Power for Development: A Review of Distributed Generation Projects in the Developing World

Jennifer N. Brass,[1] Sanya Carley,[1] Lauren M. MacLean,[2] and Elizabeth Baldwin[1]

[1]School of Public & Environmental Affairs and [2]Department of Political Science, Indiana University, Bloomington, Indiana 47405; email: brassj@indiana.edu, scarley@indiana.edu, macleanl@indiana.edu, baldwine@indiana.edu

Annu. Rev. Environ. Resour. 2012. 37:107–36

First published online as a Review in Advance on August 28, 2012

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

This article's doi:
10.1146/annurev-environ-051112-111930

1543-5938/12/1121-0107$20.00

Keywords

energy policy, electrification, renewable energy, collaborative governance, DG, developing countries

Abstract

The paradigm for providing affordable electricity for the world's poor—power for development—has begun to change. Historically, centralized governments built large consolidated power plants and distribution and transmission lines with the ultimate goal of providing electricity to all of their citizens. It has become increasingly common in recent decades, however, for donors, nongovernmental organizations (NGOs), firms, and communities to collaborate with governments to develop small-scale localized energy systems known as distributed generation (DG) either as complements or alternatives to centralized operations. DG programs have been implemented around the world but with a mixed record of success. Based on an analysis of the existing case study literature, we examine DG program goals and outcomes, identifying major factors that affect these outcomes, including appropriately chosen technology, adequate financing and payment arrangements, ongoing end users' involvement, and supportive national policies. We highlight the importance of institutions for collaborative governance in the pursuit of these factors.

Contents

INTRODUCTION: OPPORTUNITIES AND CHALLENGES OF DISTRIBUTED GENERATION

The paradigm for how to provide affordable electricity for the world's poor—power for development—has changed over the past two decades. Historically, highly centralized (and often authoritarian) governments built large-scale hydroelectric dams and power plants, as well as lengthy distribution and transmission lines, with the ultimate goal of providing electricity to all of a nation's citizens. Today, however, a wide range of actors quietly contests this centralized and top-down approach to electrification. Donors, nongovernmental organizations (NGOs), private-sector firms, and communities are collaborating with governments to develop small-scale localized energy generation systems known as distributed generation (DG). For example, a household may install a set of solar photovoltaic (PV) panels to provide lighting or a community may use a microhydropowered mill to grind residents' grain and thus add value to crops. DG is an increasingly common alternative or complement to large-scale grid electrification because of its promise to enhance local decision making, facilitate energy access for the poor, and protect the environment.

DG systems can range from microgeneration units of as little as one kW up to three MW systems (1, 2). Two or more DG units can be pieced together into a microgrid connected by low-voltage distribution lines (3). The small scale and localized placement of these DG applications allow communities or households to tailor energy supply to local demand and employ systems that match their power use, or load profile, over time in a way that centralized options cannot (4). Electricity loss is minimized, and the significant costs of grid extension are avoided. Several recent studies have found that decentralized electrification can be more cost-effective than grid extension, even for communities only 5.4 km from the grid (5–7).

A variety of energy technologies can power DG systems, including diesel, distillate oil, natural gas, geothermal, wind, biomass, microhydroelectric, solar, or a hybrid combination of these sources. Our analysis considers both renewable and nonrenewable DG resources, although we find that scholars devote far more attention to renewable forms of DG. Although diesel generation historically has been common in areas where grid access is nonexistent or unreliable (8), its drawbacks include noise, emissions, high fuel costs, and inconsistent fuel availability (9, 10). Renewable forms of DG are increasingly popular in developing countries, in part, because they avoid many of these problems. Compared to diesel, renewable DG emits less local air pollution and carbon dioxide. This latter benefit is increasingly important to donors; large development institutions like the World Bank and United Nations Development Programme (UNDP) are major funders of renewable DG.

DG systems have significant potential to serve communities without access to the grid—currently over 20% of the world's population (11). Many of these communities have few prospects for grid access because it is simply not cost-effective for central governments or private utilities to serve less-populated, poor communities where residents' electricity needs are relatively minimal (12). Access is even less likely in remote areas, where the costs of grid extension are prohibitive (10, 13–15), regardless of whether the energy provider is public or private (16, 17). DG offers a way to meet these users' basic needs without incurring the significant financial investment needed for grid infrastructure extension.

Since the 1970s, many DG projects have been implemented to serve different communities around the world. For example, Grameen Shakti, a private company connected to the Grameen Bank NGO, installed over a half million solar home systems in Bangladesh as of 2010, nearly 40% of them in 2010 alone (18). State governments in Brazil, likewise, have implemented large-scale DG programs as part of the national government's Light for All campaign. Case studies evaluating these and other DG projects and programs, however, show significant variation in DG project outcomes. Some of these projects and programs demonstrate that DG systems can provide poor communities with long-term, sustainable access to electricity (19, 20). Others have left behind a wake of inoperable systems in the years after initial installation (21, 22).

Even though some implementers have documented lessons learned from past projects (23), there has been little scholarly examination of what constitutes success or failure. Clarifying the DG project goals and outcomes is not merely an academic exercise; it is needed to support a growing DG program evaluation literature that assesses impacts. Also absent is a scholarly synthesis of the factors that lead to success in particular circumstances. Such synthesis is necessary because DG projects occur in divergent social, cultural, political, and economic settings. Thus, despite the growing global interest in DG technologies, we lack a systematic understanding of why DG programs are implemented, how they should be assessed, and what factors lead to successful programs. Individual case studies of DG projects contain a wealth of knowledge on precisely these subjects, yet few scholars have attempted to synthesize this information in a comprehensive manner.

This review provides such a synthesis. We use quasi-meta-analysis to examine the existing case study literature of DG programs in the developing world. This review proceeds as follows: We (*a*) present our methodological approach, (*b*) present a descriptive overview of the case study literature, (*c*) track and compare the outcomes of interest in the DG case studies discussed, and (*d*) examine the primary causal factors associated with these outcomes to generate hypotheses for future research and policy analysis. In the conclusion, we summarize our findings and discuss the implications for policy makers and for future research.

METHODOLOGICAL APPROACH FOR ANALYSIS OF CASE STUDY LITERATURE

Our analysis is based on 60 randomly selected case studies of DG projects that have been implemented in developing countries, published in English between January 1995 and September 2011, the time of research. We used a wide variety of search terms, including power, electricity (and variants), generation, distributed, decentralized, renewable, diesel, global South, developing countries, rural, urban, NGO, private sector, business, and collaboration. We combined these search terms in a systematic manner, drawing first from a primary list of terms and then adding secondary and tertiary terms as we moved through iterations of searching. We also used the bibliographies of selected articles to find additional DG references.

We chose 1995 as the cutoff publication date because anecdotal evidence suggested that most scholarly research on DG in the 1980s and 1990s focused on the technical feasibility of DG systems, whereas scholars began to examine the social, economic, and political contexts that affect DG outcomes beginning in the late 1990s. By this cutoff year, we captured as much of this social science literature as possible. We excluded gray literature produced by government agencies, intergovernmental organizations, donors, NGOs, and think tanks and instead relied on literature that has been vetted through the peer-review process. Our concern was that reports written by program implementers might systematically neglect to study project failure or might analyze their experiences on the ground less objectively than an unaffiliated writer.

We selected research articles that incorporated some social science component and did not focus exclusively on engineering or technology assessments. Unless it also included a review of an existing DG program, we dismissed feasibility studies, cost-benefit analyses, and prospective studies that used financial or technical feasibility modeling software, such as HOMER or RETScreen, to estimate results because we were interested in the on-the-ground implementation experience of programs.

This search process generated 605 articles pertaining to DG. Of these, we identified 107 as case studies, defined as articles that were primarily based on the empirical experience of actual DG installations. We then randomly selected 60 of the 107 case studies to read and analyze. These 60 articles were drawn from 20 journals representing social and natural sciences and energy and development foci. The 60 case studies are reasonably representative of the larger sample of 107 in terms of geographic location and type of DG technology, although slightly skewed with more cases from Asia and fewer cases from Africa. Our sample, however, may include some bias as our searches were restricted to articles in English.

To enhance coder reliability, we assigned each article to be closely read by both a faculty principal investigator and a student research assistant. We then systematically analyzed each article, focusing on the types of DG technology used; the geographic location of the project; the time period of program implementation; the time period in which research was conducted; the research design of the article including research questions, data collection, and analytic methods; the energy and developmental outcomes measured; and the political, economic, social, ecological, and technological factors that affected the outcomes. The entire research team of seven scholars met frequently during the analysis of the case study articles to ensure that the coding scheme was comprehensive, appropriate, and consistently applied.

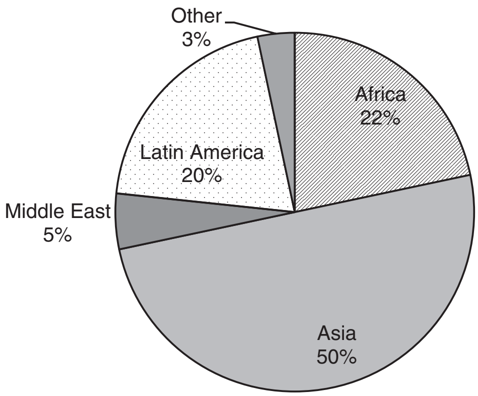

Figure 1

Regional distribution of case studies used for this review.

OVERVIEW OF DESCRIPTIVE DATA AND RESEARCH METHODOLOGY

The 60 case study articles in our sample reveal that DG is implemented and studied in many countries and in every region of the world. The distribution of case studies, however, suggests that empirical analysis of DG experiences is more common in certain countries and regions than others. For example, although our sample includes cases from five continents, half of our case studies are from Asia (see **Figure 1**). This might reflect more DG activity on the ground in Asia, or it may simply show more scholarly interest in the region. **Figure 2** identifies the countries with three or more case studies in the sample. Notably, over half of the Asian case studies are from India. The relative size and density of India's population obviously influences the level of DG activity; however, at least some of these case studies may have been motivated by the need to review and evaluate government programs and may have been facilitated by the level of high-quality universities and research centers in the country.

Just over half of our sample countries are classified as "medium human development" countries (52%), according to the United Nations Development Programme's Human Development Index (HDI). This category, the second lowest of four classifications, includes South Africa, India, Thailand, and El Salvador among other countries. As with the geographic distribution of the case studies, the distribution of case studies by HDI may be skewed by India's inclusion as a medium-HDI country. That said, DG projects do not always take place in a country's typical socioeconomic context.

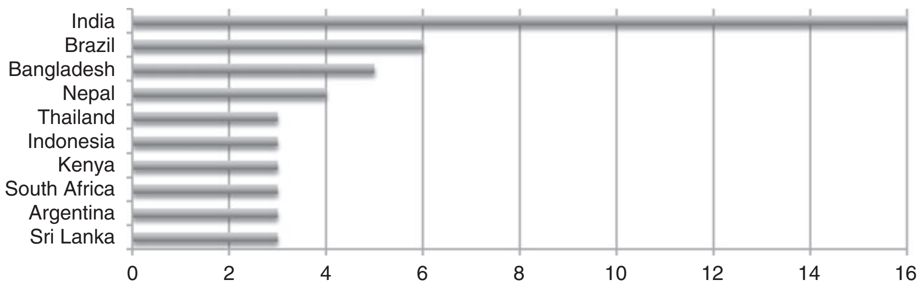

Figure 2

Frequency of the case studies, used for this review, on key countries.

