new papers published since the original search.

Table 2 – Search Terms

SOLAR ENERGY	solar* OR "micro-grid*" OR microgrid* OR "micro grid" OR "off grid electri*" OR "off grid generat*" OR off-grid
and SETTING	house* OR home* OR domestic OR residential
and USE	cook* OR cookstov* OR stove* OR heat* OR light* OR electric* OR electrif* OR "rural electrification"
and LANGUAGE	English
And TIME	2000-2017

The search was conducted and all returned results were imported into EndNote for further processing. In total, 5,454 papers were found in the three databases. Almost 200 papers were immediately excluded as duplicates within the original grouping. Web of Science returned the largest group of non-duplicate papers totaling 5,207. PAIS international returned 138 articles. Finally, EconLit found 109 articles.

Within the EndNote software, I separated the 5,454 papers into categories for record keeping. Papers that met all criteria in a scan of the title and abstract were placed in a folder for further review. Any article that did not discuss the appropriate technology, did not cover a household setting, or took place in a high-income country was placed in a separate folder. An additional 4,558 articles were excluded based on an inappropriate topic fit. Next, 566 papers were excluded for taking place in a country outside of the review's scope. Finally, 57 papers were discarded based on their coverage of household

applications for the solar products. This process concluded with 286 articles set aside for a full review. The full exclusion decision tree can be found in Figure 2.

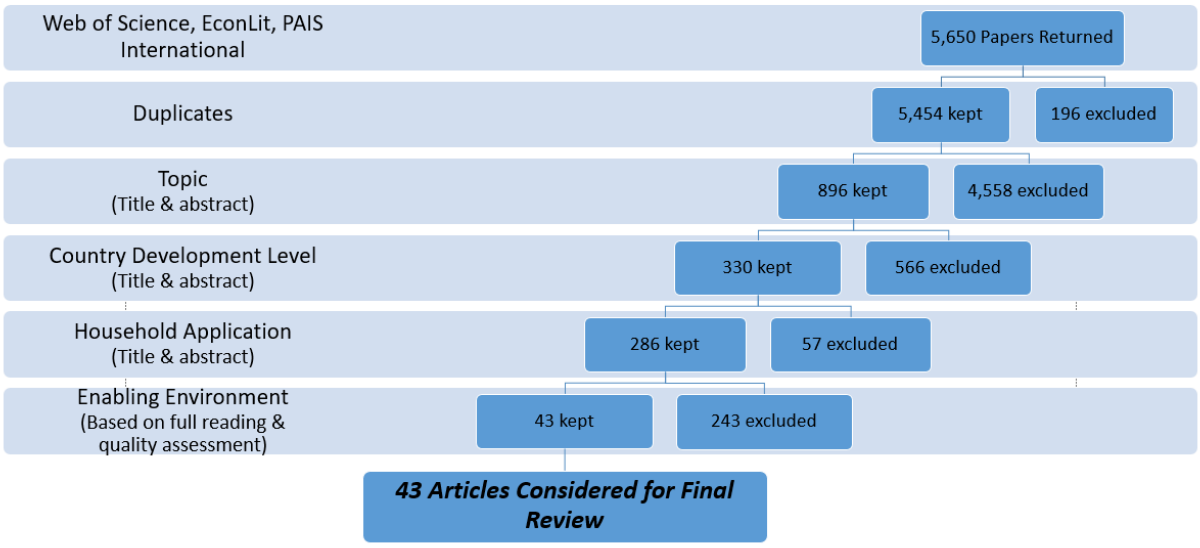

Figure 2 – Decision Tree

The remaining 286 articles were imported into an Excel worksheet for final review. I, with the help of a graduate assistant, read each paper and coded relevant works using an enabling environment matrix. The outline of the coding categories can be found in Table 3. Each paper was assessed first for relevance and 237 papers were eliminated at this stage. As reviewers, we then moved on to detailing study characteristics including country location, type of project, implementing agency, number of households served, and type of technology studied for the remaining 49 papers. Finally, each paper was coded based on mentions of each enabling environment factor. The quality of the information for each category as the paper's claim of importance was noted for each factor. This information was logged within the Excel matrix for the final 49 articles.

Table 3 – Coding Matrix Structure

Characteristics	Intervention Technology	Financial	Market Development	Program	Regulations
Author Name	Intervention Technology	Tariffs/Taxes	Product Quality	Community Involvement	Design Standards
Year Published	Implementing Entity	Pay As You Go	Supply Chain	Competition	Product Testing
Title	Cost of Implementation	Loan	Replacement Parts	Construction	Regulatory Policy
Relevance	Baseline Fuels	Banking Infrastructure	Geography/Infrastructure	Installation Training	Price Volatility
Quality Check	Ownership Structure	Mobile Money	Transportation	User Training	Material Procurement
Country		Financial Literacy	Distribution Network	Customer Support	Penalties for Non-compliance
Region		Cost to User	Demand Creation	Maintenance and Quality Control	
Target Population		Financing Option	Marketing Strategy	Government Support	
Duration of Program		Cost of Alternatives	Peer Influence		
Scale of Program		Flexible Pricing			
Urban or Rural					
Number of Participants					
Collection Methodology					

Quality Assurance

The final 49 papers were analyzed using a quality appraisal tool developed by Atkins and Sampson (2002) and adapted from Puzzolo et al. (2016). This questionnaire can be found in Appendix 2. During this phase, 6 papers were found to have covered the inclusion criteria but did not adequately discuss results of descriptions of the study setting. The results of a full review of the final 43 papers are included in the sections below.

Results

Country

The 43 papers included in the final review span a large variety of countries. India has the largest representation in this grouping with 6 papers mentioning solar energy programs within the nation. Five papers set in China are represented in this review. Following with 4 mentions each are South Africa and Bangladesh. Papua New Guinea is discussed in two papers. Articles covering a global scope, as well as

those set in Argentina, Fiji, Kenya, Mongolia, and Sri Lanka are each represented twice in this group. Finally, Botswana, Burkina Faso, East Timor, El Salvador, Ghana, Greece, Laos, Lebanon, Lesotho, Malawi, Morocco, Nepal, Philippines, and Zambia are all mentioned once in the 43 selected papers.

