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Book

Impact evaluation of energy interventions : a review of the evidence

IMPACT EVALUATION OF ENERGY INTERVENTIONS

A REVIEW OF THE EVIDENCE

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ASIAN DEVELOPMENT BANK

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In this publication, "$" refers to United States dollars.
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On the cover: Impact evaluation needs to consider the effects of Energy sector interventions on various sectors (photos by ADB).

Cover design by Joe Mark Ganaban.

Contents

Tables, Figures, and Boxes

Tables

Case Study Tables and Figures

Figures

Boxes

Foreword

Strategy 2030 of the Asian Development Bank (ADB) emphasizes the creation of knowledge during the implementation of projects and the use of evidence from past operations to design new interventions. The Strategy also envisions a more proactive role for research to backstop ADB's function as a knowledge provider that helps replicate good project practices across Asia. For these ambitions to be fulfilled, evidence on the intended and unintended effects of interventions needs to be accumulated. Impact evaluation is an important means for generating this evidence.

To build a broader evidence base on "what works" in development, impact evaluation needs to be mainstreamed across a range of development investments. Presently, impact evaluation coverage has made more progress in the health and education sectors. While sectors dominated by "hard infrastructure", such as energy, account for far more development investment, the number of impact evaluations on these sectors has remained much more limited. At the same time, energy investments have become much more complex, and have become more oriented toward environmental and social goals over time. Along with these innovations has come an increasing array of behavioral assumptions underpinning interventions, which impact evaluations can help to test.

Yet, energy sector interventions have special challenges for impact evaluation. Many energy investments, such as powerplants or transmission lines, are "small-n" interventions, which affect large geographies, so that there are insufficient numbers of treated and untreated units for enabling conventional statistical analyses. New powerplants and other infrastructure may also allow improved levels of energy provision, rather than presence versus absence of a service, as the typical context for many traditional impact evaluation techniques.

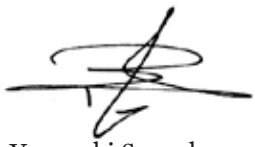
This review is intended to help navigate these challenges and offer insights to orient future impact evaluations on the energy sector. It attempts to characterize theories of change associated with many energy interventions, entry points for impact evaluation, impact evaluation challenges, and potential impact evaluation designs. It then reviews the impact evaluation literature to date,

in terms of methods applied, interventions covered, and outcomes evaluated, and identifies gaps for future studies to address. In the process, it offers practical examples that might inspire future studies.

The literature survey finds a rapidly growing body of impact evaluation studies related to energy. Of the 85 studies identified, more than 60% were published after 2012. Impact evaluation designs have also become diversified, with expanding use of more robust methods, such as randomized experiments and regression discontinuity design, as well as greater use of "big data". Evidence has been offered on a range of effects of electricity access including education, income, health, employment, business performance, and fertility.

Yet, many evidence gaps remain. Existing impact evaluation effort is mostly concentrated on rural electrification and improved cookstoves, even if most investments are in power generation and transmission. Other important areas of effort, such as energy efficiency, also have little impact evaluation to date. While many studies have evaluated effects of electricity access on education, far fewer have evaluated effects via intermediate services, such as health or agricultural extension facilities, and evidence on firms has remained limited.

With more big data increasingly available, it is hoped that the creative examples identified in this review can help to inspire new impact evaluation studies that address evidence gaps on energy. This work is more relevant than ever, as energy investments increasingly seek to experiment with innovations, high-level technologies, and behavioral change approaches to ensure sustainable, efficient, and inclusive use of energy. Continued efforts on impact evaluation will be critical to ensure that these experiments can be tested to generate evidence to improve energy operations over time. This review helps to show where future impact evaluation investments can best contribute new evidence and how such studies may be approached.



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Abbreviations

ADB	—	Asian Development Bank
CEM	—	coarsened exact matching
CFL	—	compact fluorescent lamp
CGE	—	computable general equilibrium
DiD	—	difference-in-differences
IV	—	instrumental variables
PRC	—	People's Republic of China
PSM	—	propensity score matching
RCT	—	randomized controlled trial
RDD	—	regression discontinuity design

Key Messages

Traditional economic assessment of energy interventions depends on many untested assumptions. Economic appraisal of energy interventions typically relies on the use of partial and general equilibrium models. In those models, behavior is assumed to follow mechanistic assumptions regarding demand elasticities and substitution patterns. For example, traditional energy sources are simply assumed to be replaced by modernized sources when available, and efficiency improvement is assumed to lead to lower energy consumption. However, these all depend on untested assumptions about how energy is used and how energy users behave. Understanding these behavioral aspects is critical to making energy investments more effective.

Impact evaluation can help to test key energy sector assumptions and effects. The approach can test basic assumptions about substitution effects of energy projects, as well as the effects of a range of energy policies. It can reveal which aspects of energy efficiency programs are effective. A range of outcomes for households, ranging from time use, to leisure, social capital, schooling, disease burden, and employment can all be tested, as can effects on firms and the environment.

Impact evaluation is increasingly relevant to energy programs. Energy investment is becoming more oriented toward environmental and social objectives. The sector has increasing investment that seeks to shift energy consumption behavior to be more efficient, fuel choices to be cleaner, energy usage to be more productive, and energy distribution to be more equitable. All of these effects depend on behavioral responses to energy interventions, which impact evaluation can help to test.

Impact evaluation of energy interventions is rapidly growing from low levels. Energy, especially in the power sector, has been one of the main sectors receiving official development assistance. Historically, very little impact evaluation has focused on energy. However, this is changing quickly. This study identifies 85 impact evaluations of energy projects, policies, and other investments in developing countries, of which more than 60% were published

after 2012. Even so, this is a fraction of the number of studies available for the social sectors. Energy projects are increasingly complex and dependent upon behavioral assumptions, so that only a small fraction of these assumptions have been tested through impact evaluation for a limited range of interventions, in some contexts.

Impact evaluations have offered important insights on a range of effects of energy interventions. These include significant effects of electricity access on energy use, income, consumption, education, gender disparities, health, and even fertility. However, much of the evidence is from a very limited set of interventions and contexts, and there is much variation among findings. The reasons for these variations are yet to be fully understood. Most impact evaluations have focused on the effects of rural electrification on households. The smaller set of impact evaluations conducted on electricity reforms generally find fewer significant effects.

Impact evaluation of energy interventions often requires a creative approach. There are special challenges for impact evaluation of energy projects, especially large generation and transmission infrastructure that affects large areas of countries. At the same time, several methods show promise for energy sector applications but have not been used frequently. These include synthetic controls, regression discontinuity designs, and encouragement designs.

Randomized evaluations have promise to reveal new insights on energy interventions. Although large energy infrastructure often cannot be randomly assigned, encouragement designs can introduce random variation in the use of energy, and incentive programs for demand-side energy efficiency and use of clean energy can often be randomized. These designs have untapped potential to enable testing of an expanded array of assumptions and interventions.

"Big data" can enable new impact evaluation possibilities on energy. High frequency, geospatial, and "crowdsourced" data are increasingly available, and many of these data sets are relevant to energy. For example, remote sensing can now detect luminosity and pollution, and billing data can be harvested to understand grid electricity use. These developments expand the numbers of variables and outcomes that can be included in analysis.

There are important evidence gaps on energy, and there is ample scope for further research. Only a limited range of interventions has been assessed. Investments in power generation and transmission for improved electricity capacity and reliability, incentives for clean energy deployment, smart grids, renewable energy deployment, energy efficiency measures, fuel substitution,

and energy interventions outside of electricity and improved cookstoves have received little attention. Evidence is also lacking for many intermediate channels, such as effects on public services, as well as longer-term effects on health and employment.

The development community can help address evidence gaps. As leading supporters of energy investments in Asia, development banks, such as the Asian Development Bank, are well-situated to contribute to producing new knowledge on what works in the sector.

1. Importance of Impact Evaluation in the Energy Sector

Energy is a rapidly evolving area of development assistance. Whereas energy access through conventional infrastructure has been a traditional emphasis, development assistance increasingly recognizes the potential of innovative technologies and policy reforms to contribute to a wider range of outcomes related to sustainability and social development. Yet, even as the objectives of the field have expanded, the existing body of evidence of what works in the energy sector has remained limited.

Many economic analyses have been used to assess the economic gains from energy projects through modeling that relies heavily on assumptions (ADB 2013a, 2017). Until recently, more rigorous studies examining the effects of energy interventions were mainly macroeconomic and based on time series or modeling using partial equilibrium optimization or computable general equilibrium (CGE) techniques (Torero 2014). Most of these models are ex ante, and attempt to compare alternative energy sector policies, in terms of implications for economic growth and/or environmental emissions.