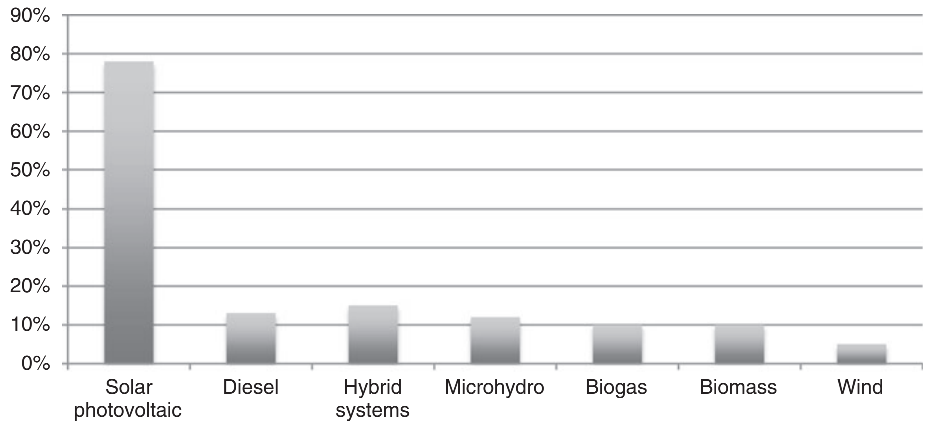

Figure 3

Percent of case studies focused on various types of distributed generation technology. The total is greater than 100% because some cases discuss more than one type of technology.

In low-HDI countries (28% of sample), the case studies suggest that households with DG systems tend to have higher incomes and more education than other residents (24). Similarly, in high-HDI countries (20% of sample), NGOs may choose to implement DG projects in particularly remote or poor communities (25).

As presented in **Figure 3**, the case study articles in our sample also span a wide range of DG technologies, including solar PV, micro- and picohydro, diesel generators, wind, biogas, biomass, and hybrid systems. Solar PV units are the most common form of DG in our sample (78% of cases) and include solar lanterns, solar home systems, and large PV generators that supply multiple households.

These cases describe programs or projects that began between 1970 and 2009. The cases suggest that DG projects—or at least scholarly analysis—have increased significantly since a turning point in the 1990s. Of the 60 cases, 3 began in the 1970s, 6 in the 1980s, 19 in the 1990s, and 15 in the 2000s. However, 17 case studies provide no information on when the project began. At the year of publication, 37 of these projects were ongoing, 8 had definitively ended, and information for the remaining 15 was undisclosed.

Critiques of the Existing Case Study Literature: Issues with Research Design and Author Perspective

Although the cases use a wide variety of research approaches, we discovered several common research design and methodology weaknesses. These weaknesses are not unique to case studies on DG. In fact, prominent donor organizations have bemoaned the widespread lack of rigorous studies that assess the impacts of development projects (26, 27). These organizations identify several reasons why this "evaluation gap" persists and recommend rigorous methodological approaches that are well-suited to the logistical, ethical, and political challenges of development projects (28). Unless these methodologies are widely adopted, however, project planners will have little understanding about which development interventions are most successful, whether interventions achieve the desired impacts, and the conditions that contribute to project success (27). Our sample of case studies illustrates this problem—the studies present a wealth of information, but their overall methodological weaknesses limit our ability to make definitive analytic inferences or draw conclusions about the factors that cause DG success or failure.

The first weakness we identified is that a substantial number of the articles lack some of the fundamental elements of empirical social science research, such as a clearly articulated question and hypothesis, properly identified research design, transparent methodology, or a systematic approach to causal inference. Thus, a significant number of the articles do not present a discernible research question (29–37), and several others allude to fieldwork but provide no information about the methods used to gather data (19, 32, 34, 35, 38–40).

Second, many case studies have weak research designs, which makes it difficult to attribute outcomes solely to the DG project. For example, few studies include a control group of nonusers as a basis for measuring the impact of DG systems on end users. Similarly, most articles report only posttreatment data from end users. Less than one-third of the studies also report pretreatment data, and many of these studies use potentially unreliable sources, such as respondent recall or publicly available information. With some noteworthy exceptions (41–43), the prevalence of posttreatment research designs with no comparison group means that most case studies do not reliably measure the actual changes in peoples' lives resulting from DG access.

Third, the majority of survey analyses in our sample rely on the head of the household as the primary respondent. These surveys neglect two potentially important types of information: (*a*) a female perspective because women generally are not considered the head of the household, and (*b*) other DG market participants' perspectives because DG projects often involve a wide range of actors. Noteworthy exceptions include the Komatsu survey (41), which specifically focuses on women's experiences with solar lanterns, and Acker & Kammen (44), who interviewed a Kenyan solar company to get their perspective on the solar PV market, as well as residential owners of solar PV systems.

Fourth, the disciplinary background of the authors is often indiscernible. It is evident from the names of authors' home departments, however, that the majority of scholars work within mechanical or electrical engineering. The remaining disciplines represented in the sample include the natural sciences, political science, public policy, and economics. A key finding from our analysis is that social science disciplines are heavily underrepresented in this group of randomly sampled case studies, despite our deliberate selection of articles with a social science component.

Finally, the research team coded for possible personal affiliation with the projects, using the information provided in the authors' contact information, descriptions of their roles or affiliations in the body of the article, and explicit mention in the acknowledgments section. Any direct sign of affiliation was considered a potential source of institutional bias or conflict of interest. A surprisingly high percentage of articles, approximately 55% of the sample, fit into this category of potential conflict of interest. This high incidence raises questions about author objectivity. Although we lack sufficient data to test whether authors with a conflict of interest were systematically more likely to claim DG project success, we find that some of the articles with possible bias made claims about DG project success that were unsubstantiated by the empirical evidence they present (33, 45). While the peer review process increases the likelihood of objectivity relative to literature that is not subject to external independent review, the potential sources of conflict of interest remain but are often less transparent. Gray literature authors are often more explicit about their affiliations and potential biases, and indeed, they often write with an express purpose to advocate for a particular outcome.

OBJECTIVES AND OUTCOMES OF DISTRIBUTED GENERATION PROGRAMS

One of our initial research goals was to examine the motivations of donors, implementers, and other actors involved in DG programs. By examining these objectives, we hoped to deepen our understanding of how project implementers defined and measured successful outcomes. It was surprisingly difficult, however, to identify the actors' objectives, analyze variation in their definitions of success, and assess whether DG projects had been successful.

Many case studies simply do not identify program objectives. As a result, our research team members had a high level of intercoder variability in the interpretation of project objectives. Some studies, for example, explore aspects of DG, such as users' preferred types of DG system, which are not directly related to the objectives or outcomes of the underlying DG project (43, 46). Other studies assess patterns of end-user interactions with DG technologies, such as users' ability to maintain systems, or changes in end users' electricity usage over time (43, 47). Still others document pilot technologies or innovative methods of disseminating DG technologies but do not address project objectives or outcomes (30, 40, 48–50). Finally, some studies do not focus on single DG projects but instead survey multiple users or implementers about their experiences (51, 52).

Even where studies claim to examine program objectives, it is difficult to infer the implementing actors' actual expectations and motivations. Some studies, for example, introduce a diverse range of potential DG outcomes, but only evaluate one or two in depth. They often choose easy-to-measure metrics, such as increased study time for children who gain electric light, which may not represent the full range of project objectives. Other studies provide insufficient information to distinguish between project objectives and an author's particular interests. For example, one study of a solar lantern project in India measures the program's impacts on low-caste women (42). It is not clear, however, whether these women were specifically targeted by the program or were a research interest of the authors. Finally, studies rarely systematically assess whether or not the project achieved the highlighted objectives.

The lack of explicit attention to objectives may reflect the fact that many projects have multiple objectives, particularly those in which multiple actors, such as government agencies, donors, NGOs, businesses, and local communities, participate in planning, funding, or implementation. These different actors may naturally have diverse goals and motivations. For example, in the same project, an international funder may be interested in reducing greenhouse gas emissions, a government agency might be interested in meeting national electrification goals, and an NGO might be interested in improving local health and education outcomes. Indeed, several case studies imply that funders' objectives differ from end users' objectives, particularly regarding environmental impacts of DG (44, 53). Objectives, moreover, can change over the course of a program, especially if it lasts for many years.

Owing to the opacity of DG project objectives, we abandoned the notion of defining or assessing project success and instead focused on examining the range of actual DG outcomes. Most case studies include observations or measurements of project outcomes, and several provide rigorous evidence from surveys, interviews, and other fieldwork. To gain analytic leverage over the wide range of project outcomes, we developed the typology presented in **Table 1**. The typology has two dimensions: (*a*) whether project outcomes are short or long term and (*b*) whether these outcomes relate to technology access or to development benefits. Here, we define development benefits broadly to include economic development and improvements in the quality of life, educational achievement, health, or environmental conditions. Below, we examine the extent to which the case studies focus on these broad categories of outcomes and identify the way that these outcomes are conceptualized and measured in the case studies. We then address the factors that affect these outcomes.

Short-Term Access to Distributed Generation Technology

Initial access to DG technology is a necessary precursor to all other DG outcomes. Accordingly, most case studies in our sample discuss or measure short-term technical outcomes in some way. The notion of access is conceived

Table 1 Conceptual typology of outcomes and prevalence in distributed generation case studies

	Short term	Long term
Focus on technology	**High prevalence in the case study literature:** Number of units installed Percentage of households using technology Initial comparisons of costs of technology	**Medium prevalence in the case study literature:** Funding stream over time User perception of costs based on long-term experience Number of units still operational Number of missing units Project replicability
Focus on development	**High prevalence in the case study literature:** Household savings on energy New commercial activities Increased study hours	**Low prevalence in the case study literature:** Environmental impacts Educational effects Health outcomes Social/cultural changes Political consequences

generally as a dichotomous variable: either households or communities adopted the DG technology, or they did not. Studies often measure access to electricity as the number of units installed (31, 42, 45, 47, 54, 55) or as the number of users or percentage of a population that adopted the technology (37, 44, 56–60). These metrics may appeal to program evaluators because they are quantifiable in discrete intervals and can be assessed within months after a DG project began implementation. Studies of large-scale projects implemented by national governments or international organizations also tend to focus on short-term access (45, 54, 55). However, measures of short-term access provide limited information about actual project outcomes, and many studies subsequently analyze other outcomes in greater depth.