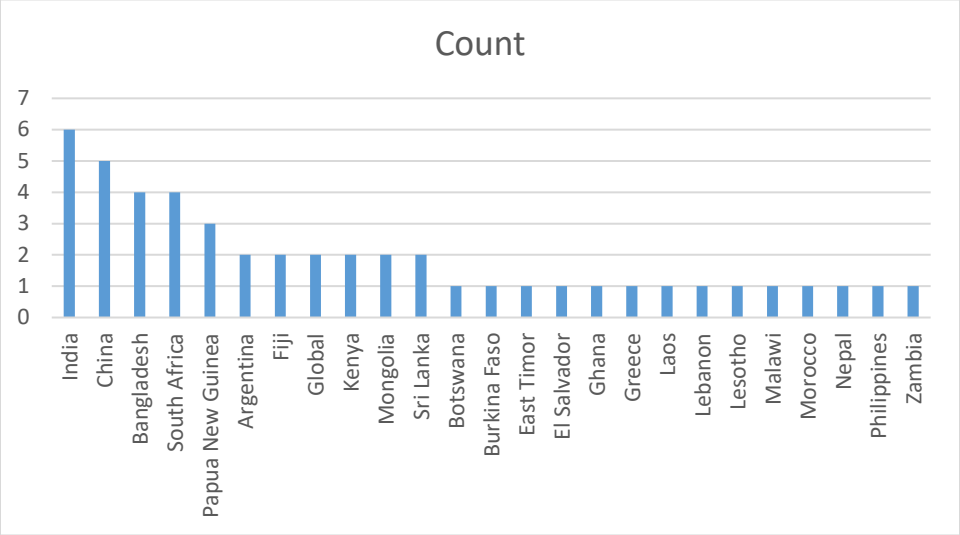

Figure 3 – Count of Papers by Country

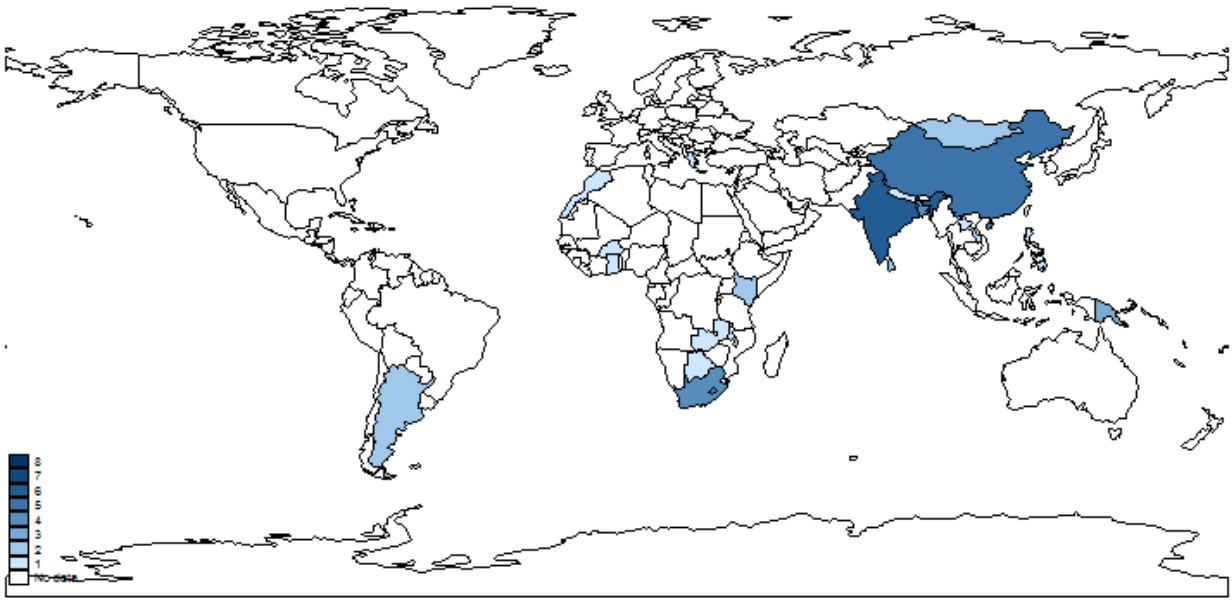

Figure 4 – Count of Papers by Country

Technology

The grouping of technologies discussed is much less diverse in the selected articles. Programs utilizing solar home systems make up a large majority of cases studied in this review. They were the main topic

in 32 articles. Solar hot water heaters were covered in 6 articles that met the inclusion criteria. Cooking products utilizing solar resources were studied in 3 settings and lanterns were mentioned in 2 articles.

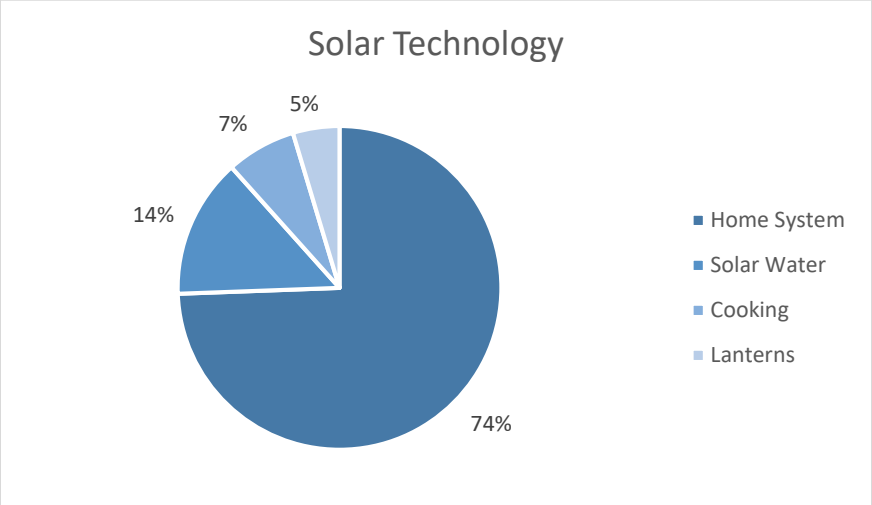

Figure 5 – Count of Papers by Technology

Ownership Model

A variety of ownership models were studied in the papers collected for this systematic review. The majority examined initiatives that utilized a fee-for-service model. In this scenario, an entity manages and maintains the solar product and a household pays a monthly fee for usage of the product. Typically, these papers discuss solar home systems within an energy service company (ESCO) model. In a handful of situations, a government body owns the physical products but provides companies with concessions to manage a service territory and facilitate the distribution of the solar panels.

Nine studies discussed scenarios where households purchase a solar product and maintain complete ownership over the product. Often, a financial body will retain the ability to claim the product until an initial loan is paid. However, the end goal is for the household fully own the product at some point in time. A small number of studies covered a variety of ownership and distribution models within one paper.

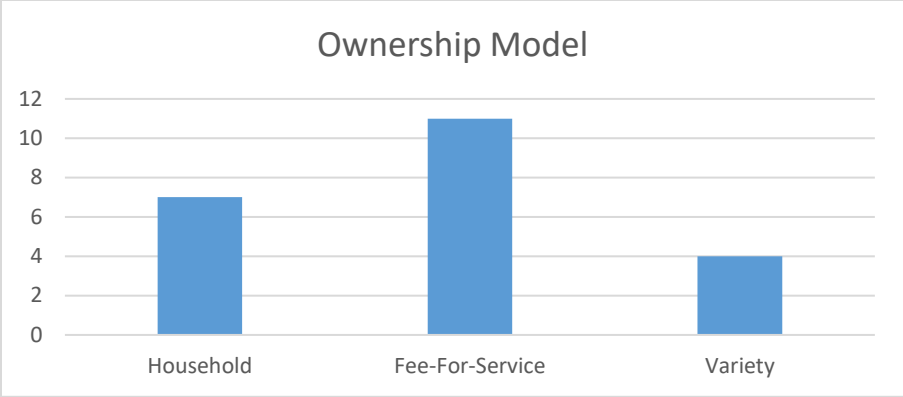

Figure 6 – Count of Papers by Ownership Model

Year Published

This review spanned 17 years to capture relevant and recent information published in peer-reviewed sources. The majority of articles selected for final review fall in the second half of the selected inclusion timeframe.