Although useful for forecasting and simulating options, such studies assume, rather than identify, causal relationships and behavioral responses to interventions. Impact evaluation, on the other hand, empirically measures the causal effects of interventions on outcomes of interest, while minimizing assumptions as much as possible. Use of impact evaluation methods for energy interventions began to grow in the early 2000s, but the number of impact evaluations in the energy sector has grown more slowly than in other sectors, and remains small. This is so, because the methodological challenges to applying impact evaluation techniques to infrastructure projects are somewhat larger than for other sectors such as health, education, or social programs.

Nevertheless, increasing numbers of innovative impact evaluations are emerging in the energy sector to address an expanding array of questions. Many energy program and project documents state intentions to improve socioeconomic

welfare, such as increased incomes, better education, and improved health. Recent studies have helped to provide causal evidence of such benefits and the pathways through which they occur, but additional impact evaluations are needed to understand how these outcomes may be enhanced. Impact evaluation of energy sector reforms is a frontier area of research. Previous studies offer important insights on which reforms have been effective, but only a tiny share of possible reforms have been subject to rigorous testing. Energy efficiency is increasingly targeted to address sustainability outcomes. Impact evaluation can help test interventions to this end, but the array of options tested to date remains limited.

Impact evaluation techniques can test effects at the levels of both energy consumers and energy suppliers. For example, governments now offer many incentives to promote clean energy supply. Impact evaluation can help to test their effectiveness. Similarly, impact evaluation can test alternative means of ensuring cost recovery, such as separation of power supply feeders for irrigation and for households. These types of insights on responses to measures taken can help in refining energy programs.

This report aims to help orient future impact evaluation work in the energy sector by reviewing what has been produced against what might be possible. To do so, this report offers a brief review of impact evaluation considerations for the energy sector, impact evaluations performed to date, and future directions for impact evaluation studies. It does so by first characterizing energy sector programming and theories of change to identify potential impact evaluation questions. Then it reviews impact evaluations performed to date in terms of interventions and outcomes covered, as well as methods applied. From these two sets of information, gaps in intervention and outcome/impact coverage are identified, and future directions for impact evaluation are proposed.

2. Types of Energy Sector Interventions

Energy is one of the principal areas for development assistance expenditure globally. In many senses, the Asian Development Bank (ADB) typifies the global pattern. ADB has provided assistance to its developing member countries in the energy sector for more than 40 years. Energy sector operations now make up the largest share of ADB lending, and they accounted for over a quarter of ADB's total lending commitments from 2008 to 2018.

ADB's first Energy Policy was developed in 1981 as a response to the energy crisis of the 1970s. The ADB (2009) Energy Policy aims to help developing member countries provide reliable, adequate, and affordable energy for economic growth in a socially, economically, and environmentally sustainable way. The policy emphasizes energy security, facilitating transition to a low-carbon economy, providing universal access to energy, and working toward achieving ADB's vision of a region free of poverty.

The dominant focus of investment in the energy sector is the electricity subsector. Major hardware investment areas in this subsector include power generation, transmission, and distribution. New power generation is often intended to be from more environmentally friendly and efficient sources than the existing energy mix, frequently with more use of renewable sources (Frankfurt School–UNEP Center/Bloomberg New Energy Finance 2018). Transmission investments generally seek to reduce transmission losses and improve transmission capacity, while distribution helps to extend electricity to new areas.

Complementing the hardware investments are investments in policy improvements. Appropriate tariff structures to encourage electricity conservation and minimize peak-time consumption are often promoted, as are reforms to reduce subsidies and make them transparent, appropriate, and targeted. New technologies are also piloted to demonstrate how electricity can be generated more sustainably.

Beyond electricity, development investments can seek to improve supply of cleaner fuels, such as natural gas or geothermal energy for heating and/or cooking. They may also target cleaner and improved cookstoves to reduce local air pollution, or provide more efficient public heating services to substitute for individual heating facilities. Interventions, such as biodigesters or interventions to scale up biofuel production, may generate new sources of fuels. Other interventions, such as fossil fuel subsidy reforms, may seek to promote more efficient and environmentally friendly substitution for transport fuels.

Programming is increasingly focused on ensuring that possibilities from energy sector development can be equitably realized (ADB 2014). For example, energy access interventions for rural electrification are increasingly being coupled with complementary interventions, such as skills training for women and poor stakeholders.

As energy programs become progressively more oriented toward objectives of inclusion and sustainability, the number of assumptions underpinning their design is increasing. Moreover, a rising share of those assumptions is behavioral, and those behavioral assumptions can often only be truly tested using impact evaluation methodologies.

3. Theories of Change for Energy Interventions

Similar to many other donor organizations, ADB has not explicitly articulated a complete theory of change for energy interventions, but it has expressed elements of a theory of change in various ways. At the aggregate level, "results indicators" are listed in the ADB Results Framework (ADB 2013b). These indicators are meant to track progress over time based on existing data, without trying to establish causality. The "level 1" results indicators of development progress in Asia and the Pacific are (i) electrification rate (%), and (ii) carbon dioxide emissions (metric tons per capita). "Level 2" indicators of ADB's contribution to these results include the following:

- Greenhouse gas emission reduction (ton of carbon dioxide equivalent per year)
- New households connected to electricity (number)
- Installed energy generation capacity (megawatts): Renewable
- Transmission lines installed or upgraded (kilometers)
- Distribution lines installed or upgraded (kilometers)

Although many project documents mention expected outcomes related to health, income, and employment, ADB does not have energy sector indicators to capture socioeconomic outcomes. Impact evaluation can help gather evidence on such advanced outcomes, as well as other indicators that cannot be captured through regular monitoring data.

As another expression of results logic, economic analysis and calculation of an economic internal rate of return is performed for each energy project. Ex ante, this is typically based on projections of cost savings through substitution for existing levels of energy consumption, as well as consumer surplus benefits from the difference between average willingness to pay and costs for expanded use of energy. In these calculations, consumer responses are mechanistically assumed, and only a small portion of possible proximate project impact pathways is considered.

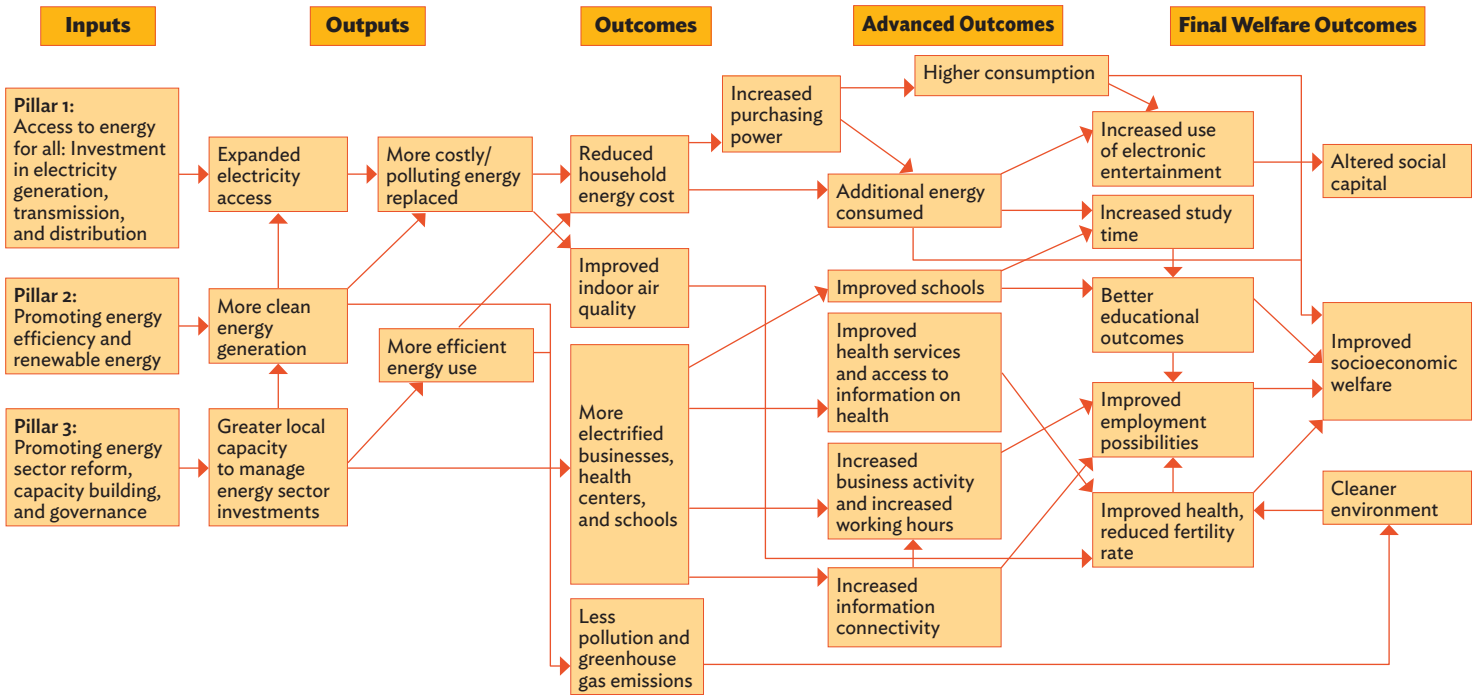
More broadly, each project has a design and monitoring framework, which lays out inputs, activities, outputs, outcomes, impacts, key risks, assumptions, and interlinkages (ADB 2015). These are the core elements of a theory of change at the project level. A theory of change can be drawn together explicitly for the sector, as is illustrated in Figure 1 for electricity projects.