Cases often explore short-term access through the lens of the end user's decision to adopt DG (e.g., 57) by surveying end users about the costs and benefits of PV systems. Some measure the up-front costs of PV systems, an issue that is particularly relevant where users have little access to credit (e.g., 24). Others compare the average energy expenses of DG users and nonusers. Here, results suggest that energy savings is variable and context specific. In two case studies, survey evidence shows that solar PV users have lower household energy expenses than nonusers who rely primarily on kerosene (41, 42). Other studies reach different conclusions, for example, finding that PV users pay more for lighting, but also enjoy the benefits of convenience and better light quality (61).

A few articles focus on the more nuanced dimensions of the sufficiency or quality of access to electricity. For example, Agoramoorthy & Hsu (42) show that, in 70% of the villages in the DG project area, grid access provides insufficient power in the hours before dawn and after dusk. Several other studies find that DG users increase electricity consumption over time, so that systems that were initially sufficient may become insufficient in subsequent years (e.g., 43). Others question whether the amount of voltage generated by DG projects—or by the grid—fluctuates (60, 62). Too much fluctuation in voltage makes a system unreliable and difficult to use.

Long-Term Access to Distributed Generation Technology

Not all DG projects continue to provide electricity access over time. Whereas most case studies assess project outcomes less than five years after installation, a small number of case studies revisit projects after a more extended period of operation to assess the systems' technical performance (15, 22, 34, 44, 63).

These studies show that the long-term technical sustainability varies considerably between

DG projects. For example, an Indonesian case study found that, nine years after installation, virtually all of the solar home systems in an Indonesian village were in good working condition (20). In contrast, the case study investigating one of the longest-running projects, a PV project begun in Thailand in the late 1980s, is also one of the most pessimistic in its tone; Green (22) reveals that 60% of the project's solar home systems were no longer operational after ten or more years of use, leading her to pejoratively term the project's systems as "white elephants" in the article's title.

The most frequent measure of long-term technical sustainability is a simple field assessment of whether DG systems are operational (20, 22, 44). However, PV systems in particular may be functional but operate below capacity owing to problems with batteries or other system components. Accordingly, several surveys assess long-term access in more nuanced ways, such as checking a system's technical compliance against the project specifications (64) or surveying long-time users about their personal satisfaction with systems (24, 44).

Some articles also discuss nontechnical aspects of long-term DG access. Several articles document innovative pilot hybrid diesel-biomass and -biogas projects in remote Indian villages, which operated successfully for over ten years with few outages (e.g., 65). A follow-up article, however, shows that some projects have been discontinued, not due to technical failure, but rather owing to problems with the financial viability of these systems once grid access became available (66). Similarly, Zerriffi (67) questions the long-term financial sustainability of the business model for utility-run DG projects in Brazil, which mandates universal access to electricity at low prices for rural users, requiring utilities to operate at a loss and ultimately requiring significant subsidies from the Brazilian government.

Short-Term Development Outcomes

Although almost every study discusses development outcomes in some way, very few measure or systematically evaluate development outcomes. In some cases, development benefits are described briefly and in overly general terms, suggesting that the author simply assumes these benefits will materialize once DG systems are installed (29, 34, 45, 57, 65, 68). For example, Claus (29, p. 22) claims that DG resulted in "health advantages, for women and children in particular" and "income-generating activities were initiated" as a result of the project.

A minority of case studies provides empirical evidence about the range of short-term benefits from DG projects. Roughly ten case studies survey or interview users about their experiences with DG systems and consistently find that users perceive improvements in their quality of life due to DG. Survey evidence shows that DG users have more access to television, radio, and cell phones, and enjoy more opportunities for entertainment and socializing (69, 70).

Educational impacts are frequently studied, usually conceptualized as the increase in study time afforded by better quality and duration of light. Although many case studies vaguely cite an increased opportunity to study in the evenings (22, 32, 44, 57, 58, 63), the survey findings from a handful of studies reinforce each other, suggesting that children in households with DG systems study between 1.26 hours to 2.25 hours more per day compared to households without electricity access (41, 42, 61). A small number of studies also provide evidence that DG helps villages attract, retain, and support better teachers. For example, Alazraki & Haselip (56) find that 63% of teachers can teach more effectively with the ability to use new tools in the classroom, such as television and radio. Teachers can also use DG lighting to prepare for the next day's classes and hold more parent-teacher conferences. Banerji & Baruah (32) find greater access to educational resources for both children and adults.

The case studies provide evidence that DG has short-term impacts on women. Survey results show that DG access extends women's morning and evening working hours (61). Other studies observe that DG can reduce women and girls' workloads; for example, when DG use displaces fuelwood use or provides electricity for water pumps, women and girls do not need to gather fuelwood or haul water (63, 69). These benefits, however, generally require DG systems that do more than merely power lights.

DG use might also improve short-term health outcomes, particularly for women. For example, in one case study, 21% of respondents on an island in West Bengal, India, report that their family members suffered from eye problems that could have been avoided by using electric power (61). In addition, other DG case study authors hypothesize that reducing indoor air pollution could also reduce the incidence of respiratory illness and the risk of burns and injury from kerosene fires, particularly for women (55, 57).

Even though many case studies claim that DG creates new economic opportunities, the empirical evidence is mixed. Several studies show that DG allows shopkeepers and women to extend their evening working hours, but few assess whether this actually increases economic gains (41, 61). For example, Chakrabarti & Chakrabarti (61) find that 46% of respondents reported a longer period of time available for trade and business but do not explore whether this boosts sales volume or incomes. A handful of studies observe that community-based biogas plants or microhydroplants add value to agricultural production by providing power for irrigation, flour milling, and coffee hulling (35, 65) but do not assess any resulting changes in income. Several studies refer to new jobs created by the DG projects themselves (29, 71), from the possibility of selling certified emissions reductions to industrialized nations (72) or from an increase in tourism and the subsequent demand for handicrafts (32, 62), but these claims are not backed by evidence. Only Kirubi et al. (73) systematically measure economic gains, showing that access to DG microgrid electricity resulted in substantial productivity and gross revenue gains for small enterprises in Kenya.

Meanwhile, several authors dispute the link between DG provision and new economic opportunities, particularly with solar PV projects (22, 56, 60, 74). For example, Green (22) finds that businesses using solar PV cannot stay open later when the energy produced is insufficient to power necessary equipment, such as sewing machines at night. Similarly, Hajat et al. (47) suggest that new economic opportunities are constrained by the limited or intermittent nature of solar PV, which may not provide enough power to run refrigeration units.

The studies rarely explore the question of whether DG differentially affects users by socioeconomic class. Several studies find that DG users frequently have higher incomes than average residents (42, 44). Two studies provide survey evidence, however, that low-income people experience the benefits of DG in different ways than higher-income people. Agoramoorthy & Hsu (42) survey end users of solar lanterns and find that users below the poverty line experience smaller increases in study time compared to users above the poverty line. Bhandari & Jana (46) find that low-income households generally prefer solar minigrid systems to solar home systems, in part because, although the minigrid systems provide less electricity to individual homes, they also impose fewer costs on end users. Preliminary evidence from other case studies suggests that low-income users may receive greater benefits from community-wide systems that provide access to all users, regardless of income (66).

Long-Term Development Outcomes

Many case studies mention the potential for DG to improve long-term development outcomes, such as environmentally sustainable use of natural resources; improved levels of health and education; and social, cultural, or political development. Even though these potential benefits from DG are often mentioned in case study introductions, very few of the case studies explicitly measure or explore these benefits in greater depth. This dearth of long-term development evaluations is likely caused, at least in part, by the practical challenge of evaluating lasting impacts of a specific project or program. Researchers who want to determine the causal impacts of a program must pay careful attention to research design and sample selection, and they need to assess the outcomes of interest both before and after the program is implemented, with an understanding of a counterfactual. Limited resources might reduce some researchers' ability to undertake this kind of long-term causal assessment of outcomes. Nonetheless, our case study selection process was designed to identify not only small-scale case studies, but also large-scale reviews of DG efforts across both time and space, and we found few articles that provided meaningful evidence or discussion about the long-term benefits of DG. The lack of assessment of enduring development outcomes shows that this is an important gap that remains to be filled in the DG literature.

Most case studies refer to the environmental benefits of DG, as one would expect given that much of the enthusiasm from scholars, policy makers, and politicians for DG stems from the renewable technologies that emit little or no carbon dioxide. Indeed, some of the largest DG donors, such as the Global Environmental Facility, are specifically interested in funding projects that promote environmentally sustainable pathways for economic development. Despite the focus of DG donors, surprisingly few studies provide evidence about the actual environmental impacts of DG projects. This may be because most case studies are too narrow in scope, both geographically and temporally, to accurately measure long-term environmental impacts, particularly regarding global environmental problems like climate change (75, 76).

Local environmental impacts receive slightly more attention, with a tendency to focus on local air quality (31, 63, 65). However, only one case study systematically measures the local environmental impact of DG projects, by comparing local emissions of pollutants from an aging diesel DG system with a new hybrid solar-diesel system (70). A handful of studies estimate the household cost savings from avoided kerosene use but do not attempt to assess any corresponding environmental benefit, whether local or global (42).

A small number of case studies identify reduced deforestation as a DG project objective, albeit with little evidence showing reduced deforestation rates (65, 77). Moreover, some case studies suggest that the electricity produced by DG is rarely used for cooking, does not offset the use of wood for preparing food, and thus is unlikely to reduce deforestation significantly (44).

Given donor interest in environmental sustainability, it is surprising that so few case studies in our sample seek to measure environmental effects of DG. Some case studies, however, explicitly state that DG projects are, and should be, motivated primarily by development concerns rather than environmental benefits. For example, two case studies from Africa conclude that the environmental benefits from DG in Africa are too minimal to provide the sole justification for DG projects and technologies (44, 78). Likewise, a survey of PV users in Kenya finds that only 3% report interest in the environmental benefits of DG (44). These findings echo a broader concern that poor nations with low historic greenhouse gas emission levels should be allowed to focus on economic development, without simultaneously seeking emission reductions (79).

Other long-term development outcomes are similarly understudied. Many case studies measure short-term impacts on education, yet only one study evaluates long-term changes in these outcomes, finding that student enrollment and completion rates increased after the installation of the DG system (69). That study, however, relies on participants' perceptions of changes in educational outcomes over time, without controlling for other factors that might have contributed to the change. An increase in nighttime study hours may result in longer-term educational outcomes, such as primary and secondary school enrollment, retention, and completion rates, but the case studies lack adequate information to prove a causal connection between DG and long-term educational outcomes.

Health outcomes receive even less attention than education, despite ubiquitous references to them in the case study introductions. Even though survey respondents often report decreases in burns and respiratory illness, only one case study attempts to measure the long-term health effects from DG, again relying on end users' perceptions of changes in their health over time (69). A number of case study authors do, however, hypothesize about long-term health effects. Some authors offer that outdoor lighting could improve security, particularly for women and the elderly, and reduce petty theft and violent crime (44, 57, 58). Others discuss the potential for electric-powered water pumps to enhance water sanitation and reduce bacterial illness (35, 58, 63), possibly contributing to lower infant and under five-year-old mortality rates. Authors also posit that DG could provide uninterrupted power to health care clinics and hospitals (32, 58, 61), enabling the refrigeration of vaccines and operation of surgical equipment, which has the potential to boost vaccination rates and lower maternal mortality rates. None of these claims are systematically measured, however; hence, these long-term health effects remain unsubstantiated.