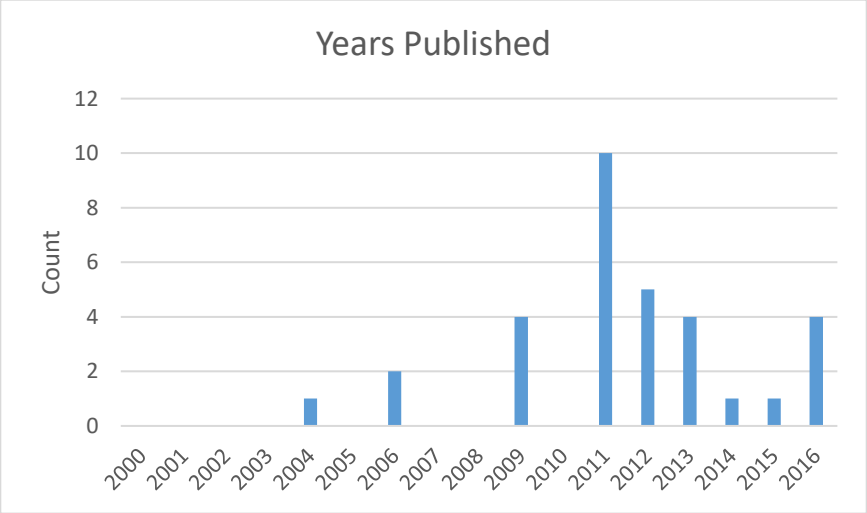

Figure 7 – Count of Papers by Year Published

Findings

In Table 6, I have identified the general breakdown of the topics covered in each paper selected for final review. The themes were identified throughout the coding process in Excel and noted as either drivers or barriers. In some cases, notes were made for topics mentioned in an initiative description but not given weight as a theme that influenced the outcome of the program. These are not shown in Table 6. An example of this situation was found in Azimoh (2015) where the comment of the high rate of solar panel theft was noted in a South African case study. However, the author made no claim that this

incidence impacted community perceptions of the systems or influenced the overall strength of the program and therefore was not included.

In the following sections, I have chosen to describe themes that appeared more than 5 times in the coding matrix and were categorized broadly as either a driver or a barrier to the success of a project.

Table 6 – Themes Mentioned by Paper

Author(s)	Year Published	Country	Financial	Market	Program	Regulation
Adkins, E., et al.	2010	Malawi	X		X	
Alazraki, R. and J. Haselip	2007	Argentina	X		X	
Azimoh, C. L., et al.	2015	South Africa				
Azimoh, C. L., et al.	2014	South Africa	X		X	
Balint, P. J.	2006	El Salvador		X	X	
Bawakyillenuo, S.	2009	Ghana		X	X	
Bikam, P. and D. J. Mulaudzi	2006	South Africa	X	X	X	
Bond, M., et al.	2010	East Timor		X	X	
Borah, R. R., et al.	2014	India		X	X	
Brooks, C. and T. Urmee	2014	Philippines			X	
Chowdhury, S. A., et al.	2011	Bangladesh			X	
D'Agostino, A. L., et al.	2011	China	X		X	X
Diaz, P., et al.	2013	Argentina				
Dornan, M.	2011	Fiji			X	
Harish, S. M., et al.	2013	India	X			
Hu, R. Q., et al.	2012	China				X
Ketlogetswe, C. and T. H. Mothudi	2009	Botswana	X			
Laufer, D. and M. Schafer	2011	Sri Lanka	X		X	
Lemaire, X.	2009	Zambia	X		X	
Lemaire, X.	2011	South Africa	X	X	X	
Li, W., et al.	2011	China		X	X	
Nygaard, I. and T. Dafrallah	2016	Morocco		X		
Opiyo, N.	2016	Kenya	X	X	X	
Palit, D.	2013	India, Bangladesh, Nepal, Sri Lanka			X	
Pohekar, S. D. and M. Ramachandran	2006	India				
Puzzolo, E., et al.	2016	Global	X	X	X	
Rolffs, P., et al.	2015	Kenya	X		X	
Ruble, I. and P. El Khoury	2013	Lebanon	X			
Sidiras, D. K. and E. G. Koukios	2004	Greece	X		X	
Sovacool, B. K.	2013	Papua New Guinea	X	X	X	
Sovacool, B. K. and A. L. D'Agostino	2012	China, Laos, Mongolia, Papua New Guinea	X	X	X	X
Sovacool, B. K., et al.	2011	Mongolia	X	X	X	X
Sovacool, B. K., et al.	2011	Papua New Guinea	X	X	X	
Sovacool, B. K. and I. M. Drupady	2011	Bangladesh	X	X	X	
Srinivas, M.	2011	India	X		X	X
Taele, B. M., et al.	2012	Lesotho		X	X	
Toonen, H. M.	2009	Burkina Faso		X	X	
Urmee, T. and D. Harries	2009	South Asia	X	X	X	
Urmee, T. and D. Harries	2011	Bangladesh	X	X	X	
Urmee, T. and D. Harries	2012	Fiji		X	X	
Xie, H., et al.	2012	China			X	
Yoon, S., et al.	2016	India	X	X		
Zhang, F.	2014	Global	X	X	X	X

Financial Themes

Cost to User

The overall cost of a system was consistently cited as a barrier to widespread household adoption of solar products across the world. The general challenge of solar home systems, hot water heaters, and cooking products being too costly for low-income households is well documented in this selection (Harish et al., 2013; Opiyo, 2016; Puzzolo et al., 2016; Ruble & Khoury, 2013; Sidiras & Koukios, 2004; Sovacool et al., 2011a; Sovacool et al., 2011b; Sovacool et al., 2011c; Sovacool & D'Agostino, 2012; Sovacool, 2013; Srinivas, 2011; Urmee & Harries, 2011; Yoon et al., 2016; Zhang, 2014). Programs might have originally been successful, as in Bangladesh (Urmee & Harries, 2011), but increasing costs over years added challenges to continue reaching rural, low-income populations. In Mongolia, systems could end up costing what amounted to roughly half a family's annual income even after government subsidies were included (Sovacool et al., 2011b). Opiyo (2016) noted a relatively affordable price tag when comparing costs to electric grid connections, but for the lowest income residents in Kenya, this technology was still out of reach. Harish et al. (2013) told a similar story for families in Karnataka, India. Even after households registered for the ESCO system in Botswana, there was a noted high level of small systems being repossessed for failing to pay monthly fees (Ketlogetswe & Mothudi, 2009).

Within the ESCO model of ownership, high costs were also prohibitive for low-income households. In many cases, the monthly payment structure allowed a household to purchase energy in small amounts and in theory opened the system to more households. However, low-income homes also had challenges in affording the monthly fees. Even after households registered for the ESCO system in Botswana, there was a noted level of small systems being repossessed for failing to pay monthly fees (Ketlogetswe & Mothudi, 2009). In South Africa, customers were not made aware of potential ongoing administration fees and there was no agreement on payment schedules (Bikam & Mulaudzi, 2006). This confusion led to the abandonment of a maintenance program and the eventual grounding of the project (Bikam & Mulaudzi, 2006). In another account of South Africa's rural electrification programs, the subsidy provided to households was discontinued and led to a poor rate of payment from lower income households (Azimoh et al., 2015).

