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Household Solar Adoption in Low- and Middle-Income Countries

A Systematic Review

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Household Solar Adoption in Low- and Middle-Income Countries: A Systematic Review

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Abstract

The astounding scope of the global energy poverty challenge has motivated many organizations to promote solar energy for lighting, heating, and cooking needs in off-grid settings. However, poorly designed or executed projects have the potential to cause unnecessary harm in communities lacking access to reliable energy. We identify and analyze the *enabling environment* that drives or blocks the diffusion, dissemination, and adoption of solar products, home systems, lanterns, hot water heaters, and cooking products in low- and middle-income countries (LMICs). To address this question, we conducted a systematic review to examine which factors support or complicate household solar adoption. We identified 42 studies in 26 countries that describe the enabling environment: the constellation of financial, market, programmatic, and regulatory factors that lead to adoption of small-scale solar systems. At the household level, the cost of technology and quality of a product have the potential to greatly impact the success of a program. On a programmatic scale, customer support and ongoing maintenance have the potential to increase sustainable use of products. Finally, supportive government-level policies and design standards can encourage the growth of high-quality products in regional markets. This complex and interconnected system can either drive increases in households transitioning from harmful fuel use to renewable energy or discourage communities from adopting the equipment under consideration. However, the small sample size and the glaring gaps in categories represented tell us that much more research is needed to fully understand this picture. 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.

Keywords: energy access, solar, enabling environment, finance, market development, programs, regulations

JEL Codes: Q4, Q48, O2

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Household Solar Adoption in Low- and Middle-Income Countries: A Systematic Review

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1. Introduction

Globally, we face a massive energy crisis, where billions of people lack access to electricity and clean cooking options. Households rely on local extraction of firewood, degrading their ecosystems, and burn biomass and liquid fuels for light, harming their health and increasing pollutants affecting global climate (Jeuland & Pattanayak, 2012). The astounding scope of the global energy poverty challenge has motivated many organizations to offer solar energy solutions to lighting, heating, and cooking needs in off-grid settings in low- and middle-income countries (LMICs). According to the Global Off-Grid Lighting Association's (GOGLA) (2017) most recent member sales data and impact data, sales in this sector have more than quadrupled since 2012. Even though the success of these private business efforts depends on the local market setting and *enabling environment* (defined below), there has been no systematic learning about what works and where. Practical Action (2016), a well-known practitioner in the energy poverty community, argues that "governments and the international community still lack the tools and approaches necessary to deliver on this important objective" of ending energy poverty. Therefore, we conduct a systematic review to identify and analyze the enabling environment: the constellation of *financial*, *market, programmatic,* and *regulatory* factors that lead to adoption of small-scale solar power systems (Puzzolo et al., 2016; Rosenthal et al., 2017).

Consider the case of off-grid solar products. Around the world, certain products are considered "mainstream" and "highly effective for enabling access to basic electricity services" (Lighting Global, 2016). However, market development has been asymmetric and the product sales boom is seen in only a handful of countries worldwide. Even with dropping 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). Some have suggested that these kinds of "know-do" gaps arise when what practitioners "do" on the ground is disconnected

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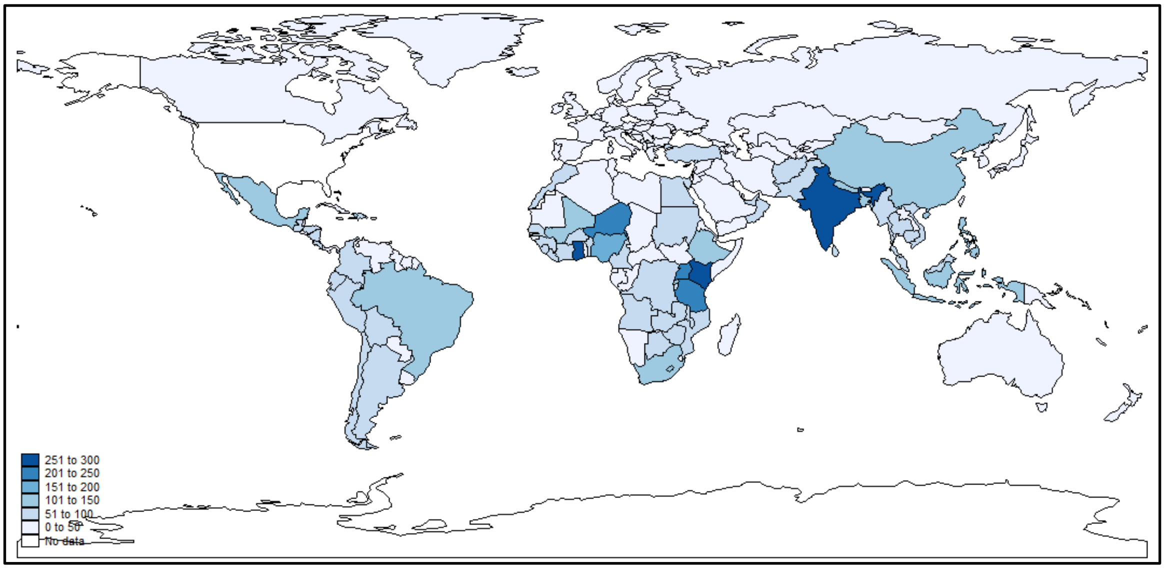
from what scholars “know” through careful evaluations and research (Köhlin et al., 2017). Given the multitude of ongoing projects, agencies, and private businesses implementing solar models to reduce energy poverty, there is an urgent need to explore what leads to a successful solar energy program.

For instance, Sovacool (2014) contends that the existing literature (e.g., scientific papers, reports, and reviews) on energy access, improved cookstoves, biogas, electrification, and solar solutions for households mainly focus on: (i) physical technology and software improvements, (ii) large-scale electrification, rather than the portfolio of renewable energy strategies, (iii) location-specific projects, or (iv) technical implementation, through ex ante feasibility studies rather than ex post assessments. The decision by households to adopt a new technology and for firms and non-governmental organizations (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) and the decision context (i.e., the enabling environment makes a big difference) (van der Kroon et al., 2013; 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). Typically, the enabling environment emerges from 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 (World Bank, 2008). The growing literature on solar adoption and diffusion rarely focuses on what has been called the *enabling environment* – *finances* (e.g., mobile money), *market ecosystem* (e.g., supply chain*), program tools* (e.g., user training), and *regulations* (e.g., product testing), especially in LMICs. Broadly speaking, experts have called for systematic syntheses employing research and evidence to inform policy-makers and practitioners working in international development (Snilstveit et al., 2012).