For electricity supply projects, a key intention is to provide electricity as a lower-cost alternative to energy that is already consumed by end users, so as to reduce expenditures on existing energy use and increase purchasing power (World Bank 2015). Substitution of electricity for kerosene lamps and combusted fuels is intended to improve air quality, leading to better health. By supplying more and more reliable electricity, energy consumption also expands, and this expansion has more value to consumers than the cost, creating increased welfare. Improved lighting from greater energy access is assumed to translate into increased studying and enhanced educational outcomes. Electricity access is also expected to allow better use of information and communication technology, such as radios and mobile phones, and thereby improve access to information and services. Better information access, expanded ability to use electrical appliances/devices, and improved lighting are expected to raise firm productivity, economic growth, and employment. Labor and study productivity may also increase under better cooling with fans in hot conditions. This is complemented by enhanced services from electrified educational, health care, and other facilities, so as to improve social outcomes more broadly.

Beyond electricity supply, clean energy projects seek to substitute cleaner fuels for dirtier fossil fuels. Such may occur through direct investment in energy supplies and generation, or through policies that incentivize more clean energy development by the private sector. A key motivation is to reduce air pollution, such as fine particulate matter and ozone, which adversely affects human health and poses risks to agriculture. In addition, cleaner energy reduces greenhouse gas emissions and contributions to climate change.

Energy can be seen as an "intermediate good," or as an enabler of development, which affects a range of economic, social, and environmental outcomes through sometimes lengthy causal chains (Cook et al. 2005, Torero 2014, Bernard 2010). Even if the availability of electricity does affect behavior as assumed, the materialization of employment generation, sustainable socioeconomic improvements, and a cleaner environment depend on other economic and environmental factors, which may vary over time and among countries.

Figure 1: Depiction of a Theory of Change for Electricity Interventions



Assumptions				
Appropriate program design	• Electricity is targeted and maintained. • Clean energy matches load/demand characteristics. • Capacity building is effective.	• Improved energy is less expensive than existing sources and substitutes for them. • Efficient energy technologies are adopted. • Public facilities make effective use of new energy. • Clean energy replaces dirty energy.	• Businesses benefit from electricity. • Electricity leads to increased study time. • Public health services are effective. • Improvement in air quality is sufficient to improve health.	• Increased study time and improved schools increase educational outcomes. • Improved education and business opportunities are sufficient to improve employment. • People make effective use of public health services and respond to increased information.

Source: Authors, drawing on ADB (2009).

Each of the steps in the theories of change outlined in Figure 1 contains behavioral assumptions, which impact evaluation can test. For example, it is assumed that existing energy sources are replaced, rather than merely supplemented by electricity access, so that indoor air quality improves. It is assumed that better lighting under electricity translates into increased study time, rather than only increased time for use of electronic entertainment, such as television. It is also assumed that increased study time is used effectively to translate into better educational performance. Table 1 shows examples of how impact evaluation can be applied to each of the pillars in ADB's Energy Policy.

Table 1: Impact Evaluation and the ADB Energy Policy

Energy Policy	Opportunities for Impact Evaluation
Pillar 1: Promoting energy efficiency and renewable energy	
Support for renewable energy and energy efficiency technologies, awareness raising, promotion of policy and regulatory incentives to encourage use of clean energy technologies, and promotion of financing packages to share risks and lower costs.	Impact evaluation can test the effect of different information schemes and financial incentive packages on the decision to deploy or take up renewable energy sources. Impact evaluation can test the effect of energy efficiency programs such as shifting to efficient light bulbs or services offered by energy service companies.
Increasing the efficiency of energy use and supply to yield greater service value from each primary energy unit consumed and produce large environmental and economic benefit.	Impact evaluation can be used to measure the economic benefits to consumers who take up or switch to renewable energy sources as well as to those who shift to energy-efficient solutions.
Pillar 2: Maximizing access to energy for all	
Support electrification especially for the rural population and remote communities.	Impact evaluation can be used to measure the socioeconomic and health-related benefits of rural electrification.
Support installation of modern transmission and distribution systems to transmit electricity efficiently from generation facilities to consumers, including upgrading of existing systems to reduce technical losses.	Impact evaluation can be used to measure different program components aimed to increasing the effect of connecting to electricity, such as training on productive uses of electricity.
Pillar 3: Promoting energy sector reform, capacity building, and governance	
Adopt appropriate tariff structures to promote energy conservation and minimize peak-time consumption. Minimize subsidies and make them transparent, appropriate, and targeted.	Impact evaluation can be undertaken on tariff structures and subsidy schemes to test different structures for promoting energy conservation and usage patterns, also in combination with potential information schemes to promote behavioral change for different user groups.
Support for research, legislation, and technology development.	All of the above can provide evidence for upscaling and policy-making processes.

ADB = Asian Development Bank.
Sources: ADB 2009; Authors.

Similarly, it is assumed that electricity enables businesses to adopt efficiency-enhancing electrical equipment and that businesses make use of new information access. It is assumed that this is sufficient to facilitate business activity expansion, and that the increased business activity leads to higher labor demand, employment, and wages.

For energy supply, it is often assumed that cleaner energy supplies integrate into energy mixes in a manner that displaces dirty fuels in pollution-affected areas. This often depends on how demand characteristics, which may differ from assumptions, evolve in the context of other energy sector developments.

Impact evaluation can go further than merely testing each of these assumptions. For each of these sets of assumptions, there may be multiple means of driving the intended effect, which can be compared. For energy sector projects, these could be mechanisms such as pricing structures or different types of information, which nudge consumers to change behavior (such as using energy more efficiently or switching to renewable energy).

4. The Challenges of Evaluating Impacts of Energy Interventions

Energy sector interventions pose methodological challenges for impact evaluation for several reasons. The core challenge of impact evaluation, which empirically identifies the effect attributable to an intervention in magnitude and statistical significance (White and Raitzer 2017), is to control for confounding factors and isolate the effects of the focal intervention. A primary confounding factor is *endogenous placement*. Energy infrastructure is generally placed strategically to promote growth where it is most needed, in areas with the greatest potential gains from increased energy supply, or in areas favored for other reasons. Program designers will often place these projects in areas with high growth potential, or in richer, more densely populated areas, which, in turn, confounds comparisons between connected and non-connected areas. That introduces project placement bias, and thus makes it more difficult to identify a credible comparison group.[1]

For electricity projects, there is additional scope for selection bias stemming from differences in the characteristics of households connected to the grid and those that are not. With connection fees often that are substantial, better-off households are usually the first to be connected when the grid reaches a particular location. Failing to account for these differences leads to an overestimation of the impact of electrification if connected and unconnected households are compared (Bernard 2010).

Ex post economic internal rate of return estimates are usually calculated for energy projects based on reflexive (before–after) comparisons of energy consumption patterns, volumes, and costs. Usually, only administrative data are used, which do not include all energy sources intended to be replaced by the project. This means that there are important limitations to this approach. First, data are not collected to characterize substitution issues and assumptions on cost reductions. Second, the project is not the only factor causing changes

[1] Project placement bias is a common source of selection bias (self-selection being the other main source).

over time. The other causes of changes, including overall trends, are confounded with the effects of the project, so that the basic assumptions of the economic analysis model are not directly tested.