Another long-term development outcome of DG highlighted in the case studies involves long-term social and cultural change. Several case studies describe a spillover effect to neighbors and others in the community from the increased availability of entertainment in well-lit community centers or on the radio and television in people's homes. In most cases, the consequences are considered positive, for example, raising people's self-esteem, strengthening social networks, and energizing the celebration of community traditions and festivals (32, 55, 56, 60). Only two studies note a negative effect on children's attention (41) or the vitality of traditional activities and cultural identities (48). Several of these changes have distinct implications for gender relations. Electricity in community centers provides women with a safe place to congregate, facilitating their economic independence and empowering them with greater social support (32).

Finally, the consequences for politics are long-term development outcomes that are almost never mentioned. Two case studies rather obliquely suggest that more television and radio might increase people's knowledge about current events (44, 57). Such enhanced civic education might invigorate political participation and lead citizens to hold their politicians accountable. Likewise, the prevalence of community- or group-based solutions might increase civil society levels, which are associated with greater democracy.

Expanded communication and governance activity at the local level might further increase citizen empowerment. For example, numerous DG projects involve local ownership and capacity building. In several case studies, an NGO worked with local communities to install a community-wide system in which a shared DG plant provides energy either to common public facilities or to all households in the village (32, 54, 59). Often, the local community eventually assumes responsibility for the DG facilities, providing new opportunities for local citizens to self-govern and to plan the future course of economic development in their community. In other cases, DG projects are designed to attract local entrepreneurs, who will eventually create businesses providing and maintaining DG systems (43, 80). This potential for citizen empowerment might also lead to greater demands for accountability from donors, corporations, NGOs, and state, regional, and national governments. Few of the case studies provide any long-term assessment of whether these systems actually build local capacity, and in at least one case, governance responsibility is later assumed by a government agency (66). None of these long-term outcomes for citizenship have been explored as of yet but certainly merit investigation in the future.

COMMON FACTORS THAT SHAPE DISTRIBUTED GENERATION OUTCOMES ON THE GROUND

Just as the case studies describe a variety of program outcomes, they also explicitly identify a wide range of factors that influence these outcomes. We examine these causal factors to identify patterns associated with particular DG outcomes. A handful of themes emerge on the necessary components for success, which include the following:

- Appropriately chosen technology to fit each context;
- Adequate financing and payment arrangements at both the program level and the individual energy system level;
- Ongoing involvement of end users in DG project planning, installation, monitoring, regulation, and maintenance;
- Supportive government policies and regulations related to program development and implementation; and,
- Effective institutions for collaborative governance.

The above themes emerge repeatedly across the case study articles, yet there are different patterns in the way that these themes operate, depending upon the technology implemented and contextual factors, such as geographic region or ranking on the UN HDI. For example, a DG project using solar home systems could require more end-user participation in maintenance than a community biogas system. Similarly, microfinance or payment arrangements may be most important in low-HDI countries, where most potential end users have no access to formal credit institutions. On the basis of these patterns, we develop several hypotheses, described at the end of each theme explanation, about the factors that are associated with successful DG project outcomes under different contexts.

Systematic empirical testing of these hypotheses, using appropriate rigorous and comparative methods, would provide valuable information to a range of actors seeking to improve DG projects, programs, and policies. Below, we discuss the ways that these five themes are identified in the cases, and we generate hypotheses for future empirical testing.

Appropriate Choice of Distributed Generation Technology and Technical Performance

Poor technical performance of DG systems frequently poses a challenge to successful projects. Unreliable, inadequate, or difficult to use systems may also undermine long-term project success. Technologies that are perceived as unreliable or inadequate are unlikely to be adopted by end users (46), and when DG systems perform poorly, existing users may become dissatisfied and refuse to pay agreed-upon tariffs (22, 25).

The case studies suggest that the likelihood of poor performance is reduced when project planners appropriately select DG technologies that match the natural and social characteristics of the community. Natural resource endowment is important for technological choice and performance, particularly when energy is derived from renewable sources that are sourced on site. For example, a sunny climate with high solar incidence is a prerequisite for solar PV DG. Obstructions and shading can reduce optimal performance (22), and weather patterns can hinder the reliability of the systems. For example, solar panels are not very productive during rainy seasons, and hydrosystems may not work at all during droughts (20, 60). Some DG projects address these resource and weather constraints by using hybrid systems, where two technologies complement each other to satisfy the full and fluctuating load (32, 59). Several authors highlight the need to gather detailed information about local conditions to choose the best-matched technology (20, 57).

The way that end users interact with DG technologies is also important. Unlike grid electricity, which in principle comes in an unwavering supply, energy from DG is limited in quantity and often intermittent, and users must adjust their consumption accordingly (37). Several authors focus on the interaction between energy supply and demand with solar PV systems, which often operate by charging batteries. For example, although smaller batteries may be sufficient to provide lighting, larger batteries potentially could provide lighting, income-generating activities, and power TVs and radios (22). Authors find that when batteries are not big enough for the load demand, they frequently operate at full load shed (i.e., where the battery is in overuse), which shortens battery life (47). While these studies explain that users must limit their electricity consumption, studies of users' actual consumption also show that households tend to increase their demand over time, until total energy demanded matches or exceeds total supply (37, 43). A small number of cases, however, suggest that community-scale DG projects are most cost-effective when used at or near full capacity (e.g., 62).

The case study articles also highlight consumers' need for convenient DG access. The findings of dos Santos & Zilles (25) demonstrate that inconvenient DG technology can lead to widespread dissatisfaction by end users and the eventual failure of the DG program. In this case study in the state of Alagoas, Brazil, users were required to carry heavy 25-kg batteries to recharging stations multiple times per week. It is not clear whether end users were involved in this technology choice, but as the program was implemented, users became unwilling to pay for the inconvenient technology.

In light of these technical constraints, projects should be designed to meet reasonable demands of citizens and communities for electric power. Some case studies suggest that project developers should consider whether the DG system is large enough to meet current needs, as well as whether the system can be scaled up to meet rising demand over time (37, 48). Others suggest that, at the very least, project implementers should ensure that end users understand performance limitations of DG systems, so that users can tailor their usage accordingly.

The above analysis suggests three testable hypotheses. First, projects that meaningfully involve end users in choosing DG technologies are more likely to achieve long-term technical success than other projects. Second, projects that account for natural resource endowment in the selection and design of the DG system will achieve greater technical success with the unit. Third, community-wide systems or hybrid systems that provide more consistent electricity may be more successful at achieving economic development outcomes.

Adequate Financing and Payment Arrangements to Manage Distributed Generation Costs

The case study articles reveal the importance of adequate financing and payment arrangements to manage the costs of implementing DG programs. Purely prospective feasibility studies that compare estimated costs were excluded from the case studies selected, but several case studies in our sample compare the actual costs of grid electrification, diesel generation, and renewable energy DG. Grid electrification is often (though not always) less expensive per kilowatt hour owing to economies of scale (81, 82). Experience over time, however, suggests that grid extension is unlikely to become available to the world's isolated, rural poor in the near future. Diesel generators typically cost two to three times more per kilowatt hour than grid electricity and are susceptible to fluctuating fuel costs. In comparison, renewable DG systems are often cost competitive with diesel per kilowatt hour but pose higher up-front costs to end users (42, 61). Thus, one of the major challenges of DG projects is helping end users overcome this initial cost hurdle.

Assistance with Financing Initial Capital Costs

Over 75% of our sample cases discuss assistance with initial capital costs. Authors mention loan mechanisms most frequently, but donations of equipment and labor, as well as subsidies for DG, are also discussed. Financial assistance comes from a wide range of actors. Governments provide some form of capital cost assistance in over half of the cases. NGOs play a financial role in about 20% of the cases, usually as microfinanciers, and about 20% of articles describe either donor or private-sector financing. These sources are not mutually exclusive; multisource funding is common. In a project in Morocco, for example, an NGO paid for capital costs, and the community end users financed the installation costs (59). Many case studies do not clearly explain where funding comes from, however, or whether assistance is in the form of donations or loans. Nonetheless, we draw some basic conclusions about capital assistance below.

Loans and donor funds are the most common way to finance the capital costs of DG projects and thus enable local government agencies or NGOs to initiate DG programs. Large donors, such as the World Bank or bilateral foreign aid agencies, often make funds for subsidized loans available to DG project implementers, which are usually NGOs or government agencies (55, 68). European donor countries sometimes provide funding, although the case studies often do not clarify whether such funds are interest-free donations or loans. Private banks sometimes provide DG program funding (55, 80), but these loans are less common and sometimes difficult to obtain, particularly for small or local actors. In Rwanda, for example, implementing microbusinesses failed to obtain loans until a multilateral development bank partially guaranteed them (80). NGOs also sometimes directly fund DG systems or provide in-kind assistance with installation and training (35, 41, 42, 55, 57).

Developing country governments also assist DG project implementers with capital funding. For example, in Brazil, India, Thailand, and South Africa, the government directly subsidized the capital costs of DG systems (22, 54, 56, 57, 83). National governments sometimes provide loans to local NGOs or to utility companies that implement programs, particularly in medium- or high-HDI countries. Governments also connect program implementers with financiers (43) or administer donor loans (55, 68).

Financing schemes for end users are also important to disseminate DG systems widely and to ensure that community members with limited incomes have access to DG systems. Governments, NGOs, and private energy companies frequently offer microfinance loan packages or repayment options to end users (e.g., 33). Without some of these lending mechanisms and subsidies, PV systems would likely remain in the hands of relatively wealthy individuals (68). Thus, financing schemes should be designed carefully; they must match end users' ability to pay, and payment methods must be reasonably convenient. Where finance arrangements do not suit end users' needs, projects may flounder because of low uptake (57) or low rates of payment (21). Additional problems may arise when the entity implementing the program does not share the donors' social objectives. In one case study, for example, the government agency administering DG loans systematically excluded certain users from receiving funds, despite donors' wishes to target these users (55).

Because many case studies do not include detailed information about lending mechanisms, it is difficult to predict the patterns that are related to success or failure. Nonetheless, several hypotheses emerge that deserve further empirical testing. First, access to microfinance/credit improves user uptake rates, especially in low-HDI countries and poor communities with less-developed credit institutions. Second, the actor that administers credit programs, e.g., a government agency, local NGO, or international donor, may be associated with significant differences in either short-term rates of dissemination or long-term rates of technical success.

Appropriate Payment Arrangements to Meet Ongoing Costs of Distributed Generation Systems

Although initial capital costs are the biggest DG project expense, other costs include ongoing administrative, program management, and system maintenance costs. In our sample, however, less than half of the authors explicitly discuss postinstallation program funding. Broader program funding often comes from national government ministries responsible for electrification programs, usually in combination with funds from a bilateral partner (7, 47) or a multilateral donor agency, such as the Global Environmental Facility, the World Bank, or the UNDP (9, 36, 56, 68, 72). Authors also discuss NGOs and the private-sector programmatic funding (7, 35, 36, 38, 45, 48, 55).