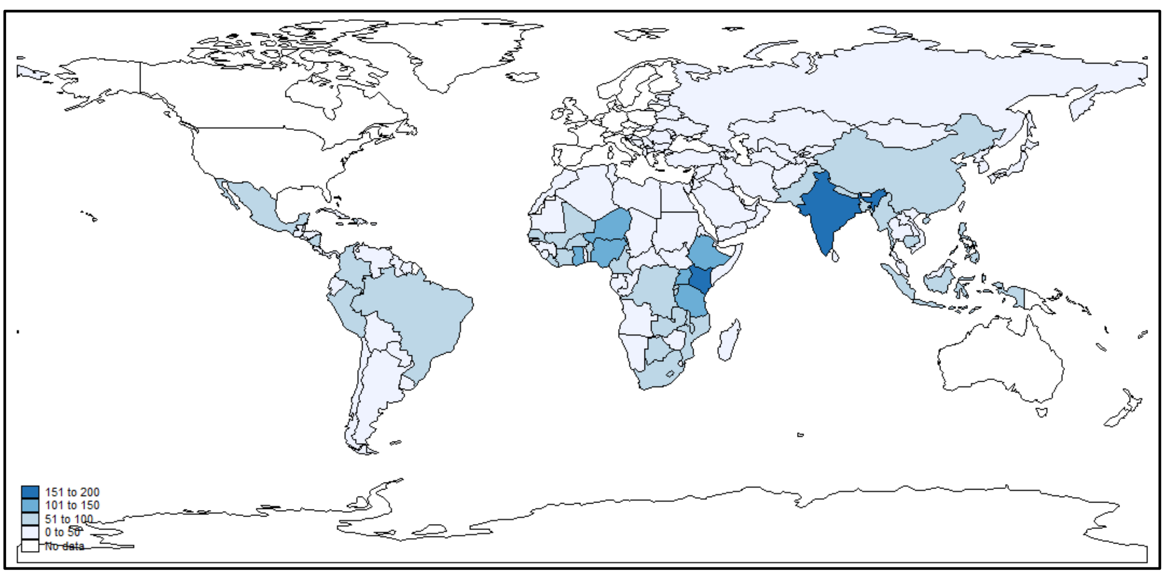
We illustrate the “know-do” gap discussed above with a set of world maps. In Figure 1a, we depict the nearly 1,500 private entities and organizations that constitute the Energy Access Practitioner Network of the United Nations Foundation (EAPN, 2017). Figure 1b provides a rough visualization of solar projects being implemented on the ground. Figure 1c, in turn, is a preview of the academic scholarship (curated by our systematic review) of the solar energy access programs. As shown, there is a large “know-do” gap between what is happening on the ground and what researchers know about these implementation practices.

Figure 1a. Number of Energy Access Practitioners by Country



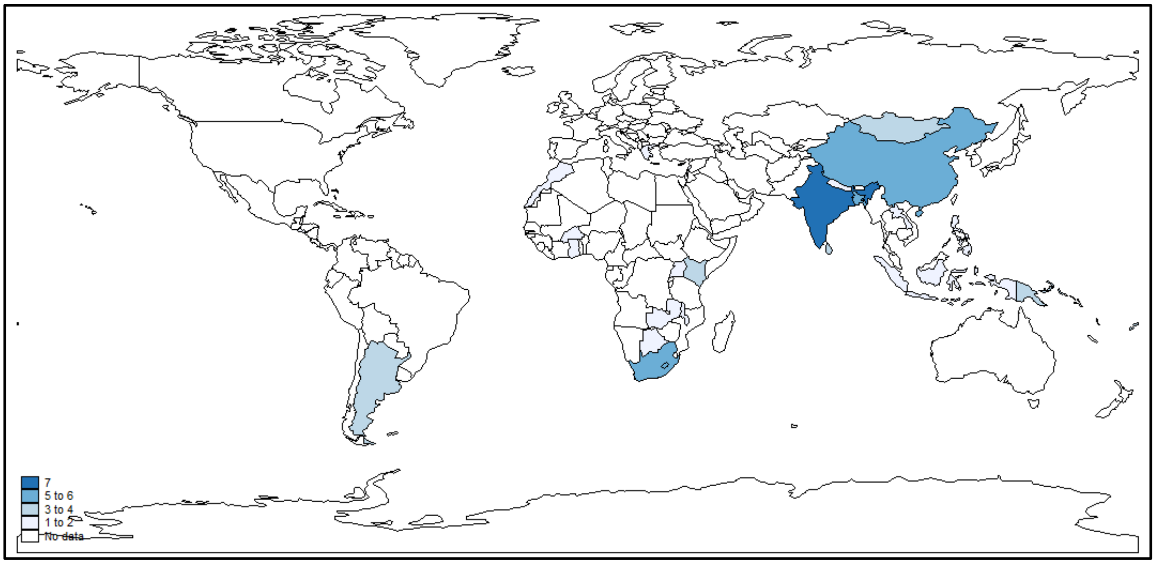
Source: EAPN, 2017

Figure 1b. Number of Solar Energy Access Practitioners by Country



Source: EAPN, 2017

Figure 1c. Number of Systematic Review Articles by Country



Source: Articles listed in Appendix 6.

Thus, our goal in this review is to identify features of programs that accurately address the challenges to disseminating solar technology in rural, off-grid, low-income communities. We follow recent systematic reviews for household cooking behaviors (Lewis & Pattanayak, 2012), but focus on the enabling environment (see Appendix 1 for a visual) for four technologies. Specifically, we focus on the financial, market, programmatic, and regulatory factors used by Puzzolo et al. (2016) for cooking technologies.

2. Methodology

2.1 Systematic Review & Scope

The main scope of this review centers on solar technology employed in an off-grid setting. To provide a snapshot of global solar uses, we have chosen to examine: (i) home systems, (ii) lanterns, (iii) hot water heaters, and (iv) cooking products (see Appendix 2 for more details). This particular scope is of great interest to multiple agencies and businesses that seek to bring electricity to poor households that have yet to receive grid-level electrical connections. The International Energy Agency has established a scenario where nearly a third of the energy access-gaining population will use off-grid technologies by 2030 (IEA, 2017). Households that do not have a grid connection to meet their electricity needs have the most to gain from appropriate solar development initiatives. In these settings, communities are also typically poor and have a multitude of concurrent needs. We have chosen to examine off-grid solutions to energy poverty. With this focus, we exclude a number of article types and program evaluations based on their fit within the inclusion and exclusion scope outlined in Table 1. 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. For example, this review does not include commercial business solar installations, programs that deal directly with schools, or any other non-household entity.

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.
	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 will be included only if they: (i) are based on empirical evidence and (ii) include enough description of solar financing, market context, regulations, and 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.) will be excluded.
	Studies superficially reporting on experience from several countries with a lack of in-depth analysis and poor description of the wider solar context will be excluded.

A typical systematic review has five parts: identifying the question, gathering the literature through an established search procedure, assessing the quality of articles, extracting data, and conducting the analysis (Khan et al., 2003). This structure provides an explicit process for answering a research question and adds transparency to the review method. Our systematic review scope was outlined to identify relevant, peer-reviewed works that cover a multitude of aspects surrounding the off-grid solar context. In our literature search, relevant work was collected through a series of searches in Web of Science, EconLit, and PAIS International. Further, these works were carefully selected and coded based on title and abstract screenings in EndNote. The quality of the studies was assessed using a constructed priority survey. Finally, the evidence from the curated articles was coded and interpreted using NVivo, a qualitative data analysis software.

2.2 Search Procedure

We selected three databases (Web of Science, EconLit, and PAIS International) to search the literature for a range of relevant search terms such as "solar," "off-grid," "household," or "electricity"; the complete list of the syntax can be found in Appendix 3. Multiple databases were chosen to reflect environmental economics studies, technical science analyses, and international papers that might not have been included in the other search engines. The search covered the years 2000 through 2016. The year 2000 was selected as a start date that would capture articles written well before global installed solar capacity began growing exponentially (BP, 2018).