In many other sectors, confounding of trends and selection/placement bias may be more easily eliminated by randomized assignment of the intervention in a randomized controlled trial (RCT). However, for energy infrastructure, this is more challenging. Energy infrastructure, especially for electricity, is often a part of overall transmission and distribution networks, so that random assignment or sequencing of project components may not be conducive to overall network functionality. Second, whereas eligibility criteria can be altered for inexpensive interventions targeting households without permanent project consequences, altering rollout of large, long-lived investments may have substantial irreversible costs.

In addition, large-scale power generation and transmission lines are “small n” interventions, where there are often too few treated units to allow sample sizes sufficient for statistically significant differences in outcomes. These interventions may also have large spillover and general equilibrium effects, so that there is no unaffected comparison population and an unbiased estimate of treatment effects cannot be generated by empirical reduced-form techniques.

5. Impact Evaluations to Date

This report attempts to characterize impact evaluations conducted to date on energy supply interventions in developing countries. To this end, a search was carried out covering the following sources to identify impact evaluations on energy interventions in developing countries:

- Impact evaluation repository of the International Initiative for Impact Evaluation (3ie)[2]
- Over 2,000 papers in JSTOR and EconLit databases[3]
- Eleven literature and systematic review papers of energy impact evaluations and any relevant references cited[4]
- Websites of the Inter-American Development Bank, Center for Global Development, International Food Policy Research Institute, Innovations for Poverty Action, and the World Bank's Development Impact Evaluation (DIME)

As such, the search covers major authoritative databases, but it is not exhaustive, and important studies may be missed. However, many studies that are widely recognized are likely to be captured.

The search aimed only to include empirical studies that attempt to control for selection/placement bias and other confounding factors, using methods described by White and Raitzer (2017). From the search, 85 completed studies qualified as methodologically rigorous impact evaluations, of which 37 evaluate

[2] The repository is based on a very comprehensive review of academic databases, organizational databases, websites, and more. Both the repository and protocol can be found at www.3ie-impact.org.

[3] Carried out in addition to the review already done by 3ie as a "double check".

[4] Including Jimenez (2017), Bensch et al. (2016), Ministry of Foreign Affairs of the Netherlands (2013), Attigah and Mayer-Tasch (2013), Bernard (2010), Bonan et al. (2014), Cook et al. (2005), Estache (2010), Torero (2014), World Bank (2008), and World Bank (2014).

interventions in Asia. This excludes evaluations of cookstoves, for which a number of impact evaluations exist, as these do not fall under the type of energy sector support that receives large-scale investment.

All studies are listed in Appendix 2. Although the older studies exclusively use quasi-experimental methods, a greater proportion of the newer studies involve randomized experiments, which use random assignment to introduce exogenous variation in electricity connection, metering, or distribution of solar kits.

The completed studies fall broadly into four categories:

(1) **Impact of electrification**: The vast majority, 57 studies, examine the impact of electricity access. This includes 24 studies in Asia. Most of these focus specifically on rural grid electrification programs, while eight studies evaluate rural electrification through off-grid systems. An additional five studies focus on solar lanterns.

(2) **Impact of energy efficiency programs:** A total of five studies evaluate interventions to increase the efficiency of energy consumption, such as the introduction of energy-efficient appliances, incentives, and information nudges aimed at conserving energy, or introduction of energy-efficient compact fluorescent lamp (CFL) bulbs. This group includes a completed ADB study of CFL lamp bulbs in Pakistan (Box 1).

(3) **Impact of electricity sector reforms**: This set includes 16 studies that evaluate effects of market-based reforms on several outcome indicators. These reforms include privatization, private sector involvement, unbundling, and change in electricity tariff design (Appendix 2).

(4) **Others**: This last small group includes six studies evaluating impacts of improved electricity supply to firms, a study of natural gas access for households, a study on effects of electricity-enabled television usage, and a recently published ADB study assessing impacts of energy-based livelihood training programs on rural women in India (Box 1).

These can be considered against major areas of energy investment described in section 2, including (1) investments to expand electricity supply and access, including basic generation, transmission, and distribution infrastructure; (2) investments in making energy cleaner, including on- and off-grid renewable generation; and (3) investments in improved governance and administration of the energy sector, including major reforms in market structures and tariffs.

Box 1: Completed ADB Studies

A total of four ADB impact studies in the energy sector have been completed so far:

(1) **The impacts of transport and energy infrastructure on poverty were evaluated in the People's Republic of China, India, and Thailand.** Cook et al. (2005) evaluate effects on quality of life and a range of economic, social, and environmental outcomes, as well as on health and schooling. Challenges, such as a lack of baseline data, meant there were methodological limitations to carrying out a robust counterfactual analysis. The study thus applies a mixed methods approach using econometric analysis where possible, as well as case studies and participatory methods. The main findings across the three countries are that the analyzed infrastructure led to (1) improved health and education service quality in rural areas; and (2) improved information flow and social capital of rural households.

(2) **Impacts of ADB-funded rural electrification projects in Bhutan were evaluated.** ADB (2010) evaluates the effects of two rural electrification projects (jointly) on indicators related to quality of life. The study applies propensity score matching using data on 1,276 electrified and 822 unelectrified households. Results suggest that electrified households experience higher incomes; that children in the electrified households completed more years of schooling; and that electrification reduced smoke-induced health problems.

(3) **Household responses to energy-efficient lighting technology were evaluated in Pakistan.** Chun and Jiang (2013) examine adoption of compact fluorescent lamp bulbs (CFLs) and use an instrumental variables approach to estimate the effects of household CFL adoption on the demand for lighting services. Respondents' CFL knowledge and the price ratio of CFL to incandescent light bulbs in the area are used as instruments for CFL adoption. The study finds that limited knowledge of the life span of CFLs negatively influences the decision to switch to CFLs as does higher CFL bulb prices. Adoption of CFLs is found to result in energy savings, but less so than expected, as a large proportion of potential energy savings is offset by households keeping lights on longer or making rooms brighter.

(4) **An impact evaluation estimated the impacts of energy-based livelihood training on rural women in Madhya Pradesh, India.** PWC (2017) evaluates the impacts of energy-based livelihood training given to women members of self-help groups on several economic and social outcomes using propensity score matching and regression analysis. The analysis finds that participation in training has a positive effect on incomes and propensity to save and take out loans, but no significant pattern on transition to low-carbon fuels and on ownership of labor-saving electrical appliances. In terms of social impact, the training is found to have no impact on time use, but are found to affect women's perception of safety and household decision-making.

Source: Authors.

Area 1 can be further subdivided into (1a) rural electrification and expansion of grid connectivity, and (1b) general enhancement of electricity supply.

- Area 1a is the major focus of impact evaluations to date, as 49 studies have assessed rural electrification. Rural electrification is a large-n intervention, as there can be many units (usually villages) assigned into and out of the intervention, so that sample power for conventional impact evaluation techniques is relatively easy to attain.

- Area 1b is increasingly the focus of energy sector investments in developing Asia, as electrification rates have already reached high levels, but the quality and duration of electricity supply remains limited. However, only six impact evaluations to date have quantified effects of enhanced electricity reliability and reduced brownouts.

- Area 2 has been the focus of 12 impact evaluations, of which most focus on off-grid or user-owned renewables. Effects of on-grid, larger-scale renewables have been evaluated in only four studies.

- Area 3 has been the focus of 16 impact evaluations. Of these, eight include coverage of privatization or private sector participation, five on regulation, and four on pricing.

Most of the studies reviewed for this report have households as the unit of analysis, but some studies that evaluate employment effects additionally explore changes at the level of the community, district, or neighborhood. Although the unit of analysis is most often the household, the unit of assignment is most often at the village, neighborhood, or subdistrict level.

The number of impact evaluations of energy sector programs is substantially lower than for the social sectors. This may be due to the methodological challenges discussed in the previous section. It may also be because many investments and development programs in the sector are led by staff with an engineering background, who may have less experience in analyzing behavioral interactions than staff with social science backgrounds, who often lead social programs. At the same time, the number of studies is growing rapidly, as over 60% of the studies identified were published after 2012.

6. Common Impact Evaluation Designs in the Energy Sector

A range of designs can be applied within the energy sector. These include both experimental and nonexperimental designs, as described in Appendix 3 and Table 2.[5]

Experimental designs

Randomized experimental designs are considered the "gold standard" in impact evaluation because they can potentially eliminate all differences other than exposure to the intervention of interest (Athey and Imbens 2017). However, power sector interventions, as the major focus of public energy investment, may be considered difficult to evaluate using randomized assignment, because grid electricity infrastructure is networked and interdependent. However, the latest "generation" of studies have had more success in utilizing experimental designs. These studies include both simple and cluster RCTs.