In most projects, end users pay for their ongoing costs and/or a portion of capital costs through fees and usage tariffs. In projects with limited donor funding, end users' ability to pay for ongoing costs is crucial to program success. Despite early concerns that remote and poor communities would be unable to pay for DG systems (55), the consensus in the literature now is that the poor are willing to pay. Indeed, in some cases, they pay many times more than their less-remote compatriots (70) or than they pay for nonelectric energy sources (29). For similar reasons, end users sometimes prefer the higher up-front costs of renewable DG systems if it will save money in the long run (61, 84). In other cases, end users are willing to pay but prefer flat access fees to per kilowatt hour tariffs because flat access fees facilitate budget planning, which is especially important for the very poor (31, 63, 65, 80). In two studies, however, demand for community-based DG electricity decreased considerably when the community switched from a flat-fee for (unlimited) access to a fee-for-use system (9, 58). While fee-for-use systems more effectively align consumers' demand with their willingness to pay, the introduction of meters measuring actual usage in these communities meant that some households had been consuming more electricity than they could afford—thus the decrease in total demand.

Nonetheless, there are many projects in which end users are unable or unwilling to pay. When end users believe that their community will soon be connected to the national grid, payment rates may decrease (59). Customers are unwilling to pay when costs are simply too high for local incomes (54, 59) and when project implementers fail to adequately maintain systems (21, 22). The case studies also reveal important trade-offs between the short- and long-term fee structures and short- and long-term DG success. Low prices might facilitate the initial uptake decision (24, 44), especially by the poor, but if low fees translate into poor installation quality or lack of maintenance, users' willingness to pay diminishes (21, 22, 25). If many end users refuse or are unable to pay, the project cannot collect enough revenue to maintain and continue the system, and the DG systems may eventually fall into disrepair and disuse.

End users' willingness to pay also depends upon the ability of the DG system to meet particular local needs, which vary both across and within communities. Relatively poor individuals and communities tend to prefer that programs install minigrids or community-level programs, whereas wealthier individuals tend to implement single-family solar home systems (29, 32, 41, 46). On the one hand, minigrids allow the very poor to spread the installation costs among several users. Solar home systems, on the other hand, are relatively easy to tailor to perceived load demand at the time of purchase, making them cost-effective for those who can afford them.

The above discussion about payment arrangements leads us to at least two hypotheses for future testing. First, projects with multiple payment options are likely to have significantly greater DG dissemination. Second, we build on our earlier hypothesis that end-user involvement in selection of technology is associated with long-term technical success. Here, we add that these end users are more likely to be satisfied with DG performance and to pay consistently when they are involved in program decision making, which, in turn, ensures funding for the ongoing maintenance that is crucial to long-term technical success. In the following section, we analyze the need for the ongoing involvement of end users, not only in financial arrangements, but also at each stage of DG projects.

Ongoing Involvement of End Users and Communities

The first two themes, on the appropriate choice of technology and the development of suitable financial assistance and fee structures, both demonstrate the critical need to involve end users in DG systems. End-user involvement is frequently cited as an important factor for success, and, conversely, failure to involve local communities and end users is frequently associated with problems in the case studies. Even though most studies emphasize end-user involvement in particular phases of the project, often the planning or maintenance stages, a small minority of studies identify the need to involve end users in all stages of DG project implementation (85).

Preproject planning. In any DG project, some actor(s) must propose an idea and begin planning when, where, and how technology will be used. Sometimes, government agencies conduct feasibility assessments (7, 84) and select suitable sites to test niche or emerging technologies (63, 65). In other cases, particularly where governments may have fewer resources to devote to these activities, donors conduct the assessments and high-level planning (45, 55, 57, 60). Regardless of who initiates planning, the case studies demonstrate that community and end-user involvement is vital in the very earliest stages. Several studies discuss the importance of community input in the preinstallation phases when technology is selected and finance schemes are developed. Although only a small number of DG projects engaged users in this way, several studies suggest that this type of involvement would have avoided later dissatisfaction with DG systems (19, 21, 48, 54, 59, 86).

Dissemination and diffusion of distributed generation. Beyond the planning stage, several studies report an important role for local community members in disseminating information about DG projects. This is particularly important in top-down approaches to DG in which international or national actors seek to disseminate DG systems to end users, and the project depends upon these end users choosing to adopt the systems. In this phase, end-user involvement operates in two ways. First, community members "buy in" to the program. Without a meaningful role in the project, potential users may see it as belonging to outsiders, and community acceptance of projects may be low (34). Second, community members are an important source of information for individuals considering using a DG system; many projects use a local NGO, community leader, or other organization to provide information about DG technologies to end users. Where DG programs fail to reach as many homes as hoped, studies suggest that greater use of community social networks could have boosted awareness and increased dissemination of programs (54).

Installation. Community members are also often involved in DG installations, which require technical competence. Unlike provision of capital costs, however, installation and implementation are likely to be done by local actors—government electricity companies or other technology-oriented agencies, private companies, NGOs, or local community members who have been trained in DG installation. The case studies suggest that community members are often involved in installation for pilot programs or small projects that receive little government or donor support (31, 32, 48). NGOs in particular often work closely with end-user communities (36, 57, 63, 65), though they are occasionally critiqued for being unsuccessful at it (34), and provide training at the local level (35, 44, 57, 62). In some cases, however, NGOs or government agencies create private enterprises to install and maintain DG systems, particularly in places where local businesses do not already fill this role (43).

Local ability to provide ongoing monitoring, maintenance, and repair. The most frequently mentioned roles for end users and the community are in the routine maintenance and repair of DG systems. DG technologies, like most power plants and consumer appliances, usually require some maintenance and repair during their functional life (22, 29, 60, 62). Particular technologies have specific maintenance requirements: Diesel generators require regular replacement of filters and belts, whereas regular maintenance of PV systems necessitates deeper knowledge of the way a system works. To maximize performance, users must stay within system limits, clean the system, replace components, and keep batteries from discharging (47). Over the long term, it is important to designate specific actors or organizations for the oversight of routine monitoring, maintenance, and repair services of the DG units (29, 62), and local capacity is frequently considered important to success (43, 52).

There is some evidence to suggest that when users purchase and install their own systems, they are more successful at maintenance (24). In many cases, local people are trained in maintenance of DG systems, particularly where community systems are shared (32, 65). Where private firms are actively involved in promoting DG, these enterprises also frequently provide training for skilled technicians and electricians (19, 44), businessmen (80), and end users on how to use and maintain the systems (57). In several cases without preexisting DG entrepreneurs, these projects train new entrepreneurs to develop these skills. The success of such projects, however, is limited where demand for DG systems is low or where the project does not create adequate payment mechanisms (68). This local maintenance may work in conjunction with maintenance provided by an NGO or private businesses (19). The preexisting availability of locally trained technicians may also be important because several case studies suggest that failure rates of PV systems are higher in areas where there is little or no local competence in PV maintenance (45).

Maintenance can pose a dilemma, however, for DG program implementers. Where there are few DG users in the region, it may be difficult to pay for outside professional maintenance or for adequate training (57, 59). There are also potential problems with exclusionary training, particularly when women, who may be more likely to rely on the systems, are not trained in their maintenance and use (22). Furthermore, DG success may be limited by the availability and quality of replacement parts, particularly in areas where there is little commercial infrastructure for DG (60). Where there is little or no local capability for maintenance by end users, DG equipment failure may go uncorrected and fall into disuse (22).

We hypothesize that end-user involvement is important at all stages of DG project implementation and that projects that meaningfully involve end users in more stages will experience greater long-term technical success. We also hypothesize that existing networks of trained DG mechanics are associated with long-term success.

Supportive Government Policies and Regulations

Although the case study literature rarely elucidates the impacts of government policy on DG outcomes, a subset of studies, many of which focus on Brazil or India, reveals that public policy can have a significant effect. These studies connect national policies that prioritize rural electrification with DG activities. Brazil and India mandated universal access to electricity in 2002 and 2005, respectively. Even though it appears unlikely that either country will meet their 100% electricity access goals within the time frames established by national policies, these efforts have prompted a significant amount of DG activity on the ground (15, 46). Notably, both of these countries have a substantial institutional infrastructure in place to deliver DG services. In Brazil, utilities have the exclusive right to supply energy services within established territories, and many of these utilities have experimented with DG and minigrid projects since the 1990s (7, 15). In the state of Minas Gerais, for example, the central utility provided electricity access to 200,000 homes in the four years after the universalization law was passed, including 2,500 solar home systems (7). In India, NGOs have long supplied communities with government-subsidized DG systems (42, 54, 61). In the Indian state of West

Bengal, 40,000 homes receive electricity from either solar home systems or minigrids (46). Supportive government policies also include demonstration projects and other public awareness programs (38, 45). Several case studies also emphasize that, where national governments do not prioritize electrification, NGOs can be particularly important in getting electricity provision on the agenda (60) or in taking the lead on rural electrification programs as government support has waned (71).

A government's promotional policies alone do not guarantee the success of DG programs, however, particularly where the infrastructure to maintain DG systems is not in place. Thailand, for example, has a national policy that helped provide solar electricity to over 50,000 households. But the governmental programs did not provide adequate local maintenance for the systems, and equipment failures have rendered half of these systems unusable (22).

Brazil and India's policies are too new for reliable assessments about their long-term sustainability. Brazil's energy access law includes several provisions that prospectively address the problem of equipment failure. DG systems must meet national performance standards that include training programs for utility installers, and utilities are tasked with providing maintenance and given the exclusive right to charge households for their electricity use (7). At the same time, the Brazilian government has a long-standing policy of ensuring that low-income customers pay low electricity tariffs. Even though utility companies are allowed to cross subsidize by overcharging urban and wealthier users, they still consistently lose money, making the long-term sustainability of the program questionable (15).

For countries that lack the capacity to implement national electrification programs, simple changes in regulatory policy may help support DG. The adoption of technical standards for DG equipment can ensure a minimum level of quality for each DG system (7); this can enable private entrepreneurs, individual buyers, and NGOs to move forward with DG projects. Governments can also adopt feed-in tariffs, which allow small-scale generators to sell electricity to the grid under an agreed price per kilowatt hour. The per kilowatt hour price of the feed-in tariff can increase the number of entrepreneurs and investors willing to enter the DG market. Feed-in tariffs are a relatively new policy instrument in developing countries and are mentioned only in case studies after 2008. Rwanda, for example, lacks an energy law and has limited regulatory infrastructure, but project implementers were able to successfully negotiate a feed-in tariff that now attracts private investment in microhydropower (80). In Malaysia, a feed-in tariff is a central component of the country's new DG initiative, but analysis suggests that the tariff is set too low to meaningfully increase investor interest (72). Absence of a feed-in tariff is sometimes cited as a barrier to distributed models of electrification (71).