The search results were imported into EndNote for further processing. In total, 5,650 papers were found in the three databases. Almost 200 papers were excluded as duplicates within the original grouping. Within the EndNote software, we separated the 5,454 papers into categories for record keeping. Papers that met all criteria (Table 1) in a scan of the title and abstract were set aside for further review. Any article (4,558 studies) that did not discuss the appropriate technology (e.g., concentrated solar power, hydroelectric energy, grid-level solar plants) was excluded based on an inappropriate topic fit. An additional 566 papers were excluded because they studied programs in high-income countries outside of the review's scope. Finally, 57 papers were discarded based on their coverage of non-household applications. Collectively, these steps led to a semi-final list of 286 articles for a full review, which were imported into an Excel worksheet for final review. A full reading of the entire paper resulted in the further elimination of 237 papers because they did not fit one or more of the criteria discussed in Table 1. For example, one paper discussed the feasibility of a solar plant to electrify an island, while others only mentioned technical or engineering aspects of designing solar energy solutions. The complete process for paper selection is shown in Appendix 4.

2.3 Quality Assurance

To be included in this study, articles had to meet all of the aforementioned criteria and provide further comment regarding the general success of a program or initiative. Included papers have a robust discussion of efforts led by a government entity, non-profit organization, for-profit business, or other agent to increase the availability of solar technology in a given area. In a majority of the 49 papers, this discussion included a sample population, description of the program and the electricity connectivity of the community, challenges to successful implementation of the program, and indicators that led to successful technology adoption. Finally, all papers were selected from peer-reviewed journals, adding a layer of quality assurance to this process.[1]

Before coding in NVivo, 49 papers were analyzed using a quality appraisal tool developed by Atkins and Sampson (2002), adapted from Puzzolo et al. (2016), and described in Appendix 5. During this phase, 7 papers were found to have met the inclusion criteria but did not adequately discuss results or descriptions of the study setting. The 42 articles that meet the inclusion criteria and quality assurance criteria are listed in Appendix 6 and discussed thoroughly in the Results section below.

2.4 Data Extraction and Analysis

The remaining 42 papers were imported into NVivo for analysis. Each paper was coded to a node hierarchy and categorized by the country of study, type of project, implementing agency, technology studied, general outcomes, and methods used in the study. Finally, each paper was coded according to its discussion of each enabling environment factor, which included a larger category of sub-factors (Appendix 7). For a full list of how each article was coded, see Appendix 8. Additionally, the coding was further sorted based on whether the factor was identified as a strong barrier, a weak barrier, a weak driver, or a strong driver.

Consider the example of Bangladesh's solar home system program. Urmee and Harris (2011) note that short-term loans to partner organizations were "key to the success of the program." This reference was coded as a "strong driver" during the NVivo phase. Statements of "weak" drivers and barriers mentioned a key sub-factor in the enabling environment, but failed to clearly connect the theme with a success or failure of a program. Bond et al. (2010) present an example of training highlighted as a "need," but do not credit lack of user training with a failure of the program.

[1] Selecting from peer-reviewed journals allowed the authors to predetermine a relative level of quality in the studies examined. However, due to the recent growth in small-scale solar systems in the world and the growing popularity of private businesses less likely to interact with academic research, this criterion potentially excludes a growing grey literature with information on drivers of and barriers to household solar adoption in the Global South.

3. Results

First, we describe our summary of the findings from a thorough review of the 42 papers in terms of spatial distribution ("country"), technology, and ownership model. This review spanned 17 years to capture relevant and recent information published in peer-reviewed sources (Appendix 9). As can be seen, this literature is fairly recent, with most articles published between 2011 and 2016. Next, we report on each sub-factor within the constellation of enabling environment factors. We focus on the sub-factors that featured most frequently and prominently in the 42 studies.

3.1.1 Location/Country

The scholarship so far spans a variety of countries, representing the major regions of the world (Appendix 10). As is evident, large swaths of the world that are energy poor are not represented by the scholarship so far. Thus, this review highlights the gaps in spatial knowledge and the limitations that practitioners face when generalizing outcomes of programs in distinctively different regions of the world.

3.1.2 Technology

As shown in Appendix 11, the selected articles represent mostly solar home systems (32 articles), with solar hot water heaters (5 articles), cooking products (3 studies), and lanterns (3 articles) constituting the rest of the technologies considered. The variation between articles mentioning solar home systems and those discussing all other technologies is unexpected. However, solar home systems have arguably higher upfront costs, which could potentially lead to more organizations and sponsors requesting an evaluation of implementation programs. There are clear implications for our global understanding of solar hot water heaters, cookers, and lanterns; we know very little about what tools support adoption of these technologies.

3.1.3 Ownership Model

The papers collected for this systematic review mention a variety of ownership models (Appendix 12). The majority examined programs using a fee-for-service model, under which an association manages and maintains the solar product and a household pays a monthly fee for use of the product. One example of such a model is an energy service company (ESCO). A different kind of model is a government concession where the government owns the physical products, but gives companies concessions to manage a service territory and facilitate the distribution of the solar panels. Other models include non-profits distributing technology for no charge or subsidizing direct sales to customers.

3.2 Narrative on Most Prominent Enabling Environment Factors

We summarize our full set of enabling environment topic results by reporting the distribution by technology for each enabling environment factor – finances, market ecosystem, program tools, and regulations (see Appendix 9). Furthermore, each of these factors is broken down by its sub-factors; for example, under the finance factor, we report on the influence of taxes, tariffs, pay-as-you-go (PAYG), mobile systems, etc. Note that an article is "counted" for a particular sub-factor only as long as authors claim that the specific sub-factor influenced adoption of the solar technology in their study setting(s). Note also that "influence" does not mean a mere mention of the sub-factor. Instead, the sub-factor must be clearly described as either a weak or strong driver or barrier, based on textual indicators in each article. This count is broken down by paper in Appendix 9.

In the following sections, we describe and further analyze themes that were categorized broadly as either drivers or barriers to the success of a project. We have selected a number of sub-factors that were most prominent in the discussion and counts of drivers and barriers, shown in Figures 2a, 2b, 2c, and 2d.

Figure 2a. Driver and Barrier Count by Finance Enabling Environment Topics

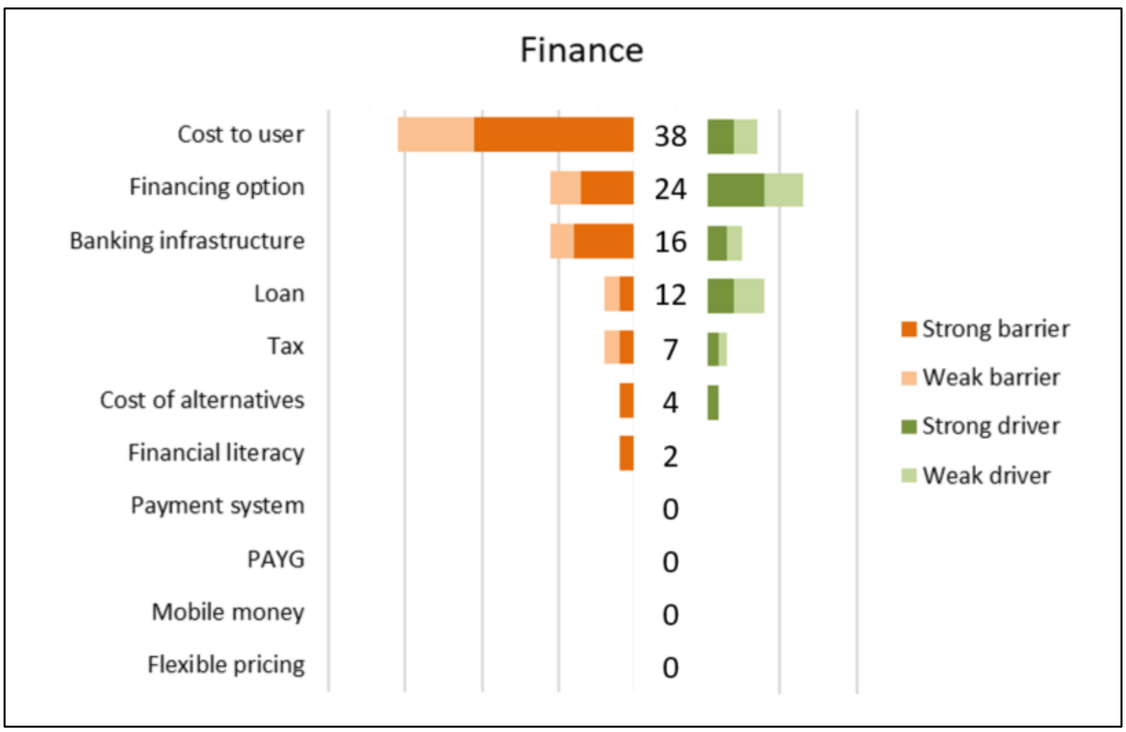


Figure 2b. Driver and Barrier Count by Market Ecosystem Enabling Environment Topics