Simple RCTs have been applied for solar lanterns (Rom, Günther, and Harrison 2017; Hassan and Lucchino 2017; Aevarsdottir, Barton, and Bold 2017). This type of intervention is relatively easy to assign at the level of individual households, as it does not have the connectivity dependencies of grid electricity.

For grid electricity, randomized experiments often use various forms of incentives to introduce exogenous variation in take-up/electricity use, as *encouragement designs*. Some encouragement designs (like other randomized experiments) have been implemented under simple randomization, where there is random assignment of the encouragement at the same level as the unit of analysis. Examples include the distribution of discount vouchers to a subset of households residing within all areas scheduled for connection to the electricity grid in a given year (Bernard and Torero 2013; Barron and Torero 2014; Lee, Miguel, and Wolfram 2018; see also Box 2 and Case Study 1); or the random

[5] White and Raitzer (2017) offer additional details on the techniques discussed.

Table 2: Impact Evaluation Designs for the Energy Sector

Experimental designs	Simple randomized controlled trial (RCT)	Randomization is generally not feasible for grid electricity itself, as the intervention is networked and clustered. Other energy interventions that are not large infrastructure, such as information campaigns, may be evaluated using this approach, if spillovers are not substantial.
	Cluster- or matched-pair RCT	Cluster- or matched-pair randomization at the level of feeder lines might be a feasible approach for certain types of rural interventions, though in practice no such experiments have been successfully implemented thus far.
	Encouragement design	Encouragement designs create random variation in the use of an intervention of interest by implementing an informational or other "nudge" that affects utilization on a randomized basis. This can recover an unbiased local average treatment effect even when the intervention itself cannot be randomized. A number of studies have successfully used this design based on electricity connection costs.
Nonexperimental designs	Regression discontinuity designs (RDD) and interrupted times series	RDD exploits discontinuities in eligibility for an intervention with respect to an assignment variable. An RDD design might feasibly be applied to examine impact of power infrastructure—e.g., if there is a particular town size threshold for electrification, or an income threshold for a connection subsidy. Similarly, interrupted time series approaches may be used for large power infrastructure that become effective at a defined point in time, such as a large new power plant, as the point of time creates a sharp discontinuity.
	Instrumental variables	Instruments are variables that predict exposure to or participation in an intervention, but does not affect outcomes directly, as a means of proxying exogenous variation in the intervention. Finding a valid instrument is challenging, and not always feasible. Researchers can consider program placement rules for a possible instrument.
	Propensity score approaches	The propensity score is the estimated probability of having an intervention given the observable characteristics from a regression model of participation. Propensity score approaches balance estimated probabilities before making comparisons. Propensity score techniques are nearly always possible, although they are more at risk from selection bias than other methods. Using the method in combination with Difference-in-differences (DiD) can reduce this risk.
	DiD and fixed effects models	These methods take the trend in a sample not exposed to an intervention as the trend that would occur for the treated sample in the absence of the intervention. They can be used if there are baseline data, though they should preferably be used in conjunction with a matching procedure or model with covariates. These methods may potentially be used to investigate urban infrastructure and policy reforms if there is spatial variation.
	Synthetic controls	Synthetic control techniques can use a long time series of pre-intervention observations to "train" a weighting algorithm to identify weights that allow a pool of comparison observations to approximate the outcome trends in one or more treated units. The treatment effect is the DiD between the synthetic control and the treated unit. Placebo tests are used in place of conventional statistical significance.

Source: Authors.

Box 2: Overcoming Nonrandom Placement through Randomized Encouragement Design

Three studies of grid expansion programs in El Salvador, Ethiopia, and Kenya, use randomized encouragement designs to overcome the endogeneity of electricity connection stemming from nonrandom placement of the grid.

Because households are required to pay a substantial fee for connecting to the grid, providing discount vouchers can increase willingness to connect for some households. Thus, by randomly assigning households to receive subsidies of varying amounts, the studies were able to introduce exogenous variation in uptake. This enables the authors to examine at the first stage, the effect of subsidies on connection, and at the second stage, the effect of becoming electrified on welfare outcomes.

The vouchers increase chances of uptake, but do not ensure uptake. The reported effects are therefore intent-to-treat estimates—i.e., the average effect of receiving a voucher, but not of connecting.

Detailed findings of the experiment in El Salvador are reported in Case Study 1.

Sources: Barron and Torero (2014), Bernard and Torero (2013) , and Lee, Miguel, and Wolfram (2018). See Appendix 2.

assignment of businesses in one area of Nairobi to receive different pricing schemes for adoption of off-grid solar power (Jack and Suri 2013).

For ethical and practical reasons, encouragement designs (as well as other randomized experiments) have often been assigned via one- or two-stage cluster randomization, where the unit of assignment to the encouragement is higher than the unit of analysis. This is often appropriate for encouragements that can be randomly assigned at the subdistrict or community level. An example of a one-stage cluster encouragement design is an experiment in which communities are randomly selected to be offered subsidized solar micro grids in rural India (Aklin et al. 2017).

An example of a two-stage cluster encouragement design is the random assignment of communities within reach of the electricity grid (first stage) in which discount vouchers are randomly assigned to villages with unconnected households (Barron and Torero 2015b, see Box 2).

Beyond evaluating the effects of energy access itself, randomized selection has been successfully employed for evaluation of metering and renewable energy interventions, often under one-stage cluster assignment. For example, random assignment was used for communal metering and group payment at the

neighborhood level in rural Bihar as a means of increasing revenue collection and reducing theft (Sudarshan et al. 2014). Pipeline randomization that randomizes which units initially receive treatment has been used with cluster assignment for an evaluation of prepaid electricity meters for low-income households in communities in Cape Town (Jack and Smith 2016).

Nonexperimental designs

As can be expected, given the difficulties of randomizing many energy interventions, the vast majority of completed impact evaluations use quasi-experimental or regression-based techniques. The most common approach is to employ difference-in-differences (DiD) techniques, which net out the before–after trend in a comparison sample from the before–after trend in a sample with the intervention, so as to measure the difference in the changes over time associated with the intervention. Two-way fixed effects models work similarly, and are grouped together with this method for ease of presentation. These techniques have been used to assess welfare outcomes from electrification, the effects of energy efficiency programs, and cross-sector effects of energy interventions on agriculture. The limitation of DiD is that the "parallel trends assumption"—the trend in the comparison population is the same as the treated population in the absence of the intervention—may not always hold. This is especially so if multiple programs are targeting the same areas simultaneously. Inclusion of covariates in a fixed effects specification can help to narrow the assumption, as can combination with matching techniques.

The next most common method used is instrumental variables (IV), in which a predictor variable that is *relevant* (highly correlated) to an energy intervention, but meets the *exclusion restriction* of having no pathway to effects of interest outside of the energy intervention, is applied as an *instrument*. This instrumentation allows the use of the predicted value from the instrument to replace the endogenous energy intervention variable in an outcome regression (see Case Studies 2 and 3 for examples). Instruments for electrification have included land gradient (Dinkelman 2011; Grogan and Sadanand 2012), distance to hydroelectric dams (Grogan and Sadanand 2012), distance to the electricity line (see Box 3), distance to power-generating plants (van de Walle et al. 2013), and lowest cost locations for transmission and distribution development (Chakravorty, Emerick, and Ravago 2016).

The challenge for this approach is to satisfy the exclusion restriction. This means that the observed variation in the instrument—such as land gradient—does not affect other types of infrastructure, agricultural production, other

Box 3: Using Instrumental Variables to Measure the Impact of Electrification on Rural Households

One of the biggest challenges of evaluating effects of electrification is that more wealthy households can better afford electricity connections, so that causal relationships are confounded in direct comparisons between households with and without electricity.

Khandker, Barnes, and Samad (2009) use an instrument to avoid this problem. They explore the pricing arrangements for electricity connections in Bangladesh and determine that distance from electric poles conditions eligibility for connection subsidies. Based on this insight, they further find a large connection cost jump for households more than 100 feet from electric poles, as that distance is the cutoff for subsidy eligibility.

They also test that there is no positive significant relationship between distance from electric poles and outcomes of interest before electrification. This allows them to conclude that distance from electric pole locations is unconfounded but predicts treatment. Household distance of less than 100 feet from electric poles is thus used as the instrument in their village fixed effects regressions.