Government policies can have deleterious effects as well, such as when import tariffs make the purchase of DG systems too costly (34, 44), when subsidies for fossil fuels deter investment in renewable power sources (39, 72), when governments fail to guarantee land rights necessary for DG projects (65), and when particular government agencies are systematically disinclined toward rural energy development (55). Occasionally, individuals in government lobby against DG programs out of fear that they would personally lose financially, as occurred in one case study with Indian grid engineers (31). Finally, macroeconomic policies can have an effect on DG outcomes. Even though most of the world enjoys decreasing DG costs resulting from technological improvements over time, countries experiencing depreciating currencies may find DG costs increasing (44).

This review of government policy suggests that the policies most closely associated with DG project success may vary considerably by countries' HDI status. Here, we hypothesize that policies, such as universal access mandates, will result in more DG in countries with highly capable administrative states. Feed-in tariffs and removal of import tariffs, however, may have a greater impact on DG in countries with low-HDI status because these policies require fewer enforcement mechanisms and direct government oversight. Instead, these policies encourage private-sector actors to implement and invest in DG. In addition, there may be important differences owing to the breadth and depth of a country's experience with DG. Thus, we hypothesize that where DG is implemented by government agencies, long-term technical success is highly correlated with the extent of that agency's prior experience with DG projects. Additional empirical evidence on the connection between national policy and DG outcomes is needed, particularly focusing on the contexts under which different policies might be most supportive of DG projects.

Effective Institutions for Collaborative Governance

Our analysis of the case study experience suggests that effective institutions for collaborative governance are a critical factor for the long-term operation of DG systems. Drawing on Ansell & Gash (87), we define collaborative governance as a collective decision-making process whereby public-sector agencies engage and deliberate with a variety of nonstate actors, including NGOs, private-sector firms, interest groups, community members, and individuals, to formulate, implement, manage, and regulate public policies, services, and programs. In virtually every case study, some combination of actors work together to implement DG programs with varying degrees of success. We conclude that each of the earlier themes—appropriate choice of technology, financing, end-user involvement, and supportive government policy—is facilitated by effective collaborative governance. We also conclude that DG project planners would benefit from greater examination of the lessons offered from previous scholarship on collaborative governance.

Collaborative governance should not be confused with collaborative project management. Disparate actors can work together to implement a particular project, but these efforts become collaborative governance when the goals of the teamwork transcend the parameters of a particular project. Collaborative governance is iterative and ongoing, and it spans the geographic and political space of specific localities. In the context of DG, collaborative governance seeks not just to implement a particular project today but also to ensure sustained access to and availability of electricity. This often necessitates more fundamental and encompassing decisions about the formal and informal rules of deliberation and decision making.

Less than half of the 60 articles explicitly mention collaborative or partnership arrangements between the actors in DG systems. Nearly all of the cases mention the involvement of several different types of actors—one even mentions 18 different actors—but very few analyze the organizational dynamics in detail, and most limit their focus to the project management dimension of the collaboration, identifying the entities that contribute funds, expertise, or equipment to the project.

Most relevant for our purposes, scholars of collaborative governance theorize that specific characteristics are associated with successful collaboration. Empirical studies in a range of policy sectors also provide evidence of the conditions under which collaborations are likely to succeed, as well as possible actions that can be taken to increase the chances of success under various circumstances (87).

Our case study analysis suggests that DG projects and programs could benefit from incorporating these lessons into project planning and implementation. One case study highlights the need for "genuine participation" that "encourages empowerment and cooperation" in contrast to "pseudoparticipation that promotes [paternalism] and domestication" (48, p. 317). Other case study authors echoed this sentiment, finding that limited or cursory local participation in the planning process undermines long-term project success (29, 68).

Cases that discuss collaboration also often focus on the need for integration of and faith in local communities (31, 32). Grameen Shakti, a private company that has received awards from USAID and has been held up as a model by the World Bank, has worked closely for a long period of time with the Grameen Bank NGO, the government of Bangladesh, and local communities to distribute DG systems. Key components of their success have been their efforts to build trust and to understand local communities to build the necessary infrastructure for DG expansion (19). Empirical research on collaborative governance suggests that such participation actually improves service provision outcomes (87, 88). The literature also discusses important barriers to participation, for example, power or resource imbalances, and suggests that these must be addressed before the collaboration can be truly participatory.

Many case studies describe projects in which an NGO or university initiated a project and then turned ownership and management responsibilities over to the local community (20, 65, 69) or to local entrepreneurs (25, 43, 80). This is particularly common in India and Southeast Asia, where projects commonly seek to build local governance capacity and ownership (31, 32, 65, 71). This kind of ownership appears to improve overall project success in surprising ways. For example, line losses owing to theft dropped from 35% to 15% in Nepal after the program shifted to a cooperatively owned model (71). These arrangements, however, are rarely examined in detail, although one case study does recount the number of challenges that the village governing council successfully addressed, including learning to manage plant finances and address nonroutine maintenance (69).

Notably, the case studies show that collaborative governance can work in a variety of political contexts, from settings where the central government takes an active role to others where the government's role is relatively minimal. In Brazil, the central government is actively working with utilities, universities, and private companies to not only implement DG, but also to ensure that DG equipment meets technical standards and that technicians are certified to maintain and install DG systems (7). In contrast, in a project in Bangladesh, the government collaborated with other actors in a successful, long-running DG project, but played a much smaller role in terms of implementing and funding the project (20). At the other end of the spectrum, two articles from the 1990s on DG in Kenya suggest that, in some cases, the government is not actively involved in promoting or regulating DG at all (24, 44). More recent work, however, notes that the Kenyan government has encouraged DG since 2006 (73).

Of course, collaborative governance is not without its costs. As Cole (36) notes, collaborative efforts can increase the amount of work needed to maintain evaluation and paper trails, making the programs less cost-effective than they might be. Similarly, the very elements of success identified in the collaborative governance literature—such as face-to-face dialogue and transparency—may make collaborative efforts time-consuming (87). Moreover, where local capacity is limited, the need for local capacity building may impose trade-offs between maximizing local decision making and quick dissemination of DG projects (80).

Because the case studies provided so few details about the nature of the collaborative relationships in DG projects, we do not develop hypotheses directly from our case study analysis. Instead, we draw on the collaborative governance literature. Here, we hypothesize that significant power or resource imbalances or prior relationships of distrust between actors will diminish the long-term technical success of DG projects. We also hypothesize that difficult contexts, for example, where there are large power imbalances between actors, can be mitigated by careful attention to the process by which the collaboration works by ensuring that objectives are made clear, procedural rules are well established, and decisions are made in a transparent manner. Finally, we predict that small initial gains from collaboration (87) will feed back positively, enhancing learning about other actors' interests and needs, building trust in the process, and contributing to increased future cooperation.

Table 2 Summary of technical and development outcomes in distributed generation (DG) case studies

	Technical outcomes		Development outcomes	
	Short term	Long term	Short term	Long term
Unit of measure	Number of DG systems installed User uptake of systems Household access to DG Sufficiency of power supply	Operability of systems User satisfaction Technical performance Financial viability of program	Household energy savings Increased evening study hours Access to entertainment Access to cell phones/Internet New or expanded economic opportunities	Reduced local or global pollution Reduced deforestation Improved education Improved health Social or political changes
Summary of findings	A large number of DG systems have been installed in every region of the world Potential energy savings to users depends on particular context Access to credit may hinder uptake of DG systems Some DG systems do not provide sufficient power for growing energy demands	Short-term diffusion does not guarantee long-term operation Long-term success requires adequate maintenance and appropriate sources of funding	DG systems improve access to lighting, entertainment, and communication DG capacity is not always sufficient for income-generating activities DG users study more and are exposed to less indoor air pollution than those who lack electricity DG allows users to expand hours spent working or socializing DG is adopted most often by middle- and high-income households	Impacts are rarely studied, but evidence suggests possible long-term positive changes in health, education, and cultural, economic, and political development

CONCLUSION

Summary of Findings

We have reviewed DG case studies from around the world to identify the outcomes of projects and the key factors that affect these outcomes (see **Table 2**). Our survey reveals that the academic literature identifies two main types of DG project outcomes: technical outcomes that describe the quantity and quality of DG systems and development outcomes that describe the social, economic, and environmental impacts of DG access. These outcomes can be assessed from either a short-term or a long-term perspective.

The case studies reveal that DG projects have experienced a wide range of technical outcomes. Most DG projects experience short-term technical success, but some projects have installed fewer systems than expected, usually owing to user reluctance to adopt systems. Most case studies assess project performance within two or three years of installation, so less is known about the long-term technical performance of DG projects. A handful of case studies show that properly maintained DG systems can reliably provide long-term electricity access. Other DG projects, however, have experienced widespread system failure in a few years. This variability in long-term technical outcomes suggests that more systematic research is needed on the factors that cause long-term technical failure and success.

Most case studies look beyond technical outcomes to examine the impact that DG has on end users' lives. Overall, the case studies reveal that end users overwhelmingly perceive that access to electricity through DG systems improves their lives by increasing the quality and quantity of lighting and by providing access to entertainment and communication devices, such as television and cell phones.

Access to lighting in particular has several well-documented benefits: It allows children to study more, it allows adults to spend more time either working or socializing, and it reduces exposure to indoor air pollution from kerosene. The evidence on these factors suggests but does not yet prove that DG can be an important factor in improving long-term health, education, social, or economic outcomes. Additional systemic studies are needed to verify these findings. The literature has paid even less attention to the potential long-term political and social outcomes of DG. The decentralized nature of DG, however, offers communities a greater role in decision making and economic development—both of which also warrant future study.

On the issue of factors that determine DG project outcomes, a key finding of our analysis is that DG systems are not only technical tools, but they also have social and political implications. As such, their success depends upon overlapping relationships between the actors involved in the DG project. Although the case studies present a wealth of information about DG projects, they rarely provide definitive answers about how social and political arrangements affect DG project success. Drawing on our sample cases, we have identified five factors that appear repeatedly and have developed a number of hypotheses about the way these factors affect DG project outcomes. These hypotheses are summarized in **Table 3**.

The format of **Table 3** may imply that these factors are separable, but we posit that they are interdependent. For example, when end

Table 3 Factors that influence technical success of distributed generation (DG) projects

Factor	Hypotheses[a]
Appropriate technology choice	End-user involvement in technology choice improves long-term technical success It is important to account for resource endowments when selecting and designing DG systems Community-wide and/or hybrid systems may foster greater economic development than household DG systems
Financial arrangements	Multiple payment options tailored to different users' circumstances increase uptake rates Access to microfinance/credit improves user uptake rates Access to microfinance is most important in low-HDI countries or poor communities with less-developed credit institutions High technical performance is associated with higher payments by end users
End user and community involvement	End-user involvement in all stages of DG project implementation improves technical and development outcomes Preexisting networks of trained DG mechanics are associated with technical success
Policy	Universal mandates are most successful in countries with high administrative capability Where governments implement DG projects, success varies with extent of agency experience with DG Feed-in tariffs and import tariffs have the largest effects on DG dissemination in low-HDI countries
Collaboration	Significant power or resource inequalities or prior relationships of distrust among actors will undermine success of DG systems Careful attention to collaborative processes can mitigate power imbalances and facilitate DG success Small initial gains from collaboration will feed back positively and contribute to increased future cooperation

[a]Abbreviation: HDI, Human Development Index

users are involved in DG project planning, the project may be more likely to use technology that meets local needs. This, in turn, may boost end-user uptake rates and increase the likelihood that users will pay any ongoing fees that are necessary to fund DG system maintenance. The interdependence of these factors relates to the importance of collaboration to DG project success. The way that users interact and make decisions at all stages of DG program implementation can determine the eventual outcomes of the project.