Banking Infrastructure

The discussion around banking infrastructure was varied in the reviewed articles. Projects reported success when partnerships with banking institutions were fully incorporated and utilized in the

processes (Adkins et al., 2010; Urmee & Harries, 2011; Sovacool & D'Agostino, 2012). In Malawi and Bangladesh, joining forces with a microfinance institution led to successful group lending practices and a move away from cash sales (Adkins et al., 2010; Urmee & Harries, 2011). During Mongolia's solar home system program, a partnership with local banks allowed seasonal workers flexibility in their loan packages and gave necessary flexibility for repayment (Sovacool & D'Agostino, 2012). The rural presence of institutions was mentioned as a driver in India's Karnataka state (Harish et al., 2013).

On the other hand, the necessity of cooperative, rural financial institutions can a because of challenges in a solar dissemination program. Because they were critical to adoption in India, Harish et al. (2013) notes that these institutions remain a bottleneck for programs. Microfinance institutions, typically more adept at serving low-income customers, were excluded from the financing selection process in Papua New Guinea's solar home program for teachers. The bank that was chosen did not fit the local community's need and became a barrier to the success of the program (Sovacool, 2013). In Papua New Guinea, a lack of formal financial infrastructure added to the program's challenges and emphasized a national trend of barriers to financial inclusion (Sovacool et al., 2011).

Financing Option & Loan Structure

Similar to the discussion regarding costs of products and the banking institutions that facilitate loan agreements, the option to finance a product was mentioned often in the included studies. However a low number of articles noted a positive association with a financing scheme (Harish et al., 2013; Palit, 2013; Puzzolo et al., 2016; Urmee & Harries, 2011). Palit's (2013) survey of South Asian solar PV electrification programs notes the role of financial innovation as one of the "main factors that assisted in higher penetration of solar PV technology to enhance rural electricity access." Solar cooking products were determined to be "too costly" without a financing option in articles examined in Puzzolo, et al. (2016). Specifically in the context of Indian solar cooking programs, the introduction of subsidies was found to "enhance" adoption and sustained use of cookers (Puzzolo et al., 2016). In India, Harish et al. (2013) noted the significant role played by the banks as most households procured a loan to purchase their products. Lebanon's solar water heater program allowed the Lebanese Central Bank to provide solar loans without interest for multiple renewable energy and energy efficiency technologies, leading commercial banks to consider thousands of applications in this program (Ruble & Khoury, 2013). This financing procedure "boosted market development." Urmee & Harries (2011) noted that microfinance was "recognized as the fundamental strength of the Bangladeshi SHS program and what has made it unique."

A greater number of studies mention financing options that did not serve their purpose of easing the fiscal burden for low-income customers (Bikam & Mulaudzi, 2006; Ketlogetswe & Mothudi, 2009; Rolffs et al., 2015; Sidiras & Koukios, 2004; Sovacool 2013; Urmee & Harries, 2009). In South Africa, households participating in the PV pilot were not unaware of the recurring payment schedule and had difficulty maintaining the fees required for their systems (Bikam & Mulaudzi, 2006). The agricultural landscape and economic realities for households in a Botswanan rural electrification project presented a challenge to the implemented fee-for-service model (Ketlogetswe & Mothudi, 2009). Rural residents "were not willing to make payment[s]" during the seasonal times they were tending to land and cattle (Ketlogetswe & Mothudi, 2009). In Papua New Guinea, the selected financing system was ill-fitted to support the teaching staff customers and plagued by poor capacity generally (Sovacool & D'Agostino, 2012). A complicated loan structure bridging the financial institution's norms and the project guidelines created confusion about the timeline of the project and individuals' loan responsibilities (Sovacool, 2013). The lack of "suitable financing" for customers was seen as a critical barrier in the adoption of solar systems in a survey of South Asian program implementers (Urmee & Harries, 2009). Similarly, Zhang (2014) found the lack of financing as a barrier for low-income households wishing to purchase solar technology. High interest rates in microfinance projects were said to have been a barrier to reaching rural populations in Kenya (Rolffs et al., 2015). In the Greek solar water heater context, surveyed households noted the availability of loans but described the long payback period for the product as a barrier to their purchase (Sidiras & Koukios, 2004).

Market Themes

Product Quality & Offerings

A general lack of quality products influenced a number of studies set in low- and middle-income countries. In Papua New Guinea, Sovacool et al. (2011) highlighted a challenge in procuring high quality solar home systems for the rural electrification program. Similarly, in Bangladesh, Urmee & Harries (2011) commented on the low quality of the components. In Sri Lanka, household batteries quickly wore out and individuals were only supplied with used products until the end of the warranty period (Laufer & Schafer, 2011). In the first few years of the program, Bond et al. (2010) highlighted the "significant" number of systems that ceased to supply energy to households. The perception of quality, when compared to grid-level electricity, impacted the success of a solar home system initiative in Morocco as communities saw this as a second-best option (Nygaard & Dafrallah, 2016).

In a collection of articles covering solar cooking initiatives, the barriers to success fell in a technical realm (Puzzolo et al., 2016). Solar cookers were too heavy, took too long to make meals, and had poor packaging (Puzzolo et al., 2016). A similar frustration with the technical capabilities was documented in Burkina Faso (Toonen, 2009).

In a large majority of studies, inappropriate uses, rather than quality, led to a great number of failures. Out of 43 papers, almost half distinctly mentioned battery and charge failure due to overuse, incorrect use, or improperly-sized systems. These technical shortcomings were a result of poorly defined community needs, low-quality products, or a lack of user training and impacted customer perceptions of the quality of solar energy. For a variety of reasons, households did not understand the load requirements of their system and would add higher wattage bulbs, run a T.V. and other appliances at once, or would bypass the charge controller altogether (Azimoh et al., 2014; Diaz et al., 2013; Lemaire, 2011; Sovacool et al., 2011A; Stone; Urmee & Harries, 2011; Urmee & Harries, 2012). Any of these actions led to a system failure or a depletion of the components that diminished the power delivered to households.

In the Zambia ESCO model, only one size of system was offered to households- a challenge for those wanting more power or those seeking lower prices (Lemaire, 2009). Urmee & Harries (2012) report a similar customer frustration in Fiji's ESCO initiative.

In El Salvador and Mongolia, the quality of products offered to households was noted as a driver and benefit of solar home system dissemination models (Balint, 2006; Sovacool & D'Agostino, 2012). In Mongolia, this program was credited with pushing more companies to join the solar market (Sovacool & D'Agostino, 2012. El Salvador's project was unique due to the supply of solar panels to households in exchange for supporting local environmental protection efforts near a national park (Balint, 2006).