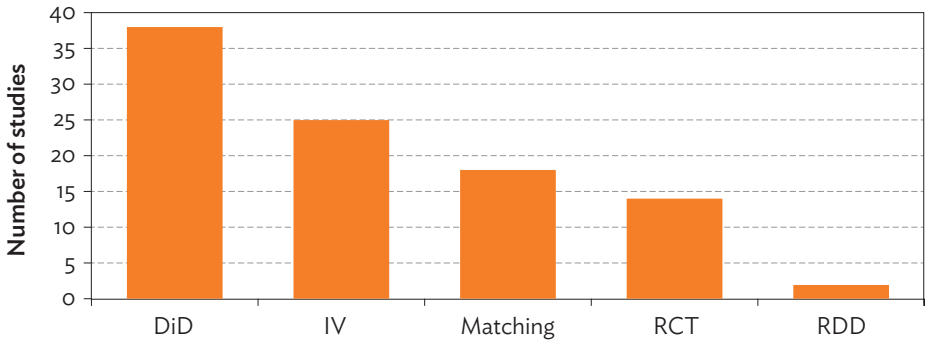
A first stage regression is used to predict the value of household electricity access as a function of the instrument, village characteristics, and household attributes. In the second stage, the authors regress key outcomes against predicted electrification and household and village characteristics. This finds positive effects on all major outcomes tested, including schooling completion, study time, consumption, and income.

Source: Khandker, Barnes, and Samad (2009).

economic activities, or the outcomes of interest (e.g., Barron and Torero 2014). It is difficult to find instruments that satisfy this requirement while being relevant to energy interventions.

Several studies have also used propensity score matching—either alone or in combination with DiD. When used alone, this technique remains susceptible to selection bias when there are determinants of intervention participation/use that remain unobserved (King and Nielsen 2016). For this reason, the technique is considered of lower rigor, unless used in combination with DiD. Case Study 3, which examines the long-term impacts of household electrification in rural India is an example of a study that combines IV and DiD. Figure 2 provides an overview of the methods applied in the studies reviewed, with the total number reflecting that some studies use several methods at once.

Figure 2: Overview of Methods Used for Energy Sector Studies



DiD = difference in differences, IV = instrumental variables, RCT = randomized controlled trial, RDD = regression discontinuity design.
Note: Some studies use multiple methods.

Source: Authors.

7. Outcomes Measured

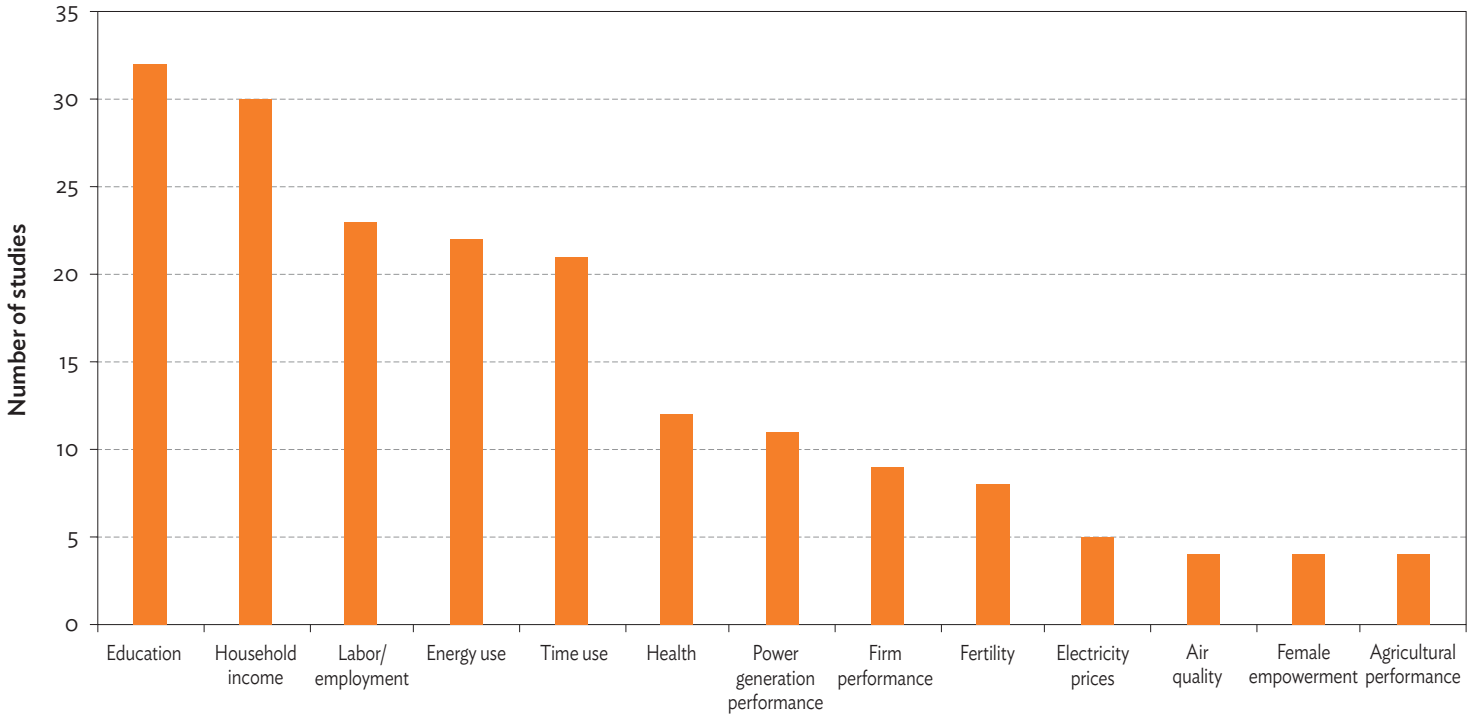
Most of the outcomes studied can be grouped broadly into five categories: (i) energy consumption or expenditure, (ii) labor/time use, (iii) income, (iv) education, and (v) health. Most studies examine several of these outcomes simultaneously. Time use is often a step in the causal chain leading to other outcomes as shown in the theory of change diagram in Figure 1. The main outcomes reported in the 85 completed studies are shown in Figure 3.

These studies have found the following effects.

(1) *Electrification can lead to substantial changes in time use.* Several studies find that access to electricity resulted in positive changes in time allocation, especially among women and children. Grid electricity and provision of solar home systems were found to lead to increased study time for schoolchildren after nightfall in several countries (Bensch, Kluve, and Peters [2011]; Bensch, Peters, and Sievert [2012]; Grimm, Peters, and Sievert [2013]; Asaduzzaman et al. [2013]; Banerjee, Singh, and Samad [2011]). These effects have been observed as more modest in certain cases of lower capacity solar home systems and solar lanterns (Aklin et al. 2017; Rom, Günther, and Harrison 2017).

(2) *Electrification can lead to improved educational outcomes for children.* Impact evaluations have found positive effects on school enrollment, with an average increase of about 7% (Barkat et al. 2002; Aguirre 2014; Barnes and Binswanger 1986). Household electrification has been found to increase school attendance by 6.3% for boys and 9.0% for girls in Viet Nam (Khandker, Barnes, and Samad 2013). Positive significant electrification effects on attendance were found by Guarcello, Lyon, and Rosati (2004) in rural locations of El Salvador, Ghana, Guatemala, Morocco, and Yemen, and urban areas of Guatemala. Hassan and Lucchino (2017) find large effects of solar lanterns on both study hours

Figure 3: Most Common Outcome Variables in Energy Impact Evaluations



Note: Labor includes labor supply, labor activities, and employment; Education includes school attendance, years of schooling, and school performance; Household income includes expenditure, consumption, and poverty. Some studies evaluate multiple outcomes.

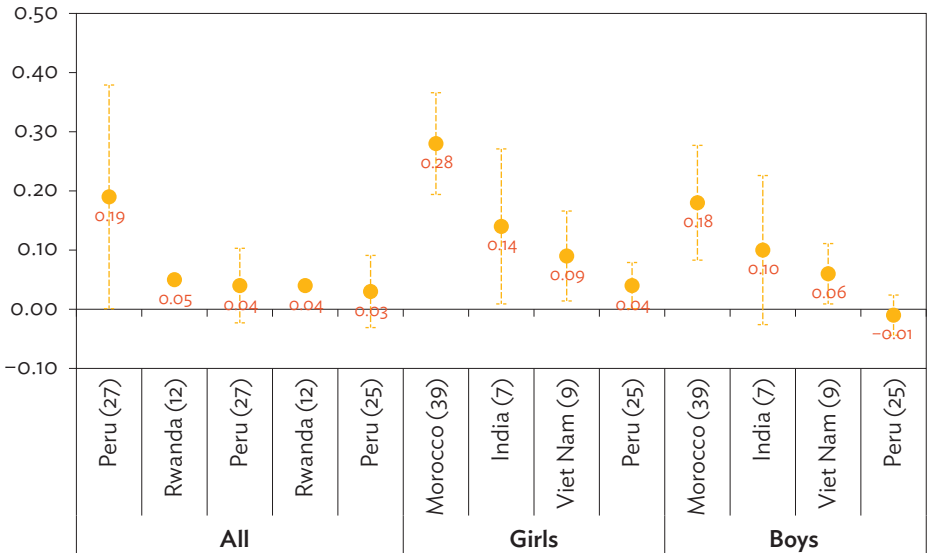
Source: Authors.

and grades in Kenya, whereas Kudo, Shonchoy, and Takahashi (2015) find that increased study hours from solar lanterns in Bangladesh do not translate into observable education outcomes. Conversely, an impact evaluation in Peru found that increased child labor demand due to electricity access led to a significant and negative effect on boys' enrollment (Dasso, Fernandez, and Nopo 2015). In Honduras, another impact evaluation similarly found increased dropout rates among school boys (4.3%) and a negative effect on girls' years of schooling (–34.7%) from electrification (Squires 2015).