Finally, our synthesis suggests that the factors that underlie success depend on the context in which these projects occur. For example, the policies that are supportive of DG in a country with a well-funded, capable bureaucracy may be ineffective in a country with a weak administrative state. Alternately, the finance options that are necessary for very poor villagers to afford a DG system may differ from the options necessary in areas with higher incomes. Future research testing these and similar hypotheses should consider the role that context places in determining how these factors affect DG outcomes.

Policy Implications for Future Distributed Generation Projects and Programs

Our analysis of the current case study literature generates several important policy implications. First, our analysis illustrates the importance of systematically evaluating and documenting results and learning from past experiences. The case studies do not all demonstrate an accumulation of learning about the conditions and outcomes from DG in the developing world. Knowledge too often appears to remain within regional, disciplinary, or policymaking silos. Even though DG programs must be customized to the specific needs, objectives, and constraints of particular contexts, policy makers could share the guidelines for a range of practices, for example, the variety of financial models and pricing schemes that have worked effectively in the past under certain sets of parameters.

Second, the current research suggests the importance of customizing DG projects to local needs and contexts, including increased user demand for electricity over time. To accomplish local goals, private-sector firms, NGOs, donors, and governments should develop formal guidelines for their policies on community and household involvement. Over the past decade, significant progress has been made formalizing the legal and policy framework for prior and informed consent but with a focus only on indigenous communities. For example, the World Bank has developed a policy that requires borrowers to obtain indigenous community consent before receiving World Bank funds (89). Indigenous groups are distinguished in international legal frameworks by their political sovereignty (90, 91); guidelines for more general community and household involvement could build on this existing platform of indigenous communities' right to participate in decision making.

Third, in addition to facilitating ongoing involvement with the relevant communities, the key actors also need to develop policies for improving the coordination and cooperation between them. Nearly every case study described roles for more than one different type of actor, but very few investigated the ways that these diverse groups might collaborate. Future policies should include in the design and formulation stage a holistic account of how various actors might interact. Furthermore, program monitoring and evaluation should account for the processes undertaken in addition to the metrics for specified outcomes. It is important to examine critically the nature of the partnership or interactions among actors to learn more about what institutional arrangements are more successful than others.

Finally, the narrow focus of the case studies limits our ability to draw conclusions about the long-term environmental impacts of DG. Moreover, the actors involved in DG have divergent views about whether it should be pursued for environmental or development purposes, or for a combination of the two. Policy makers should be aware of these macrolevel, long-range issues. They should assess the conditions under which DG technologies are environmentally benign and replace harmful energy use in order to provide rigorous empirical evidence about the long-term environmental benefits of DG.

Implications for Future Research

Finally, our analysis of the current case study literature leads to suggestions for future research. First, we argue that scholarship in this area should move toward multidisciplinarity, with more attention from the social sciences. The existing disciplinary bias in the case study literature not only skews the research questions, but also the research design and analysis.

Future research should also disaggregate the household and the community in the design and analysis of DG systems. The case studies reveal that the formulation, implementation, and impacts of a DG project have significant gendered dimensions. Depending on the objectives of the study, households may not be the most appropriate unit of analysis because men and women within the household use and benefit from energy choices in very different ways. The case studies also highlighted the importance of community engagement, yet new research should also examine more critically the contentious political economies within these sites by disaggregating communities.

The future scholarship on DG should also incorporate a more long-term, holistic, and explicitly comparative perspective. This is not a critique of case study methodology per se but rather of the dominant analytic approach, which was often singularly focused on the adoption of one particular DG technology by one lead actor in one particular context and time period with one specific development outcome. A broader analytic lens would enable scholars to examine the interaction and feedback effects between various energy technologies, actors, and development outcomes, which would, in turn, enable the critical examination of "technological snowball effects" (44) for the diffusion of technology, as well as of the positive and negative spillovers between development and environmental outcomes.

A broader, long-term lens would also allow researchers to measure the effects of DG system implementation on the ultimate goal of human development. Although one may be inclined to infer that electrification in a community automatically increases long-term development outcomes, few studies in our sample conceptualized or measured these outcomes systematically, even in the short term. Proving the link between electrification and development benefits is necessary. But future research should also attempt to disentangle what benefits are derived from the general provision of any electrification at all, and which benefits might be over and above this resulting from the unique nature of electric provision through DG systems.

Finally, future research can test more systematically the role of politics in DG projects and programs. Specifically, we propose further work on the nature of collaboration and governance for DG at the local, national, and global levels. This multilevel research would build on the more recent scholarship on DG, highlighting the importance of institutional context for the success of DG uptake and implementation (67). In particular, examining contexts where political regimes are new, where democracy is fragile, and where state capacity is lower than the oft-studied cases of Brazil, China, South Africa, and India would enhance our collective knowledge.

Political activities are crucial not only for understanding the successful design and initial implementation of a DG project, but also for its long-term management and sustainability. We are interested in how politics affect DG on the ground and how DG then feeds back to politics. DG often involves new governance arrangements and collaborative partnerships between private-sector firms, NGOs, donors, governments, and communities. How does this experience then affect citizens' views of state legitimacy, their own citizenship, and their attempts to demand accountability from any of these actors? DG is not simply a technical issue concerning the diffusion of new technologies. Instead, we argue that DG involves a significant reorganization of political authority and responsibility with potential long-term consequences for the consolidation of new democracies and strengthening of citizenship around the developing world.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

We wish to express our appreciation to Scott Breen, Ashraf El-Arini, Swati Garg, and Shannon Lea Watkins for excellent research assistance. We thank the Mitsui & Co., Ltd. Environment Fund, the Indiana University Office of Sustainability, and the Indiana University School of Public and Environmental Affairs for generous funding. Earlier drafts of this review were presented at the Vincent & Elinor Ostrom Workshop on Political Theory & Policy Analysis, the American Political Science Association, the Association for Public Policy Analysis and Management, and the Midwest Political Science Association annual meetings in 2011–2012. We are grateful for comments received at these presentations, as well as those from ARER reviewers. All remaining errors are our own.

LITERATURE CITED

1. Ackermann T, Andersson G, Söder L. 2001. Distributed generation: a definition. *Electr. Power Syst. Res.* 57:195–204
2. Carley S. 2009. Distributed generation: an empirical analysis of primary motivators. *Energy Policy* 37:1648–59
3. Bazilian M, Welsch M, Divan D, Elzinga D, Strbac G, et al. 2011. Smart and just grids: opportunities for Sub-Saharan Africa. *Rep. Energy Futures Lab*, Imperial Coll., London, UK
4. Kassiri OK. 2003. *Options for Sustainable Energy Generation in the Developing World: Financing Mechanisms, Technologies and Policies*. Boston: Mass. Inst. Technol.
5. Adkins E, Eapen S, Kaluwile F, Nair G, Modi V. 2010. Off-grid energy services for the poor: introducing LED lighting in the Millennium Villages Project in Malawi. *Energy Policy* 38:1087–97
6. Contreras Z. 2008. Planning paths for the electrification of small villages using decentralised generation: experience from Senegal. *Int. J. Energy Sect. Manag.* 2:118–38
7. Diniz A, Neto L, Camara CF, Morais P, Cabral CVT, et al. 2011. Review of the photovoltaic energy program in the state of Minas Gerais, Brazil. *Renew. Sustain. Energy Rev.* 15:2696–706
8. Goldemberg J, Reddy AKN, Smith KR, Williams RH. 2000. Rural energy in developing countries. In *World Energy Assessment: Energy and the Challenge of Sustainability*, ed. J Goldemberg, pp. 367–89. New York: UN Dev. Program.
9. Casillas CE, Kammen DM. 2011. The delivery of low-cost, low-carbon rural energy services. *Energy Policy* 39:4520–28
10. Foley G. 1992. Rural electrification in the developing world. *Energy Policy* 20:145–52
11. Int. Energy Agency. 2010. *Ending Energy Poverty: How to Make Modern Energy Access Universal.* Paris: IEA
12. Mondal AH, Kamp LM, Pachova NI. 2010. Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh an innovation system analysis. *Energy Policy* 38:4626–34
13. Huacuz JM, Agredano J. 1998. Beyond the grid: photovoltaic electrification in rural Mexico. *Prog. Photovolt.* 6:379–95

14. Chaurey A, Ranganathan M, Mohanty P. 2004. Electricity access for geographically disadvantaged rural communities—technology and policy insights. *Energy Policy* 32:1693–705
15. Zerriffi H. 2008. From acai to access: distributed electrification in rural Brazil. *Int. J. Energy Sect. Manag.* 2:90–117
16. Wamukonya N. 2003. Power sector reform in developing countries: mismatched agendas. *Energy Policy* 31:1273–89
17. Wengle SA. 2010. *Power politics: the political economy of Russia's electricity sector liberalization*. PhD thesis. Univ. Calif., Berkeley. 203 pp.
18. Grameen Shakti. 2009. *Solar System*. Daka, Bangladesh. **http://www.gshakti.org/**
19. Barua DC. 2004. Grameen Shakti—a model for and integrated approach to rural energy service. *Energy Dev.* 1(1). **http://www.energyanddevelopment.com/issue0101.htm**
20. Reinders AHME, Pramusito, Sudradjat A, van Dijk VAP, Mulyadi R, Turkenburg WC. 1999. Sukatani revisited: on the performance of nine-year-old solar home systems and street lighting systems in Indonesia. *Renew. Sustain. Energy Rev.* 3:1–47
21. Bikam P, Mulaudzi DJ. 2006. Solar energy trial in Folovhodwe South Africa: lessons for policy and decision-makers. *Renew. Energy* 31:1561–71
22. Green D. 2004. Thailand's solar white elephants: an analysis of 15 yr of solar battery charging programmes in northern Thailand. *Energy Policy* 32:747–60
23. World Bank. 2008. *Operational Guidance for World Bank Group Staff—Designing Sustainable Off-Grid Rural Electrification Projects: Principles and Practices*. Washington, DC: World Bank
24. van der Plas RJ, Hankins M. 1998. Solar electricity in Africa: a reality. *Energy Policy* 26:295–305
25. dos Santos RR, Zilles R. 2001. Photovoltaic residential electrification: a case study on solar battery charging stations in Brazil. *Prog. Photovolt.* 9:445–53
26. Garbarino S, Holland J. 2009. *Quantitative and Qualitative Methods in Impact Evaluation and Measuring Results*. London, UK: Dep. Int. Dev.
27. Cent. Glob. Dev. Eval. Gap Work. Group. 2006. *When will we ever learn? Improving lives through evaluation.* Washington, DC: Cent. Glob. Dev.
28. Baker JL. 2000. *Evaluating the Impact of Development Projects on Poverty: A Handbook for Practitioners*. Washington, DC: World Bank
29. Claus D. 2001. Involving the user: community based management of solar home systems in Indonesia. *Refocus* 2:18–21
30. Bojic M, Blagojevic M. 2006. Photovoltaic electricity production of a grid-connected urban house in Serbia. *Energy Policy* 34:2941–48
31. Sanjit R. 1996. De-mystification of SPVs to provide lighting: an example of community-supported on-site initiative in Ladakh in the Indian Himalayas. *Energy Sustain. Dev.* 2:45–51
32. Banerji G, Baruah M. 2006. Common energy facilities based on renewable sources—enabling sustainable development in highland areas in the Indian Himalayas. *Mt. Res. Dev.* 26:98–103
33. Barua DC. 2001. Strategy for promotions and development of renewable technologies in Bangladesh: experience from Grameen Shakti. *Renew. Energy* 22:205–10
34. Diarra DC, Akuffo FO. 2002. Solar photovoltaic in Mali: potential and constraints. *Energy Convers. Manag.* 43:151–63
35. Thornbloom M, Ngbangadia D, Assama M. 1997. Using micro-hydropower in the Zairian village. *Solar Energy* 59:75–81
36. Cole JF. 2003. Installation and operation of a large scale RAPS system in Peru. *J. Power Sources* 116:243–47
37. Diaz P, Peña R, Muñoz J, Arias CA, Sandoval D. 2011. Field analysis of solar PV-based collective systems for rural electrification. *Energy* 36:2509–16
38. Benecke GE. 2008. Success factors for the effective implementation of renewable energy options for rural electrification in India—potentials of the Clean Development Mechanism. *Int. J. Energy Res.* 32:1066–79
39. Dehghan AA. 2011. Status and potentials of renewable energies in Yazd Province-Iran. *Renew. Sustain. Energy Rev.* 15:1491–96
40. Patankar M, Patwardhan A, Verbong G. 2010. A promising niche: waste to energy project in the Indian dairy sector. *Environ. Sci. Policy* 13:282–90