Lack of Replacement

An additional barrier to the market development of off-grid solar products is often the lack of product replacements when pieces of a system fail. In Ghana, Fiji, Sri Lanka, and across Southeast Asia, there was a noticeable lack of mechanics able to service solar energy products (Bawakyillenuo, 2009; Bikam & Mulaudzi, 2006; Dornan, 2011; Laufer & Schafer, 2011; Urmee & Harries, 2009). In Ghana, the promised mechanics were not available after installation (Bawakyillenuo, 2009). South Africa's solar home system trial faced a host of other issues which eventually led to nonpayment of the fees that were allotted to cover maintenance (Bikam & Mulaudzi, 2006). Without promise of payment, mechanics discontinued

their services (Bikam & Mulaudzi, 2006). Fiji's solar home system customers waited long periods before replacements were offered to households (Dornan, 2011) and the article summarizing Sri Lanka's experience noted a lack of local repair services for rural areas (Laufer & Schafer, 2011). From the cooking perspective, low demand for products caused a shortage of stock parts in studied areas (Puzzolo et al., 2016). The lack of replacement parts and ongoing maintenance challenges coincide with a lack of customer support and training seen in programmatic themes.

Marketing & Promotion Strategy

The strategies utilized in solar dissemination programs varied across mentioned case studies. In Greece, customers surveyed regarding their perception of the market noted quality of life, self-sufficiency, and overall comfort in their decision to purchase solar hot water heaters (Sidiras & Koukios, 2004). For solar home systems in Bangladesh, a general awareness among potential customers was emphasized and is considered critical to the success of the program (Urmee & Harries, 2011). These actions also contributed to market strength in the area, furthering success of the Bangladeshi program (Urmee & Harries, 2011).

A number of program studies found a poorly executed marketing strategy to be a key barrier in solar adoption. In El Salvador, one of the studied programs put few resources into marketing and advertising the program in the targeted communities, contributing to the failure of the project (Balint, 2006). In a Kenyan context, customers in a community near Lake Victoria did not understand that systems come in varying sizes, according to energy demands of a household (Opiyo, 2016). This lack of a diverse local market and promotion in the area led to household's poor understanding of solar PV potential (Opiyo, 2016). In Bangladesh, Sovacool & Drupady (2011) note that Grameen Shakti implemented an effective promotion campaign and conducted multiple demonstration projects. However, an awareness gap about the technical aspects of solar technology persists (Sovacool & Drupady, 2011). This missing knowledge presents a challenge to Grameen Shakti's promotion of solar home systems in new communities (Sovacool & Drupady, 2011).

Peer Influence

As mentioned in six articles, the influence of neighbors and peers had a number of effects on the success of solar product dissemination around the world. In the Millennium Villages Project intervention in Malawi, a number of households reported hearing about the lantern from friends, neighbors, and local stores (Adkins et al., 2010). In addition to planned focus groups, these interactions were critical to

success of the program (Adkins et al., 2010). In Kenya, neighbor influence was categorized as three forms- observation, word-of-mouth, and social pressure (Opiyo, 2016). Each of these influence categories motivated additional households to adopt solar home system technologies in the area (Opiyo, 2016). In addition, the technology was said to have elevated a household's social status and others sought to install systems as well (Opiyo 2016). In the case of solar cookers, Puzzolo et al. (2016) note a positive social impact when the systems were lent to others in the community. Puzzolo et al. (2016) also noted a South African paper that highlighted local community mentors as successful technical assistance ambassadors.

Downsides to the impact of community structures featured prominently in studies of the Papua New Guinea Teacher's Solar Lighting Project. Sovacool et al. (2011a) describe Papua New Guinea's strong ties to community and the culture of obligation to the tribe over individual families as a barrier to success for household technologies. This deeply-rooted mentality translated to negative outcomes in cases where jealousy over solar systems led to vandalism and theft (Sovacool et al., 2011). In addition, the targeted customers, teachers, often performed their tasks outside and had little desire to use the technology in an isolated setting- within their individual homes (Sovacool, 2013). The structure of the program, and the solar home system itself, "[did] not fit with the core values, the cultural mores of PNG rural life," as noted by a survey respondent (Sovacool, 2013). In Mongolia's Rural Electricity Access Project (REAP), Sovacool found that herding households purchased a solar home system, achieving the goal of the project, but mainly due to their neighbor's choice (Sovacool et al., 2011b). When questioned, many herders "[could not] articulate the reasons behind their decision to purchase" or "voiced unrealistic expectations about SHS' capacity" (Sovacool et al., 2011b).

Program Themes

Government Support

Government support has taken multiple forms within the solar product studies in this review. In a handful of articles, the support of the government has led to success and higher adoption rates. India's solar hot water market has the government to thank for subsidies, low-interest loans, as well as accelerated depreciation rates for the households that choose to adopt this technology (Srinivas, 2011). The Malawian government hosted trainings for the registered lantern cooperative and also granted a waiver on import duties and a value-added tax exemption for their sales (Adkins et al., 2010). Similarly, subsidy policies and exemptions from import taxes and value-added taxes were credited with Nepal's

solar home system growth (Palit, 2013). In the case of solar hot water in China, the sector has experienced varying levels of support. A handful of local and municipal governments have implemented a mandatory installation of this technology on appropriate new construction projects (residential & commercial buildings less than 12 stories) (Hu et al., 2012). In addition, the national government applied a policy to promote consumption of electronic appliances, including solar water heaters, in rural areas (Hu et al., 2012). This subsidy program "has greatly promoted the application of solar water heater[s] in rural areas" (Hu et al., 2012). The suppliers were required to place a high emphasis on maintenance and customer support, increasing the strength of sales and servicing in the regions (Hu et al., 2012). The Lebanese government allowed banks to offer interest-free loans to customers wishing to invest in solar water heaters (as well as other renewable energy appliances and efficiency measures) and offered a 200 USD subsidy to interested parties (Ruble & Khoury, 2013). For the population eligible for a bank loan, these efforts were said to boost market development of the technology in Lebanon (Ruble & Khoury, 2013).

The lack of, or mismanaged, support from local and national governments was widely discussed in nearly a quarter of the review papers. These scenarios can be broadly defined as poor support, unclear coordination, and a general lack of support.

In South Africa, the fee-for-service model was disrupted when municipalities did not make payment deadlines to the energy service company (ESCO) to offset the subsidy offered to customers (Azimoh et al., 2015). This resulted in a raise of the energy tariff charged to households, causing understandable frustration (Azimoh et al., 2015). In Sri Lanka, "political and financial arrangements" set a price for the design of the offered solar home system (Laufer & Schafer, 2011). Due to this limit, the implementers were forced to use undesirable batteries within the solar home system package, causing failures and poor performance within households (Laufer & Schafer, 2011). During World Bank projects in China, India, and Philippines, government- and donor-sponsored projects distributed solar home systems for free, disrupting the young markets for the same products (Zhang, 2014).