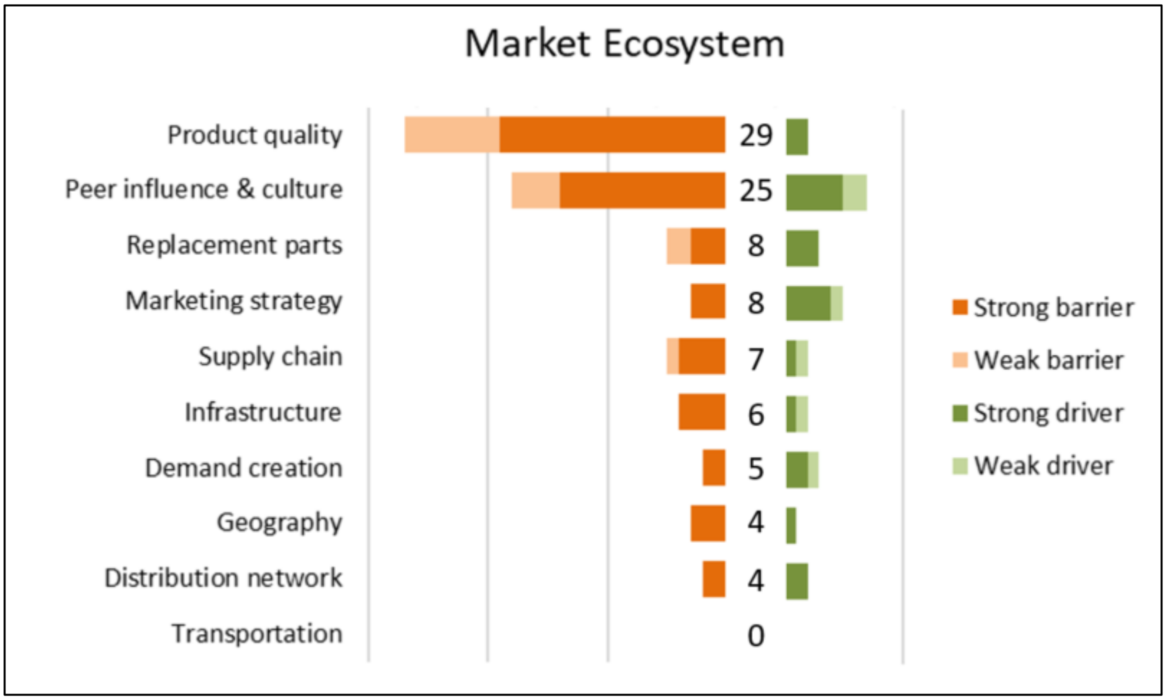


Figure 2c. Driver and Barrier Count by Program Tools Enabling Environment Topics

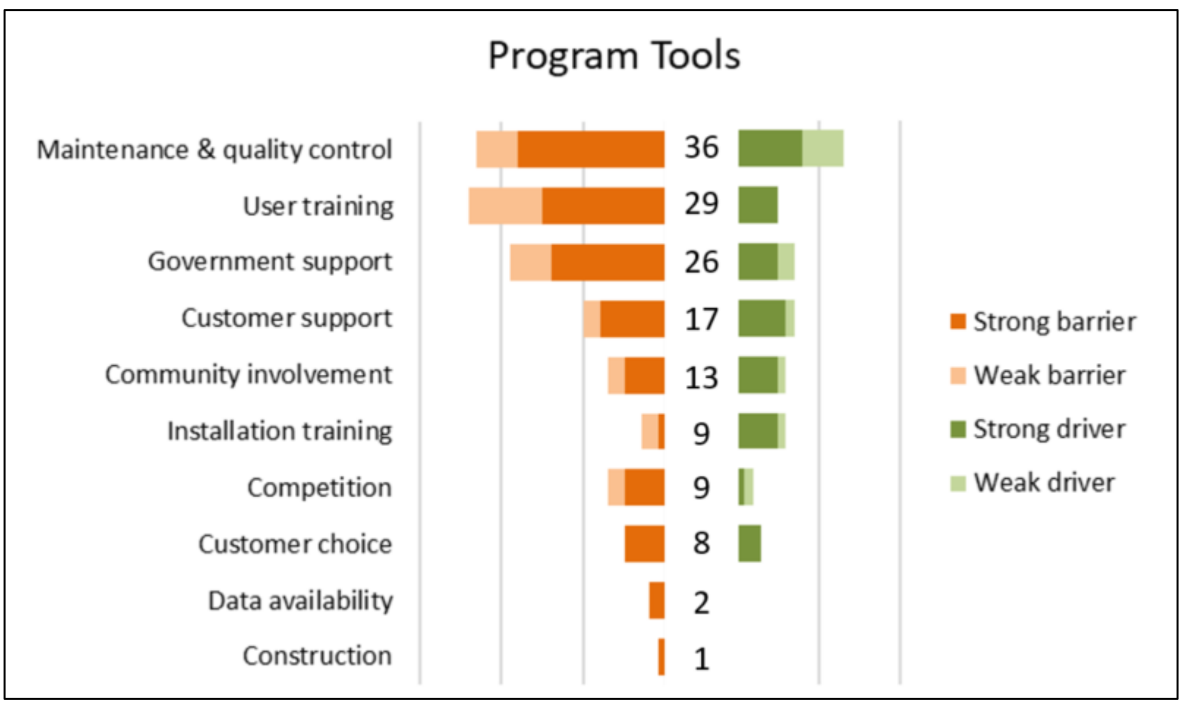


Figure 2d. Driver and Barrier Count by Regulations Enabling Environment Topics

3.2.1 User Cost

The cost of solar home systems, hot water heaters, and cooking products 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). Thus, it is no surprise that the overall cost of a system was consistently cited as a barrier to widespread household adoption of solar products across the world. Programs that were originally successful, as in Bangladesh, eventually ran into challenges when trying to reach rural, low-income populations because of increasing costs over time (Urmee & Harries, 2011). In Mongolia, systems could end up costing what amounted to roughly half a herder's annual income ($300-$400 per year) even after the 50% government subsidies were included (Sovacool et al., 2011b). In Kenya, even a relatively affordable price tag for a solar home system (compared to electric grid connections) seemed to be out of the reach of the lowest-income residents (Opiyo, 2016).

In some cases, the monthly payment structure of the ESCO model allowed a household to purchase energy in small amounts and, in theory, opened the system to households with liquidity constraints. However, even after households registered for the ESCO system in Botswana, there was a notable level of small systems being repossessed for failing to pay monthly fees (Ketlogetswe & Mothudi, 2009).