(3) *Educational outcomes of electrification can reinforce gender equality,* as the estimated effects tend to be greater for girls than for boys. This pattern is evident for a range of educational outcomes, such as years of schooling, attendance, literacy, and time allocated for studying at home. An impact evaluation of rural electrification in India found positive effects on schooling for girls, but not for boys (van de Walle et al. 2013). Significant effects on years of schooling only for girls were also found by Banerjee, Singh, and Samad (2011) in Nepal. Effects on employment have been found to be more positive for women than men (Barron and Torero 2015b; Grogan and Sadanand 2012). A review by Jimenez (2017) of rural electrification impact evaluation studies summarizes effects on school attendance and illustrates that effects in a number of studies are greater for girls than for boys (Figure 4.1).

(4) *Electrification can impact female empowerment*. Burney et al. (2017) observe significant effects of solar microgrids for irrigation on an index measuring female empowerment. Grogan (2018) finds significant increases in female paid work time from rural electrification in Guatemala. PWC (2017) also finds that training on energy use, coupled with electricity access, can help to change the relative role of women in household decision-making. In Nepal, Banerjee, Singh, and Samad (2011) find that electrification leads to higher female time study and leisure activities and increased independence of female decision-making, and Asaduzzaman et al. (2013) find similar effects in Bangladesh. On the other hand, access to electricity via solar-powered home systems in Peru was found to have effects on time use among women, as they spend more time taking care of children, doing household chores for the family, but less time in productive activities outside the home, such as farming (Arraiz and Calero 2015).

Figure 4.1: Effects of Access to Electricity on School Enrollment

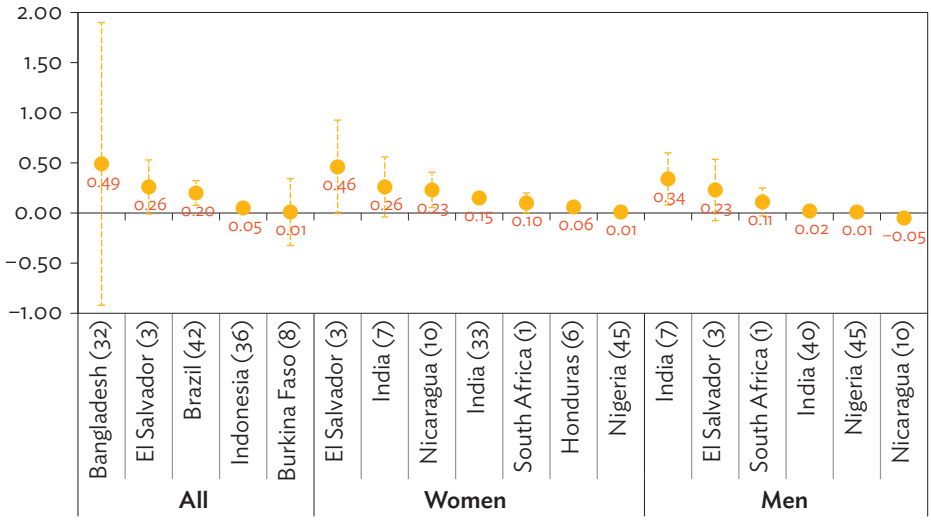


Notes: Estimated effects are expressed as proportional changes with respect to the control mean, with the standard errors represented by whisker lines. X-axes indicate the country where the study took place, with study number in Appendix 2 in parentheses.

Source: Adapted from Jimenez (2017).

(5) *Electrification can affect labor outcomes.* Jimenez (2017) observes that selected studies find significant and large effects of access to electricity on labor market participation, particularly on employment and hours worked per month (Figure 4.2). The average of the reviewed studies is that access to electricity leads to an increase in labor market participation by 25%, with women tending to benefit more in terms of labor outcomes. In Peru, an evaluation found that rural electrification increased working hours and probability of working in agriculture among men and increased employment by 3.5%, and increased earnings and hourly wages by 35% among women (Dasso and Fernandez 2015). In Nicaragua, rural electrification was found to increase the propensity of women to work outside of home by 23%, but there was no impact on male employment (Grogan and Sadanand 2012). Other studies similarly found that electrification enabled rural women to participate in employment in South Africa (Dinkelman 2011) and particularly in nonfarm employment and operating home businesses in El Salvador (Barron and Torero 2015b).

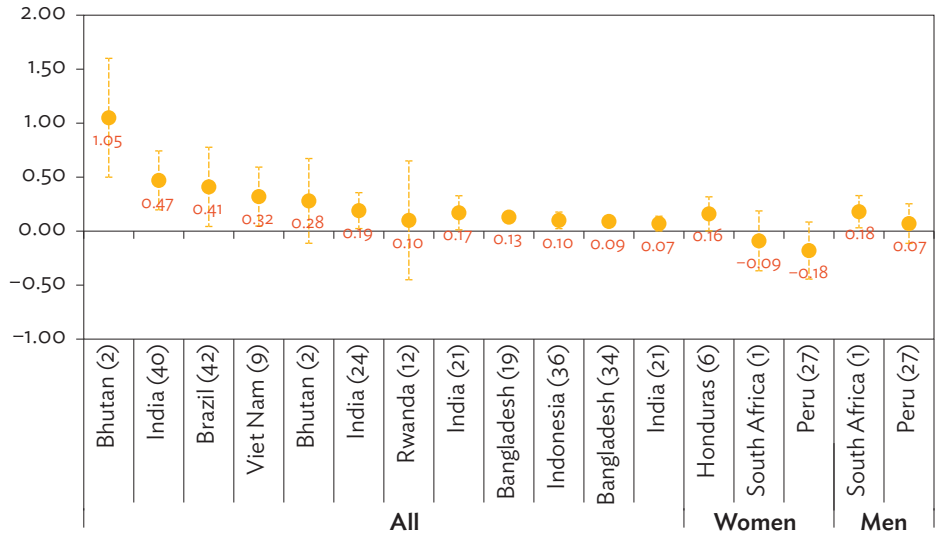
Figure 4.2: Effects of Access to Electricity on Employment



Notes: Estimated effects are expressed as proportional changes with respect to the control mean, with the standard errors represented by whisker lines. X-axes indicate the country where the study took place, with study number in Appendix 2 in parentheses.

Source: Adapted from Jimenez (2017).

Figure 4.3: Effects of Access to Electricity on Income



Notes: Estimated effects are expressed as proportional changes with respect to the control mean, with the standard errors represented by whisker lines. X-axes indicate the country where the study took place, with study number in Appendix 2 in parentheses.

Source: Adapted from Jimenez (2017).

(6) *Access to electricity can lead to increased household income, consumption, and expenditure.* Household electrification was found to raise total income by 28% and expenditure by 23% in Viet Nam (Khandker, Barnes, and Samad 2013). In the Philippines, Chakravorty, Emerick, and Ravago (2016) find a 38% increase in household expenditures and a 56% decrease in the deprivation index due to electrification. Similarly, Saing (2018) finds a 17% increase in household consumption in Cambodia from electrification. Ding, Qin, and Shi (2018) also find significant rural electrification effects on agricultural income in the People's Republic of China. Electricity access is found by Rao (2013) to be associated with at least 18% higher household enterprise income in India. However, Burlig and Preonas (2016) find effects on households that are only a few percentage points in small villages in rural India, and Aklin et al. (2017) and Lee, Miguel, and Wolfram (2018) find insignificant effects of electrification in India and Kenya, respectively. The range of evidence also reviewed by Jimenez (2017) suggests a heterogenous effect of electricity access on income, ranging from a drop in income to more than 100% increase (Figure 4.3).