Complicated and confusing organizational structures were considered barriers in a number of initiatives that involved government support. The ESCO model in Fiji designed a split in responsibilities that greatly impacted the outcome and success of the project. Service providers were responsible for the maintenance of products installed in homes, but the Department of Energy of Fiji (DoEF) was unwilling to relinquish control over the systems, claiming a lack of capacity in the selected ESCOs (Urmee 2012). This structure led to a number of challenges, including long service times (technicians were forced to

consult with DoEF for replacements), a lack of funding from DoEF, and uncertainty in the sustainability of long-term maintenance from the ESCO (Urme & Harries, 2012). In Mongolia, divided priorities in the national government tended to steer support away from rural, off-grid, and renewable energy projects (Sovacool et al., 2011b). In addition to the structural challenges facing the Papua New Guinea program, Sovacool et al. (2011a) described political barriers to the success of the program. These included tribal loyalties and patronage, a national commitment to oil and natural gas, and other subsidized forms of electricity generation (Sovacool et al., 2011a). Similar political challenges were identified in Bangladesh, where politics and corruption delayed progress on national energy policy (Sovacool & Drupady, 2011c). In China, the number of ministries responsible for energy policy is said to complicate and delay renewable energy initiatives (Li et al., 2011). Without an overarching commitment to set targets, programs such as solar water heating disseminations are "often overlooked" on a national level (Li et al., 2011). However, this barrier is not as readily exhibited on a regional level where some states and municipalities, like Dezhou, have become solar water heater industry and policy leaders (Li et al., 2011).

In a handful of studies, a complete lack of government support was highlighted. A surveyed community in Kenya has experienced a growing private market, but noted the slow uptake due to "very little support from the government" (Opiyo, 2016). A survey of South Asian practitioners highlighted a current barrier in the lack of government policy support (Urmee & Harries, 2009). In Bangladesh, program implementers cite the lack of government backing in relation to other programs in India (Urmee & Harries, 2011). The absence of a support network providing financial incentives and exemptions is credited with low participation of financial partners (Urmee & Harries, 2011).

User Training

A large number of programs mention the need for better training in future implementation efforts. Often, product failures can be attributed to improper use of the technology. Supplying users with tailored trainings on how to use and maintain their product could save time and money for all parties involved. Instances matching this concept were noted in South Africa, East Timor, Philippines, Bangladesh, China, Papua New Guinea, and Fiji (Azimoh et al., 2014; Bikam & Mulaudzi, 2006; Bond et al., 2010; Brooks & Urmee, 2014; Chowdhury et al., 2011; Sovacool et al., 2011a; Sovacool et al., 2011b; Sovacool & D'Agostino, 2012; Sovacool, 2013; Urmee & Harries, 2012). In Papua New Guinea, Sovacool and D'Agostino (2012) and Sovacool et al. (2011a) also note an improper training setup. Teachers receiving the products were made to travel into a distant city to watch video trainings (Sovacool and

D'Agostino (2012). This costly trip placed a large burden on a low-income, rural customers and was a barrier to technology adoption (Sovacool and D'Agostino (2012).

In different settings, customer trainings were thoughtful exercises that served to benefit the program and customer base. Bangladesh's successful programs created training centers for users and training played a critical, although costly, role in the entire program (Sovacool & Drupady, 2011; Urmee & Harries, 2011). Rural electrification efforts provided trainings to community representatives in Lesotho (Taele et al., 2012). Cooking demonstrations were held to allow women many opportunities to learn to make traditional dishes in Burkina Faso (Toonen, 2009).

Customer Support

A clear deficit of customer support and after-sales service is highlighted as a barrier to household technology adoption and use in multiple cases within this review. In Argentina, the replacement support didn't come quickly enough for households to continue using their solar home systems (Alazraki & Haselip, 2007). Kenya's and Ghana's programs were plagued by a lack of mechanics to service broken products (Rolffs et al., 2015; Bawakyillenuo, 2009). For financial reasons, South Africa's ESCO model mechanics abandoned their positions (Bikam & Mulaudzi, 2006) and Fiji's ESCO employees took hundreds of days to respond to service requests in some cases (Dornan, 2011). Sri Lanka and Fiji faced challenges related to confusion around the parties responsible for providing support (Laufer & Schafer, 2011; Urmee & Harries, 2012). In Bangladesh, Sovacool & Drupady (2011) note that customer service has been seen positively but there is discussion of a decline in support (Sovacool 2011). Greece's solar water heater industry faced marketing challenges around perceived high maintenance costs (Sidiras & Koukios, 2004).

In a few cases, the abundant customer support network was a driver for solar product adoption. Lemaire (2011) describes a program in South Africa that visits households monthly and maintenance costs are included in regular, set fees. Households in Bangladesh are reportedly pleased with their solar home system warranty that lasts throughout the loan repayment period (Urmee & Harries, 2011).

Maintenance and Quality Control

Due to the strength of the solar water heating market in Dezhou, China, the network of maintenance suppliers within the city reduces the technological risks customers face (Li et al., 2011). In fact, customers listed service and maintenance as the most significant factor they analyze when choosing to purchase this product (Li et al., 2011). As Hu describes, the rural appliance program in China set

stringent rules regarding maintenance of solar water heating systems (Hu et al., 2012). This, as noted earlier, let to a stronger system and market (Hu et al., 2012).

In a survey of South Asian programs, Palit (2013) notes that maintenance and monitoring are the "most critical determinants of limited success of many programs in the region." The author found that government-sponsored programs tended to outsource the responsibility of providing maintenance for solar home systems. When this was the case, there was a higher level of dissatisfaction by implementing partners (Palit, 2013). In India, one village perceived the trained technicians for the fee-for-service model as more expensive than their local repair shop and declined to pay for their services (Borah et al., 2014). In another village, the technicians were simply not present in the area (Borah et al., 2011). However, other areas reported a successful implementation of the technician support system (Borah et al., 2011). In Fiji, the maintenance was sparse and drawn out for solar home systems needing repair (Dornan, 2011). This issue was driven by the challenges in the program initiation and shared responsibilities, as well as a concern that maintenance fees did not appropriately cover the necessary work (Dornan, 2011). In addition to the barriers of ongoing maintenance, Fiji's program suffered from a lack of proper data management. The information gained from household's purchase cards was not collected in a timely manner, making the forced removal for nonpayment "virtually impossible" (Urmee & Harries, 2012).

Regulatory Themes

Design Standards

Design standards and certification processes were mentioned in a small subset of articles in this review. Briefly noted in a review of South Asian programs, India and Bangladesh were said to have better success due to "quality standards…for PV panels, batteries, and other components" (Palit, 2013). In China's Renewable Energy Development Project, penalties were issued to companies supplying solar home systems without observing quality standards (Sovacool & D'Agostino, 2012). In Mongolia, a similar structure was put in place and only companies distributing systems that passed quality tests were eligible to receive a subsidy once a sale was made (Sovacool & D'Agostino, 2012). However, it was noted that this subsidized system might have had a negative impact on the "healthy number" of distributors already operating in the sector. World Bank projects in China utilized a similar process of granting subsidies to companies supplying quality products (Zhang, 2014). This system "served as an incentive to improve quality, provided small firms with capital for expansion, and were to some degree passed on to

consumers, boosting demand" (Zhang, 2014). In the Chinese solar water heating industry, the quality principles are relatively well understood. Hu et al. (2012) noted over 20 standards to regulate systems in China. The inspection of quality and design standards through multiple centers has "played a good role in regulating the SWH market" (Xie et al., 2012). However, there is still a need for training on the existing standards, improvement of their scope, and a larger push to test product quality (Hu et al., 2012). A similar suggestion was made to support the Bangladesh solar home system market with a quality assurance program to achieve sustainability in this sector (Chowdhury et al., 2011).