3.2.2 Financing Options

Just over 30% of articles noted a positive association with a financing scheme (i.e., that finance was a driver of technology adoption) (Harish et al., 2013; Palit, 2013; Puzzolo et al., 2016; Urmee & Harries, 2011). Solar cooking products were determined to be "too costly" without a financing option (Puzzolo et al., 2016). Palit's (2013) survey of South Asian solar photovoltaic (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." Thus, similar to the discussion regarding user costs, finance and banking are widely viewed as key drivers or barriers. 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). 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).

An additional 26% of studies discussed how limited or poorly implemented finance options became barriers 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 onfused about the levels and frequency of payment schedules and had difficulty maintaining the fees required for their systems (Bikam & Mulaudzi, 2006). 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, while households noted the availability of loans, they argued that the long payback period became a barrier to their purchase (Sidiras & Koukios, 2004).

3.2.3 Banking Infrastructure

The discussion around banking infrastructure was varied. Projects reported success when partnerships with banking institutions were fully incorporated and used in the processes (Adkins et al., 2010; Urmee & Harries, 2011; Sovacool & D'Agostino, 2012). For example, joining forces with a microfinance institution led to successful group lending practices and a move away from cash sales in Malawi (Adkins et al., 2010) and Bangladesh (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 options for repayment (Sovacool & D'Agostino, 2012).

The contrast to this driver scenario was discussed in 26% of the articles. The lack of cooperative, rural financial institutions that match local needs can be a barrier for dissemination of solar 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 needs and became a barrier to the success of the program (Sovacool, 2013).

3.2.4 Product Quality and Offerings

A general lack of quality products influenced a number of studies set in LMICs. Out of 42 papers, almost half specifically mentioned battery and charging 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. Here, we summarize a few examples.

In Sri Lanka, household batteries quickly wore out, after which individuals were only supplied with used products until the end of the warranty period (Laufer & Schafer, 2011). In Papua New Guinea, Sovacool et al. (2011) highlighted a challenge in procuring high-quality solar home systems for the rural electrification program. In Burkina Faso, solar cookers were too heavy, took too long to make meals, and had poor packaging (Puzzolo et al., 2016). For a variety of reasons, households did not understand the load requirements of their system and would add higher wattage bulbs, run a television and other appliances all at once, or bypass the charge controller altogether (Azimoh et al., 2014; Diaz et al., 2013; Lemaire, 2011; Sovacool et al., 2011a; 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 a few cases, the quality of products offered to households was noted as a driver and benefit of solar home system dissemination models. 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).

3.2.5 Peer Influence

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 the success of the program (Adkins et al., 2010). In the case of solar cookers, peers influenced each other when the systems were lent to others in the community, or, as in South Africa, when local community members served as mentors and ambassadors (Puzzolo et al., 2016).

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 barriers to success for household technologies. This deeply-rooted mentality translated into negative outcomes in cases where jealousy over solar systems led to vandalism and theft. 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).

3.2.6 Maintenance and Quality Control

A recent survey of South Asian programs suggests that maintenance and monitoring are the "most critical determinants of limited success of many programs in the region" (Palit, 2013). The author found that government-sponsored programs tended to outsource the maintenance for solar home systems and, in such cases, there was a higher level of dissatisfaction by the implementing partner. In Fiji, the response was limited and slow for solar home systems needing repair, for reasons including challenges in the program initiation, shared responsibilities, and maintenance fees that were too low to cover costs (Dornan, 2011).

Compared to these notes about barriers, the network of maintenance suppliers within Dezhou, China, has been shown to reduce customer risks, with many customers listing maintenance as the most significant driver of product purchase (Li et al., 2011).

3.2.7 Customer Support

Multiple articles highlight a clear lack of customer support and after-sales service as a barrier to household adoption and use. In Argentina, the replacement support did not come quickly enough for households (Alazraki & Haselip, 2007). Kenya's and Ghana's programs were plagued by a shortage of mechanics to service broken products (Rolffs et al., 2015; Bawakyillenuo, 2009). South Africa's ESCO 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). Greece's solar water heater industry faced marketing challenges around perceived high maintenance costs (Sidiras & Koukios, 2004).

Evidence from other locations shows that solar product adoption was driven by the customer support network. Lemaire (2011) describes a program in South Africa where employees visit households monthly and maintenance costs are included in regular, set fees. In Bangladesh, customers liked their solar home system warranty because it lasted throughout the loan repayment period (Urmee & Harries, 2011).

3.2.8 User Training

Almost 70% of articles identified user training as a key driver or barrier in program implementation. Often, product failures can be attributed to improper use of the technology – as noted in South Africa (Azimoh et al., 2014; Bikam & Mulaudzi, 2006), East Timor (Bond et al., 2010), the Philippines (Brooks & Urmee, 2014), Bangladesh (Chowdhury et al., 2011), China (D'Agostino et al., 2011), Papua New Guinea (Sovacool et al., 2011a; Sovacool, 2013), and Fiji (Urmee & Harries, 2012). One clear example of a barrier is the case of Papua New Guinea, where the customers for solar home systems were forced to travel into a distant city to watch training videos. This costly trip placed a large burden on low-income, rural customers (Sovacool et al., 2012).

In other settings, user trainings were viewed as drivers. Bangladesh's successful programs created training centers for users, with the training itself playing a critical, although costly, role in the entire program (Sovacool & Drupady, 2011; Urmee & Harries, 2011). Trainings for community representatives in Lesotho improved uptake of solar-powered rural electrification (Taele et al., 2012). Demonstrations of how traditional dishes could be prepared with solar cookers improved outcomes in Burkina Faso (Toonen, 2009).

3.2.9 Quality Standards

Design standards and certification processes contributed to the success of Indian and Bangladeshi programs (Palit, 2013). In Mongolia, only companies that passed quality tests received subsidies (Sovacool & D'Agostino, 2012). In China's Renewable Energy Development Project, subsidies were provided to companies that met quality standards (Zhang, 2014) and penalties were imposed on those that did not (Sovacool & D'Agostino, 2012). In the Chinese solar water heating industry, the quality principles are relatively well understood, even though there are over 20 regulatory standards (Hu et al., 2012). While the presence of multiple centers for inspection of quality and design standards has helped regulate the solar water heater market (Xie et al., 2012), 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).

3.2.10 Government Support

Lastly, and not surprisingly, the role and, especially, the support of governments remains key to program success and higher adoption rates. In India, the market for solar hot water systems depends on government subsidies, low-interest loans, and accelerated depreciation rates (Srinivas, 2011). In Malawi, the 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). In China, both the federal government and a handful of local and municipal governments have implemented mandatory installation of solar hot water heaters on new construction projects less than 12 stories tall (Hu et al., 2012). In addition, the Chinese government has implemented a policy to promote consumption of solar water heaters in rural areas (Hu et al., 2012). In Lebanon, the government allowed banks to offer interest-free loans and subsidies to customers wishing to invest in solar water heaters (Ruble & Khoury, 2013).

In contrast, the lack of government support can be a barrier, as discussed in nearly a quarter of the papers in our review; these represent both poor support and unclear coordination. In South Africa, the fee-for-service model was disrupted when municipalities did not make payment deadlines to the ESCO to offset the subsidy offered to customers, resulting in a tariff hike, causing understandable frustration (Azimoh et al., 2015). In Fiji, the ESCO model designed a split in responsibilities: 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 (Urmee & Harries, 2012). This structure led to a number of challenges, including long service times because 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. In Kenya, a private market is growing, but there is slow uptake due to "very little support from the government" (Opiyo, 2016). In Bangladesh, the absence of financial incentives and exemptions by the government are blamed for the minimal participation of financial partners (Urmee & Harries, 2011).