41. Komatsu S, Kaneko S, Ghosh PP. 2011. Are micro-benefits negligible? The implications of the rapid expansion of Solar Home Systems (SHS) in rural Bangladesh for sustainable development. *Energy Policy* 39:4022–31
42. Agoramoorthy G, Hsu M. 2009. Lighting the lives of the impoverished in India's rural and tribal drylands. *Hum. Ecol.* 37:513–17
43. Gustavsson M. 2007. With time comes increased loads—an analysis of solar home system use in Lundazi, Zambia. *Renew. Energy* 32:796–813
44. Acker RH, Kammen DM. 1996. The quiet (energy) revolution: analysing the dissemination of photovoltaic power systems in Kenya. *Energy Policy* 24:81–111
45. Marawanyika G. 1997. The Zimbabwe UNDP-G.E.F solar project for rural household and community use in Zimbabwe. *Renew. Energy* 10:157–62
46. Bhandari AK, Jana C. 2010. A comparative evaluation of household preferences for solar photovoltaic standalone and mini-grid system: an empirical study in a costal village of Indian Sundarban. *Renew. Energy* 35:2835–38
47. Hajat A, Banks D, Aiken R, Shackleton CM. 2009. Efficacy of solar power units for small-scale businesses in a remote rural area, South Africa. *Renew. Energy* 34:2722–27
48. Alvial-Palavicino C, Garrido-Echeverria N, Jiménez-Estévez G, Reyes L, Palma-Behnke R. 2011. A methodology for community engagement in the introduction of renewable based smart microgrid. *Energy Sustain. Dev.* 15:314–23
49. Al-Soud MS, Hrayshat ES. 2004. Rural photovoltaic electrification program in Jordan. *Renew. Sustain. Energy Rev.* 8:593–98
50. Mahmoud MM, Ibrik IH. 2003. Field experience on solar electric power systems and their potential in Palestine. *Renew. Sustain. Energy Rev.* 7:531–43
51. Raja P, Dickie L, Vasanthi PM. 2006. Adoption of photovoltaic power supply systems: a study of key determinants in India. *Renew. Energy* 31:2272–83
52. Urmee T, Harries D. 2009. A survey of solar PV program implementers in Asia and the Pacific regions. *Energy Sustain. Dev.* 13:24–32
53. Ilskog E, Kjellstrom B. 2008. And then they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Energy Policy* 36:2674–84
54. Velayudhan SK. 2003. Dissemination of solar photovoltaics: a study on the government programme to promote solar lantern in India. *Energy Policy* 31:1509–18
55. Miller D, Hope C. 2000. Learning to lend for off-grid solar power: policy lessons from World Bank loans to India, Indonesia, and Sri Lanka. *Energy Policy* 28:87–105
56. Alazraki R, Haselip J. 2007. Assessing the uptake of small-scale photovoltaic electricity production in Argentina: the PERMER project. *J. Clean. Prod.* 15:131–42
57. Green JM, Wilson M, Cawood W. 2001. Maphephethe rural electrification (photovoltaic) programme: the constraints on the adoption of solar home systems. *Dev. South. Afr.* 18:19–30
58. Moharil RM, Kulkarni PS. 2009. A case study of solar photovoltaic power system at Sagardeep Island, India. *Renew. Sustain. Energy Rev.* 13:673–81
59. Muñoz J, Narvarte L, Lorenzo E. 2007. Experience with PV-diesel hybrid village power systems in southern Morocco. *Prog. Photovolt.* 15:529–39
60. Smits M, Bush SR. 2010. A light left in the dark: the practice and politics of pico-hydropower in the Lao PDR. *Energy Policy* 38:116–27
61. Chakrabarti S, Chakrabarti S. 2002. Rural electrification programme with solar energy in remote region—a case study in an island. *Energy Policy* 30:33–42
62. Fulford DJ, Mosley P, Gill A. 2000. Recommendations on the use of micro-hydro power in rural development. *J. Int. Dev.* 12:975–83
63. Ravindranath NH, Somashekar HI, Dasappa S, Reddy CNJ. 2004. Sustainable biomass power for rural India: case study of biomass gasifier for village electrification. *Curr. Sci.* 87:932–41
64. Chowdhury SA, Mourshed M, Kabir SMR, Islam M, Morshed T, et al. 2011. Technical appraisal of solar home systems in Bangladesh: a field investigation. *Renew. Energy* 36:772–78

65. Somashekhar HI, Dasappa S, Ravindranath NH. 2000. Rural bioenergy centres based on biomass gasifiers for decentralized power generation: case study of two villages in southern India. *Energy Sustain. Dev.* 4:55–63
66. Romijn H, Raven R, de Visser I. 2010. Biomass energy experiments in rural India: insights from learning-based development approaches and lessons for strategic niche management. *Environ. Sci. Policy* 13:326–38
67. Zerriffi H. 2011. *Rural Electrification: Strategies for Distributed Generation*. Vancouver, BC: Springer Sci. +Bus. Media 203 pp.
68. Mulugetta Y, Nhete T, Jackson T. 2000. Photovoltaics in Zimbabwe: lessons from the GEF Solar project. *Energy Policy* 28:1069–80
69. Gurung A, Gurung OP, Oh SE. 2011. The potential of a renewable energy technology for rural electrification in Nepal: a case study from Tangting. *Renew. Energy* 36:3203–10
70. Phuangpornpitak N, Kumar S. 2011. User acceptance of diesel/PV hybrid system in an island community. *Renew. Energy* 36:125–31
71. Yadoo A, Cruickshank H. 2010. The value of cooperatives in rural electrification. *Energy Policy* 38:2941–47
72. Seng LY, Lalchand G, Lin GMS. 2008. Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia. *Energy Policy* 36:2130–42
73. Kirubi C, Jacobson A, Kammen D, Mills A. 2009. Community-based electric micro-grids can contribute to rural development: evidence from Kenya. *World Dev.* 37:1208–21
74. Wijayatunga PDC, Attalage RA. 2005. Socio-economic impact of solar home systems in rural Sri Lanka: a case-study. *Energy Sustain. Dev.* 9:5–9
75. Richards K, Andersson K. 2001. The leaky sink: persistent obstacles to a forest carbon sequestration program based on individual projects. *Clim. Policy* 1:41–54
76. Chomitz KM. 2002. Baseline, leakage and measurement issues: How do forestry and energy projects compare? *Clim. Policy* 2:35–49
77. Waddell R, Bryce P. 1999. Micro-hydro systems for small communities. *Renew. Energy* 16:1257–61
78. Ilskog E. 2008. Indicators for assessment of rural electrification—an approach for the comparison of apples and pears. *Energy Policy* 36:2665–73
79. Rajamani L. 2000. The principle of common but differentiated responsibility and the balance of commitments under the climate regime. *Rev. Eur. Community Int. Environ. Law* 9:120–131
80. Pigaht M, van der Plas RJ. 2009. Innovative private micro-hydro power development in Rwanda. *Energy Policy* 37:4753–60
81. Zerriffi H. 2007. *Making Small Work: Business Models for Electrifying the World Program on Energy and Sustainable Development*. Stanford, CA: Program Energy Sustain. Dev.
82. Sarkar MAR, Ehsan M, Islam MA. 2003. Issues relating to energy conservation and renewable energy in Bangladesh. *Energy Sustain. Dev.* 7:77–87
83. Diaz P, Arias CA, Peña R, Sandoval D. 2010. FAR from the grid: a rural electrification field study. *Renew. Energy* 35:2829–34
84. Silva SB, de Oliveira MAG, Severino MM. 2010. Economic evaluation and optimization of a photovoltaic-fuel cell-batteries hybrid system for use in the Brazilian Amazon. *Energy Policy* 38:6713–23
85. Zilles R, Lorenzo E, Serpa P. 2000. From candles to PV electricity: a four-year experience at Iguape–Cananéia, Brazil. *Prog. Photovolt.* 8:421–34
86. Borges Neto MR, Carvalho PCM, Carioca JOB, Canafístula FJF. 2010. Biogas/photovoltaic hybrid power system for decentralized energy supply of rural areas. *Energy Policy* 38:4497–506
87. Ansell C, Gash A. 2008. Collaborative governance in theory and practice. *J. Public Adm. Res. Theory* 18:543–71
88. Newman J, Barnes M, Sullivan H, Knops A. 2004. Public participation and collaborative governance. *J. Soc. Policy* 33:203–23
89. World Bank. 2005. *Operational Policy 4.10—Indigenous Peoples*. Washington, DC: World Bank
90. Int. Labor Organ. 1989. *ILO Convention Indigenous and Tribal Peoples, C169*. Geneva, Switz.: ILO
91. United Nations. 2007. *Declaration on the Rights of Indigenous Peoples*. New York: UN

Annual Review of Environment and Resources

Volume 37, 2012

Contents

Errata

An online log of corrections to *Annual Review of Environment and Resources* articles may be found at http://environ.annualreviews.org