Discussion

Summary of Findings

This systematic review process has identified a group of factors that are critical to the success of solar technology adoption in low-income, off-grid communities around the world. While cultural, social, economic and geographical characteristics of each setting will impact individual results, the identified themes have a noted impact on a number of recorded scenarios. The factors below, when utilized properly and in tandem with others, have the ability to drive successful solar home system, lantern, hot water heater, or cooking dissemination projects. They have been organized to reflect varying levels of impact and responsibility- households, program implementers, and government agents. A truly enabling environment will require context-specific support on each of these levels (World Bank, 2008).

Household Level: Unsurprisingly, the most critical factor in the success of a program is the cost of the technology. An individual's ability to afford a product is the first level to be considered when designing an off-grid program. Similarly, the sizing of the solar panel or system should reflect the household's energy needs and income. The second critical piece is the quality of the products marketed to price-sensitive rural homes. Low quality panels or batteries have caused multiple programs to fail in the included articles. Poor quality products also have enormous potential to discourage future market adoption and uptake of other off-grid solutions to energy poverty. Finally, the value of customer support was strongly noted in the 43 reviewed articles. The lack of after-sales servicing and long delays in repair led to frustration and customer departure from the program in some cases.

Program level: A comprehensive project plan will include a structured system for ongoing maintenance, local availability of replacement parts, a community-appropriate financing model, marketing systems, and a plan for training end users and/or technicians. As mentioned in a majority of articles, solar systems are not necessarily low-maintenance products in an off-grid and low-income setting. There are a number of challenges that need to be consistently addressed to continue providing homes with solar

energy including battery maintenance, correcting inefficient placement of panels, responding to overloaded systems, and others. Local availability of replacement parts has the potential to reduce the downtime of solar systems in need of repair and travel time for technicians. A structured financing scheme has the ability to greatly enhance the success of a program when appropriately tailored to customer needs, culture, and income stream. Once these processes have been established, an exhaustive training program should be implemented for customers. Their ability to fully understand the capabilities of the system in their home will reduce the need for ongoing maintenance and ideally increase their satisfaction with the product.

Regional Level: Government support and high-level design standards are noted as drivers of success in a number of articles found in this review. Support from public entities ranges from Department of Energy initiatives to import tax reductions for specific technology components. It is noted that support from the public institution should not interfere with the design and function of the project but should ease barriers to entry, provide financial support, or comply with national energy access targets where fitting. As best showcased in the studies on China's solar water heater industry, design standards should be utilized to encourage high quality products dominate the market. These standards can be implemented through a certification program to receive subsidies, as in Mongolia, or as regional and municipal goals for the sector.

The drivers and barriers in the reviewed 43 articles provide lessons for future program designers seeking to eliminate energy poverty for low-income communities globally. As noted in many of the included papers, it is critical to examine these guidelines in the context of a network of factors. Comprehensive *program design, community participation and consultation, committed government/sponsor support,* and an *appropriate financing mechanism* should encourage a successful solar dissemination project for each of the four technologies described.

Absent Factors

A number of topics were not mentioned (at least more than 5 times throughout the systematic review process) but could have some influence over the success or failure of a solar dissemination project in certain contexts. These include:

(1) Private businesses: Aside from the private energy service companies described in fee-for-service model articles, no papers mention the multitude of private, for-profit companies currently supplying communities with similar products in rural, low-income areas of the world. These agents are

reported to be responsible for a large portion of recent sector growth yet are missing from the literature gathered in this review.

(2) Payment methods: Mobile money and pay-as-you-go (PAYG) systems have gained widespread popularity in many regions. Their dissemination models could point to additional drivers and barriers as technology and mobile phones become a critical piece of the adoption process.

(3) Import duties or taxes: These national measures were rarely mentioned in the selected literature. Future analyses could expand the review to include nation-wide policies that affect the cost of the product to the end user.

(4) Competition: Most programs in this review were supported by NGOs in isolated areas or governments with essential monopolies over electrification. Advances in this research has the potential to examine competition within technology offers, regional competition of private firms, or the future threat of grid infrastructure reaching off-grid communities.

(5) Other solar products: A clear lack of appropriate and quality studies on solar lanterns, solar cooking products, and solar hot water heater dissemination models points to a need for additional research regarding these technologies. An alternative review process could also produce varying results with a different set of articles and technologies.

Limitations

As noted in the scope of this systematic review, there are some limitations to this study. First, there was a large variation in the consistency and quality of the reported data in this review. Many papers are qualitative assessments of projects and initiatives and have different reporting standards than other forms of research. Some articles have large sample sizes while others focused on as few as 22 interview responses. I utilized a quality assessment questionnaire to reduce the number of poorly constructed articles, but was unable to apply more rigorous methods to this sample of work without losing data for this review. Second, in the final stage of paper selection, only 25 countries were represented in this sample. This number is too small to make large generalizations about solar technology adoption globally. Additional research is required to fill the national and continental gaps in this representation of programs implemented around the world. Third, my review is limited to peer-reviewed studies. No grey literature, reports from multilateral development banks, annual reports from nonprofits or international aid agencies, or assessments from private solar distributors were included in the scope of this analysis. There is a wealth of knowledge about the drivers and barriers of solar business and program models in other forms of literature and these sources should be explored in future studies.

Conclusion

This systematic review of the off-grid, small-scale solar distribution literature sought to identify the characteristics of successful models in rural, low-income communities. A clear discussion of drivers and barriers in particular thematic groupings emerged in an analysis of 43 papers, ranging in technology and location. The experiences documented in the literature describe complex programmatic, financial, and regulatory challenges that must be addressed in order to provide the rural energy poor with services for lighting, heating, and cooking. This review contributes to the understanding of the enabling environment for off-grid solar adoption programs. However, more research is needed to examine understudied locations, adjust the imbalances in the technologies studied, and address themes missing or underrepresented in this set of works on solar distribution models in low- and middle-income countries.

The critical enabling environment factors have been organized into levels of impact and responsibility- households, program implementers, and government agents. For households, the cost of technology and quality of a product have the potential to greatly impact the success of a program. Customer support and ongoing maintenance increase the initiative's sustainability and impact as customers continue using solar technologies in their daily lives. Programs including training programs and financing mechanisms provide customers with new platforms to address their energy needs and maintain agency over their household purchasing choices. Finally, market growth is encouraged when governments facilitate product testing and high quality standards. This complex and interconnected system of factors can either drive increases in households transitioning from harmful fuel usage to renewable energy or discourage communities from adopting the equipment under consideration. Each of these topics should be addressed in future planning with an understanding of the complex and varied enabling environment network. Addressed together and with location-specific cultural contexts in mind, these factors may increase the ability of projects to overcome energy poverty using off-grid solar.