4. Discussion

Our systematic review of the off-grid, small-scale solar distribution literature focused on *enabling environment* factors critical to the success of solar technology adoption in off-grid communities in LMICs around the world. Although the enabling environment is influenced by context-specific and country-specific drivers (World Bank, 2008), our summary of the drivers and barriers provides clear lessons for future program designers seeking to eliminate energy poverty for low-income communities globally. In this short section, first we discuss the key enabling environmental factors, organized to reflect varying levels of impact and responsibility: households, program implementers and businesses, and government actors. We then examine the factors ignored by the published articles and the limitations of our analysis.

From this review, we discovered that the household impacts of *user cost* and the availability of financing mechanisms in programs and businesses targeting low-income customers have been extensively studied. However, cost continues to be a barrier to reaching the lowest-income households experiencing energy poverty. On a similar note, there is a general understanding in the literature that supports *financing models* to reduce the immediate cost of these products. Different models perform better than others, but the availability of assistance to low-income customers is critical. Having secure (long-term), accessible, and flexible *banking infrastructure* that works well with the targeted population can drive the success of an off-grid solar program.

This review notes the *product quality* of products marketed to price-sensitive rural homes as a critical factor in the success of programs. Low-quality panels or batteries have caused multiple programs to fail. Compounding this challenge is the potential of poor quality products to discourage future market adoption and uptake of other off-grid solutions to energy poverty. The weight of *peer influence* and cultural factors varies by location, as shown in this review. Unsuccessful programs are further hampered by poor understanding around community norms, lack of property ownership, and theft. Programs reporting higher success rates point to positive neighbor influence and the lure of social status gains through technology adoption.

Enabling environment factors also drive or constrain successful technology rollouts on a firm or program level. As mentioned in a majority of articles, solar power systems are not necessarily low-maintenance products in an off-grid and low-income setting. There are a number of *maintenance* challenges that need to be consistently addressed to continue providing homes with solar energy. Some examples include battery upkeep, correcting inefficient placement of panels, and responding to overloaded systems. The value of *customer support* was a strong influence in the success of a number of reviewed programs. In some cases, the lack of after-sales servicing and long delays in repair led to frustration and customer departure from the program. An exhaustive *user training* program should be considered for customers unfamiliar with the solar technology. Customers' ability to fully understand the capabilities of the system in their homes will reduce the need for ongoing maintenance and, ideally, increase their satisfaction with the product. Supplying users with tailored trainings on how to use and maintain their product could save time and money for all parties involved. The articles in this review list a range of *public entity support* – from national Department of Energy initiatives to import tax reductions for specific technology components. Support from a public institution should ease company barriers to entry, provide financial support, or assist programs in complying with national energy access targets where fitting.

Taking a step up to a government level, we know that enabling environment factors can influence regional markets and national programs as well. A supportive *regulatory policy* environment favoring mandatory installations on new buildings or incentives for rural installations was reported to increase sales in the solar hot water market, specifically in the Chinese context. As best showcased in the studies on China's solar water heater industry, *design standards* should be utilized to encourage high quality products to 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.

A number of topics were not considered by the researchers and scholars. Here, we single out those touted to influence diffusion (but still not featured in the peer-reviewed literature). First, while *mobile money* and *pay-as-you-go (PAYG) systems* have gained widespread popularity in many regions, especially in East Africa, these schemes have not been studied. As barriers to cell phone ownership and mobile banking continue to drop, this topic will be critical to understanding the off-grid product financing environment. Second, *import duties* or *national taxes* were rarely mentioned in the literature. In different locations, these fiscal policy instruments could substantially change product price and, therefore, acceptance by local populations. Third, no paper considered the impact of rural *transportation* and *infrastructure* challenges, possibly because programs and projects are located (by NGOs, donors, and bureaucrats) in accessible sites, even though remoteness is a well-known challenge to rural development.

Finally, except for the articles on the fee-for-service model implemented by firms, very few articles considered the general participation of private sector for-profit companies (e.g., M-KOPA, Off Grid Electric, and BBOXX) in the solar market. These private actors are responsible for a large portion of recent sector growth, yet are missing from the literature. This large gap in peer-reviewed literature leads us to call for more reflection on the enabling environment in countries experiencing high private solar sector growth in recent years.

As noted in the scope of this review, there are some limitations to this study. First, the studies vary in terms of rigor and the details reported. Many papers are qualitative assessments of projects and typically report differently from other quantitative forms of research. Some articles have large sample sizes, while others focused on a handful of interview responses. While we utilize a quality assessment questionnaire to choose only high-quality studies, we are unable to apply more rigorous methods. Second, our final sample includes only 27 countries, making it difficult to generalize about solar technology adoption globally. Third, this review is limited to peer-reviewed studies published in journals. We do not include reports from multilateral development banks, annual reports from non-profits or international aid agencies, assessments from private solar distributors, or grey literature, in general. While there are errors of exclusion of the potential knowledge in this literature, this scattered body of work is not available in any systematic or organized manner and has not benefited from academic peer review and scrutiny.

5. Conclusion and Recommendations

There is a significant amount of information in the 42 articles reviewed and the authors have made great contributions to our collective understanding of how the enabling environment impacts solar technology implementation in LMICs. However, the small sample sizes and the glaring gaps in categories represented tell us that there is much more research needed to fully understand this picture. With over 850 energy access practitioners (out of 1,487) working in the solar PV industry in the United Nations Foundation Energy Access Practitioner Network *alone*, there is clearly more information to be written down and shared (EAPN, 2017). Closing this “know-do” gap will be essential to ensuring access to energy for all.

The peer-reviewed science captured in these papers is slow to follow the explosive action of the off-grid solar technology landscape. While we have made big strides in understanding the public health, environmental science, and engineering aspects of the energy poverty problem, we have paid little attention to the complex and interconnected enabling environment (e.g., the constellation of *financial*, *market, programmatic,* and *regulatory* factors). This means that practitioners are not using the rigorous evaluation tools that the social sciences provide, thus widening the gap between what we "know" from practice-based evidence and what is actually being "done" on the ground. This gap between scientific literature and practice must be narrowed if the global community is to efficiently solve the energy poverty crisis within the next decade.

To start, we recommend additional research on the following. First, we clearly need more evidence on both for-profit businesses and non-profit entities in the off-grid solar, mobile money, and pay-as-you-go systems, targeting home systems in particular. Second, we recommend tackling the "know-do" gap by focusing on areas where energy poverty is most stark, where practitioners are engaged in implementation, and where research seems to be completely absent (e.g., Central America, most of sub-Saharan Africa, and Central Asia, as shown in Figure 1c). Finally, to balance the overwhelming reliance on qualitative case studies, we advocate for more rigorous evaluations of program impacts. Because of the quickly evolving context in which solar technologies are being sold, donated, or distributed – and due to the need to examine sales, adoption levels, and technology lifespans – such evaluations must adopt a mixed-method, interdisciplinary approach that is co-produced with practitioners.

While more is clearly needed, we have presented the first known systematic review of the enabling environment (policy context) for off-grid, small-scale solar distribution literature. The 42 papers in our review help us identify the characteristics, in four thematic groupings (with further sub-groups), of successful models in rural LMICs around the world. At the risk of repeating, in the previous section, we have summarized how user cost, product quality, user training, customer service, and regulatory policy influence the diffusion of solar products in households around the world. The experiences documented in the literature describe complex programmatic, financial, market, and regulatory challenges that must be addressed in order to provide the rural energy poor with services for lighting, heating, and cooking.

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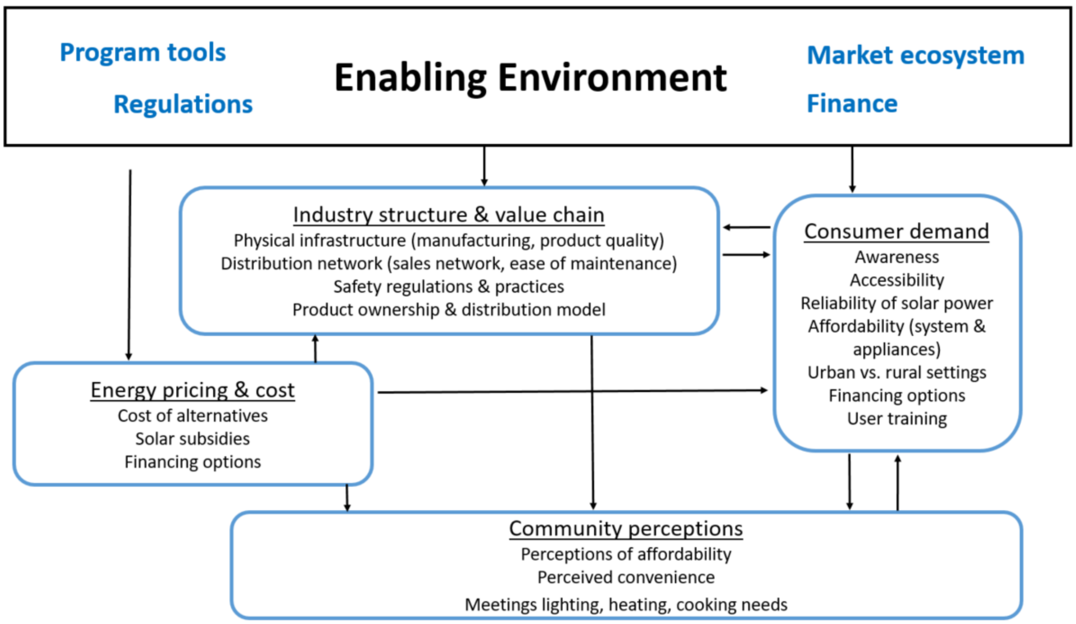
Appendix

Appendix 1
Solar Enabling Environment Concept Model



Appendix 2
Technology Definition

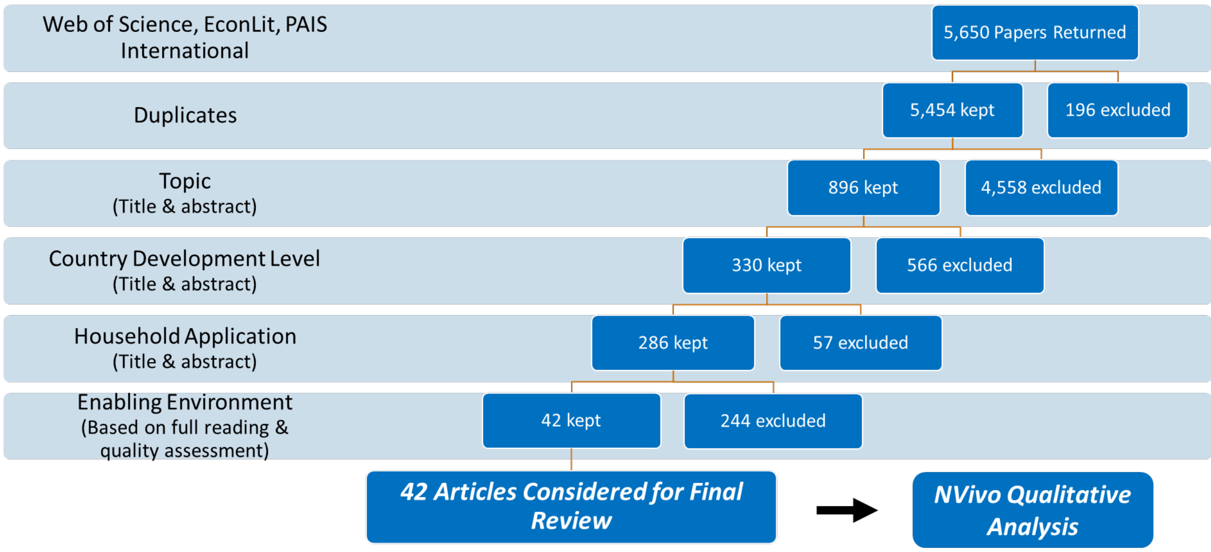
The technologies below cover the vast majority of off-grid, small-scale products marketed to individuals and households in low- and middle-income countries.

Solar Home System	Solar home systems include products with some version of a panel, one to five light bulbs, a battery, a charge controller, and potentially a radio or TV.
Solar Lantern	Solar lanterns are much smaller products, typically charging one light bulb or a cell phone and are intended for mobile use.
Solar Hot Water Heater	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 Cooker	Solar cooking utilizes a similar principle to reflect direct sunlight to a cooking vessel.

Appendix 3
Systematic Review 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	2000-2016

Appendix 4
Systematic Review Decision Tree



Appendix 5

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

<table>
<tr><td>STUDY ID</td><td></td><td>EXTRACTED BY</td><td></td><td>EXTRACTION DATE</td><td></td><td></td><td></td></tr>
<tr><td colspan="8">1) Ways and quality of reporting</td></tr>
<tr><td colspan="5">Were the aim and objectives of the study clearly reported?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there an adequate description of the context in which the research was carried out?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there an adequate description of the study design used?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there any information on sampling (sample size and how it was identified)?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there any attempt at representativeness and/or report on different views from stakeholders?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there any information on data collection?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there an adequate description of the methods used to analyse the data?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Was there enough data presented to allow the reader to verify findings and/or interpretation?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Are limitations to the study acknowledged and described?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="8">2) Bias</td></tr>
<tr><td colspan="5">Any risk of bias due to author(s) being closely associated with the implementers?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Are conclusions made well-grounded in the data?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="8">3) Appropriateness</td></tr>
<tr><td colspan="5">Does the study place the findings in the context of interest?</td><td colspan="3">Yes/Partly/No</td></tr>
<tr><td colspan="5">Does the study suggest if and how the findings might be transferable to other settings?</td><td colspan="3">Yes/Partly/No</td></tr>
</table>

Appendix 6

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?
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 7
Coding Matrix Structure and Topic Description

Characteristics	Intervention Technology	Finances	Market Development	Program Tools	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					

Coding Topic Description

Finance Enabling Environment Categories	
Topic Name	**Description**
Banking Infrastructure	Banking services included in the program, but outside the control of the implementer; notation of traditional finance institutions in the community; proximity of infrastructure to community
Cost of Alternatives	Cost of different lighting or heating sources used within the household currently or previously (e.g., kerosene, electricity, batteries, etc.)
Cost to User	Cost of the technology highlighted in the program description
Financial Literacy	Community members' understanding of finances, generally or specific to the program and technology loan options
Financing Option	Program, company, or organization financing plan for product payment over time
Flexible Pricing	Varying terms of payment for different segments of the population or at different times in a loan period (e.g., quarterly payments for farmers, monthly payments for non-farming households)
Loan	Specific mention of a loan granted for purchase of the solar technology
Mobile Money	Payments made for a technology or service via mobile phones
Pay-As-You-Go (PAYG)	System for customers/program participants to make regular payments towards a technology or service
Payment System	Description of the non-mobile, ongoing payment methods available to customers (e.g., purchasing tokens, fee collection, card renewals, etc.)
Tax	Taxes or duties levied by governments on solar technologies