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Appendix 1

List of Papers in Systematic Review

Authors	Year Published	Country	Title
Adkins, E., et al.	2010	Malawi	Off-grid energy services for the poor: Introducing LED lighting in the Millennium Villages Project in Malawi
Alazraki, R. and J. Haselip	2007	Argentina	Assessing the uptake of small-scale photovoltaic electricity production in Argentina: the PERMER project
Azimoh, C. L., et al.	2015	South Africa	Illuminated but not electrified: An assessment of the impact of Solar Home System on rural households in South Africa
Azimoh, C. L., et al.	2014	South Africa	An assessment of unforeseen losses resulting from inappropriate use of solar home systems in South Africa
Balint, P. J.	2006	El Salvador	Bringing solar home systems to rural El Salvador: lessons for small NGOs
Bawakyillenuo, S.	2009	Ghana	POLICY AND INSTITUTIONAL FAILURES: PHOTOVOLTAIC SOLAR HOUSEHOLD SYSTEM (PV/SHS) DISSEMINATION IN GHANA
Bikam, P. and D. J. Mulaudzi	2006	South Africa	Solar energy trial in Folovhodwe South Africa: Lessons for policy and decision-makers
Bond, M., et al.	2010	East Timor	Solar lanterns or solar home lighting systems - Community preferences in East Timor
Borah, R. R., et al.	2014	India	Comparative Analysis of Solar Photovoltaic Lighting Systems in India
Brooks, C. and T. Urmee	2014	Philippines	Importance of individual capacity building for successful solar program implementation: A case study in the Philippines
Chowdhury, S. A., et al.	2011	Bangladesh	Technical appraisal of solar home systems in Bangladesh: A field investigation
D'Agostino, A. L., et al.	2011	China	And then what happened? A retrospective appraisal of China's Renewable Energy Development Project (REDP)
Diaz, P., et al.	2013	Argentina	Solar home system electrification in dispersed rural areas: a 10-year experience in Jujuy, Argentina
Dornan, M.	2011	Fiji	Solar-based rural electrification policy design: The Renewable Energy Service Company (RESCO) model in Fiji
Harish, S. M., et al.	2013	India	Adoption of solar home lighting systems in India: What might we learn from Karnataka?
Hu, R. Q., et al.	2012	China	An overview of the development of solar water heater industry in China
Ketlogetswe, C. and T. H. Mothudi	2009	Botswana	Solar home systems in Botswana-Opportunities and constraints
Laufer, D. and M. Schafer	2011	Sri Lanka	The implementation of Solar Home Systems as a poverty reduction strategy-A case study in Sri Lanka
Lemaire, X.	2009	Zambia	Fee-for-service companies for rural electrification with photovoltaic systems: The case of Zambia
Lemaire, X.	2011	South Africa	Off-grid electrification with solar home systems: The experience of a fee-for-service concession in South Africa
Li, W., et al.	2011	China	China's transition to green energy systems: The economics of home solar water heaters and their popularization in Dezhou city

Nygaard, I. and T. Dafrallah	2016	Morocco	Utility led rural electrification in Morocco: combining grid extension, mini-grids, and solar home systems
Opiyo, N.	2016	Kenya	A survey informed PV-based cost-effective electrification options for rural sub-Saharan Africa
Palit, D.	2013	India, Bangladesh, Nepal, Sri Lanka	Solar energy programs for rural electrification: Experiences and lessons from South Asia
Pohekar, S. D. and M. Ramachandran	2006	India	Multi-criteria evaluation of cooking devices with special reference to utility of parabolic solar cooker (PSC) in India
Puzzolo, E., et al.	2016	Global	Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use
Rolffs, P., et al.	2015	Kenya	Beyond technology and finance: pay-as-you-go sustainable energy access and theories of social change
Ruble, I. and P. El Khoury	2013	Lebanon	Lebanon's market for domestic solar water heaters: Achievements and barriers
Sidiras, D. K. and E. G. Koukios	2004	Greece	Solar systems diffusion in local markets
Sovacool, B. K.	2013	Papua New Guinea	Energy Poverty and Development in Papua New Guinea: Learning from the Teacher's Solar Lighting Project
Sovacool, B. K. and A. L. D'Agostino	2012	China, Laos, Mongolia, Papua New Guinea	A comparative analysis of solar home system programmes in China, Laos, Mongolia and Papua New Guinea
Sovacool, B. K., et al.	2011	Papua New Guinea	The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea: "Choosing pigs, prostitutes, and poker chips over panels"
Sovacool, B. K., et al.	2011	Mongolia	Gers gone wired: Lessons from the Renewable Energy and Rural Electricity Access Project (REAP) in Mongolia
Sovacool, B. K. and I. M. Drupady	2011	Bangladesh	Summoning earth and fire: The energy development implications of Grameen Shakti (GS) in Bangladesh
Srinivas, M.	2011	India	Domestic solar hot water systems: Developments, evaluations and essentials for "viability" with a special reference to India
Taele, B. M., et al.	2012	Lesotho	Grid electrification challenges, photovoltaic electrification progress and energy sustainability in Lesotho
Toonen, H. M.	2009	Burkina Faso	Adapting to an innovation: Solar cooking in the urban households of Ouagadougou (Burkina Faso)
Urmee, T. and D. Harries	2009	South Asia	A survey of solar PV program implementers in Asia and the Pacific regions
Urmee, T. and D. Harries	2011	Bangladesh	Determinants of the success and sustainability of Bangladesh's SHS program
Urmee, T. and D. Harries	2012	Fiji	The solar home PV program in Fiji - A successful RESCO approach?
Xie, H., et al.	2012	China	Review of solar obligations in China
Yoon, S., et al.	2016	India	Willingness to Pay for Solar Lanterns: Does the Trial Period Play a Role?
Zhang, F.	2014	Global	Can solar panels leapfrog power grids? The World Bank experience 1992-2009

Appendix 2

Quality Appraisal Criteria adapted from Puzzolo et al. (2016), as adapted from Atkins and Sampson (2002)

STUDY ID		EXTRACTED BY		EXTRACTION DATE			
1) Ways and quality of reporting							
Were the aim and objectives of the study clearly reported?				**Yes/Partly/No**			
Was there an adequate description of the context in which the research was carried out?				**Yes/Partly/No**			
Was there an adequate description of the study design used?				**Yes/Partly/No**			
Was there any information on sampling (sample size and how it was identified)?				**Yes/Partly/No**			
Was there any attempt at representativeness and/or report on different views from stakeholders?				**Yes/Partly/No**			
Was there any information on data collection?				**Yes/Partly/No**			
Was there an adequate description of the methods used to analyse the data?				**Yes/Partly/No**			
Was there enough data presented to allow the reader to verify findings and/or interpretation?				**Yes/Partly/No**			
Are limitations to the study acknowledged and described?				**Yes/Partly/No**			
2) Bias							
Any risk of bias due to author/(s) being closely associated with the implementers?				**Yes/Partly/No**			
Are conclusions made well-grounded in the data?				**Yes/Partly/No**			
3) Appropriateness							
Does the study place the findings in the context of interest?				**Yes/Partly/No**			
Does the study suggest if and how the findings might be transferable to other settings?				**Yes/Partly/No**			