Market Development Enabling Environment Categories	
Topic Name	**Description**
Demand Creation	Description of factors leading to increased demand for product or technology (e.g.,. marketing campaign, word of mouth, etc.)
Distribution Network	Distributors, sales agents, and suppliers of the solar technologies to the end customer
Geography	Physical geography (terrain) and resulting impacts on distribution of the solar technologies
Infrastructure	Human-constructed physical space (e.g., roads, transport facilities, etc.) and the capacity of an area to meet electrification needs of community
Marketing Strategy	Effort to conduct outreach to community, promote the technology, or explain the product to potential customers/recipients
Peer Influence & Culture	Theft, vandalism of the solar technologies by community members; altering ideal solar technology conditions due to cultural norms and daily needs of the household; program goals alignment with local values or training needs; individual/community influence on purchasing decisions of neighbors
Product Quality	Understanding the degree to which the technology meets the expectations of the customer/recipient during the course of the program or interaction
Replacement Parts	Availability of and need for replacement parts to repair products
Supply Chain	The flow of products from manufacturer to customer/recipient
Transportation	Discussion of the movement of products around a given area

Program Tools Enabling Environment Categories	
Topic Name	**Description**
Community Involvement	Integration of community members in the planning, design, or implementation of a program or business model to distribute solar products
Competition	Suppliers, distributors, or sales agents marketing similar products in the area; perceived competition from grid extension programs
Construction	Installation of systems in an area
Customer Choice	Customer ability to choose between solar products within a program or offering
Customer Support	Interaction between customer and program/business to address issues with technology or service
Data Availability	Availability of data when making program/business decisions
Government Support	Strategic government support for program or technology stated in the article
Installation Training	Training of technicians and solar technology installers within a program or business
Maintenance & Quality Control	Program or business response to repair needs; response time for maintenance requests; cost of ongoing maintenance supply
User Training	Training of customer/recipient on proper use of the technology; ability of customer/recipient to use technology as intended

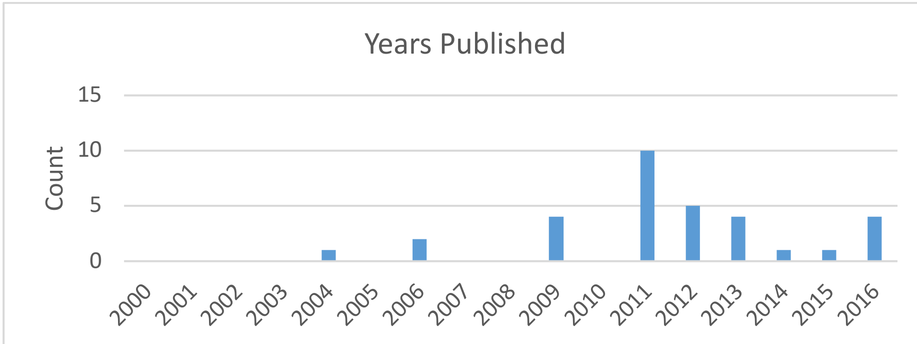
Regulations Enabling Environment Categories	
Topic Name	**Description**
Design Standards	Government-imposed or expert entity-developed standards of product quality, design, and installation
Material Procurement	Regulations around procurement of any materials necessary for products
Penalties for Non-Compliance	Fines or penalties for not complying with quality standards or installation mandates/quotas
Price Volatility	Regulations on price of product; unpredictable changes in pricing structures
Product Testing	Government-approved testing and certification for solar technologies
Regulatory Policy	Broad mention of policies to promote technology adoption (e.g., standards or guidelines for product quality, installation mandates, maintenance requirements to qualify for subsidies, etc.)

Appendix 8

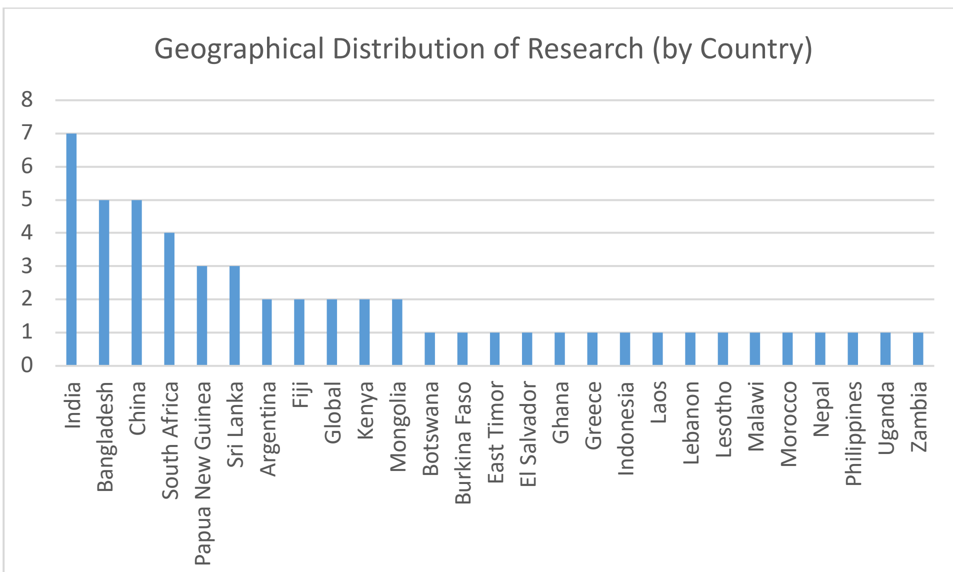
Themes Mentioned by Paper

Author(s)	Year Published	Country	Financial Context	Market Development	Program Implementation	Government 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	
Yoon, S., et al.	2016	India	X	X		
Zhang, F.	2014	Global	X	X	X	X

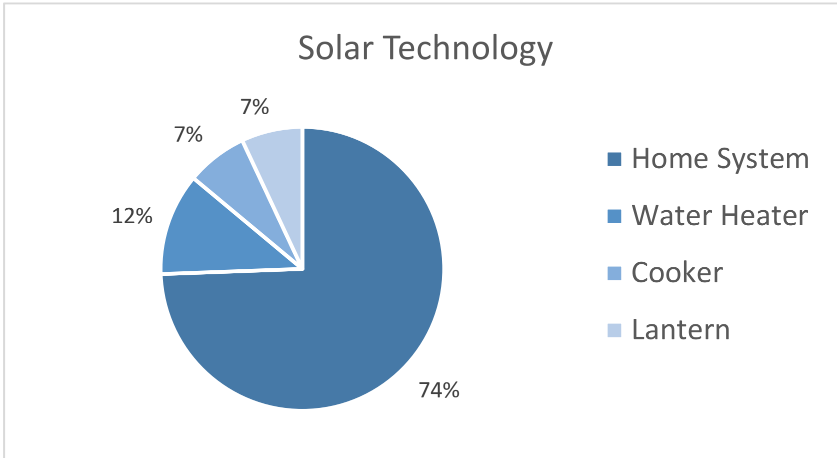
Appendix 9
Distribution of Papers by Year Published



Appendix 10
Count of Papers by Country



Appendix 11
Distribution of Research by Technology



Appendix 12
Distribution of Papers by Ownership Model