(7) *Electricity can help improve indoor air quality and human health.* An electrification program in El Salvador was found to reduce overnight minute-by-minute fine particulate matter ($PM_{2.5}$) concentration by 65%, resulting in a 6% reduction in incidence of respiratory infections among children under 6 (Barron and Torero 2015b). Electrification-induced improvements in indoor air quality were observed in Bhutan, as households replaced use of fuelwood and other polluting sources of energy such as kerosene and candles with electricity (ADB 2010). In Buenos Aires, the provision of natural gas connections to households was found to reduce the incidence of flu or fever by 30% and reported respiratory infections by 14% (Goytia, Pasquini, and Sanguinetti 2011). In Tanzania, solar lanterns were also found to significantly reduce $PM_{2.5}$ concentrations (Aevarsdottir, Barton, and Bold 2017).

(8) *Electricity access can reduce fertility.* Increased television viewing due to electrification has been observed to reduce fertility by 18%–24% in Indonesia, partly as a result of increased exposure to family planning information that helps increase utilization of contraception (Grimm, Sparrow, and Tasciotti 2015). Reduced fertility from household electrification has also been observed in Bangladesh, Colombia, Ghana, and Tanzania (Fuji and Shonchoy 2017; Asaduzzaman et al.

2013; Fetzer, Pardo, and Shanghavi 2016; Grogan 2016; Akpandjar and Kitchens 2017; and Burlando 2014). Increased use of contraceptives was also observed by Banerjee, Singh, and Samad (2011) in Nepal.

(9) *Energy efficiency interventions can have important effects on energy consumption, but can also encounter large rebound effects.* A large-scale appliance replacement program in Mexico was found to reduce electricity consumption by an average of 11 kilowatt-hours per month for refrigerator replacement, but air-conditioning replacement was found to increase consumption by an average of 6 kilowatt-hours per month (Davis, Fuchs, and Gertler 2012). Sudarshan (2017) found a 7% reduction in summer electricity consumption in India from information nudges regarding electricity use. In Ethiopia, an energy efficiency program of distributing free compact fluorescent bulbs resulted in an estimated 13.3 megawatts of energy savings (Costolanski et al. 2013). However, the study also finds a rebound effect, as about 20% of the initial energy savings disappeared within 18 months of the program's completion.

(10) *Market-based power sector reforms have limited observed effects on end users.* A systematic review of 26 impact evaluations on the effects of different market-based power sector reforms, including privatization, private sector involvement, liberalization, and regulation on several outcomes (Bensch et al. 2016) found no strong evidence of effects. The overall direction of findings suggests that liberalization and private sector involvement are weakly associated with greater supply efficiency and investment, but those effects are usually not significant, and other effects are rarely found. On the other hand, the introduction of prepaid meters for electricity in South Africa significantly reduced electricity consumption (Jack and Smith 2016).

8. Evidence Gaps

Given the vast amount of development expenditure that focuses on energy, the amount of evidence on its effects is relatively limited. There are gaps in the *coverage of interventions* subjected to impact evaluation thus far and gaps in the *types of outcomes* measured.

Coverage gaps

As shown in section 7, the number of studies in each category remains very small. In particular, there is need for additional studies within many areas, including

- *Improvement of electricity supply*: Few impact evaluations quantify the effects of investments to improve hours of electricity provision, amounts of electricity that can be provided, or other aspects of electricity quality. These investments often take the form of large-scale power plants, transmission lines, and grid upgrades, and account for much energy sector investment. Similarly, there is very little impact evaluation of urban electricity enhancement.

- *Deployment of on-grid clean energy*: Solar and wind power have very different patterns of availability compared with conventional baseload power sources. There is little evidence as to the effects of renewable deployment in the grid.

- *Incentives for clean energy development*: A range of financial incentives has been put in place in many countries to encourage development of clean energy, including feed-in tariffs, tax incentives, green energy options, and concessional credit. No study has assessed the effects of these measures.

- *Measures to enhance grid efficiency:* Substantial investments are underway to reduce transmission and distribution losses, and improve the balance of load and generation. Moreover, smart grids can enable net metering,

peak-demand pricing, and demand-side management if employed optimally. Smart grid options are also emerging even for micro grids of off-grid users. None has been specifically subjected to impact evaluation.

- *Tariff and payment structures:* Electricity has a wide array of possible payment structures, which may involve cross-subsidies, tiered pricing, time of use pricing, prepayment or post payment, and various amounts of up-front financing of connections. Similarly, liquefied petroleum gas has various pricing arrangements and subsidies that are intended to reduce fuelwood and charcoal use. In recent years, many efforts have been made to reduce subsidies and make prices more market-based. Few impact evaluations have assessed the effects of alternative pricing options.

- *Electricity programs for agriculture:* In substantial areas of Asia, especially South Asia, much irrigation is carried out via electric tube wells. Electricity pricing is often highly subsidized for agriculture, but there are efforts to change this. Hydropower development may also affect agriculture via changes to water availability. Both aspects of the energy–water nexus have not been subject to much impact evaluation.

- *Bioenergy (other than improved stoves):* Many countries offer incentives for cultivation and consumption of bioethanol, biodiesel, or biogas. Little impact evaluation has focused on effects on either producers or consumers.

- *Non-electricity energy infrastructure:* There are few impact evaluations on the energy sector outside of electricity and cookstoves. Interventions to improve oil and gas extraction and transport, or to develop improved sources of community heating have not been subjected to impact evaluation in terms of effects.

- *Promotion of energy efficiency*: Many programs and approaches have been used to enhance demand-side energy efficiency, including labeling, subsidies for efficient units, information campaigns, and support to companies offering energy efficiency services. Merely a few impact evaluations in developing countries have focused on these efforts.

Outcome gaps

Only a small number of possible outcomes have been evaluated, usually in a limited set of contexts. Evidence is especially lacking on the areas described below. However, even those outcomes that are relatively well studied have small absolute numbers of estimates and would benefit from additional evidence.

- *Intermediate impact channels:* Although education, consumption, and labor market participation are more studied than other outcomes, few studies evaluate the mechanisms by which those changes occur. For example, a small number of studies distinguish whether estimated effects are due to electricity access itself, improved information connectivity due to electrification, improved public facilities, or other intermediate effects.

- *Effects on public services:* Few studies evaluate the impact of electrification on public institutions, such as schools and health centers via the ability to use electricity-dependent technology, or on teacher and health staff absenteeism in remote rural areas. Nor are there many studies that evaluate the effects of electricity on knowledge and use of public services.

- *Effects on health:* Reduced indoor air pollution from cooking energy substitution has been evaluated as a mechanism for improving health in several impact evaluations, but only two studies (Barron and Torero 2015b; Aevarsdottir, Barton, and Bold 2017) actually measure air quality. The others record perceptions of air quality. The effects of electricity on knowledge of issues such as health and family planning have been rarely evaluated, nor have adverse health effects, such as from electricity accidents, been evaluated (Grimm, Sparrow, and Tasciotti 2015).

- *Effects on firms:* There are relatively few studies that quantify outcomes for firms from improved electricity access, in terms of productivity, market access, or diversification of business when electricity is in place.

- *Effects on social capital:* Electricity can both create new forms of connectivity and introduce more solitary electronic entertainment. This can have long-term effects on social capital and socio-emotional skills, which have little evaluation to date.

- *Environmental effects:* Although energy consumption is the focus of a number of impact evaluations, relatively few impact evaluation studies estimate energy efficiency outcomes, or effects of clean energy on pollutant or greenhouse gas emissions.

- *Effect heterogeneity:* For more studied outcomes, such as time use, employment, and income, there is substantial variation among effects found, and results are often inconsistent among studies. Much more research is needed to understand the conditions under which these effects are larger and smaller.

9. Future Studies

This review finds both room and potential for further impact evaluations in the energy sector. There is ample scope to increase both the diversity of the programs and the types of outcomes evaluated.

Recent RCTs provide good examples of how experimental approaches can be used innovatively to test welfare outcomes from being connected to electricity, as well as many other aspects, such as metering mechanisms and pricing structures. Further potential for such studies may be explored. Some examples of energy sector projects and the potential for impact evaluation in each type of project are described below.

Large-scale power plants and transmission lines may pose challenges for traditional impact evaluation methods, which rely on observation of spatial variation in treatment, as these plants may feed into grids that affect large populations. This leads to a small-n problem, as there are insufficient treatment units for statistical power. In some cases, interrupted time series approaches may be used to detect the effects of large power plants or transmission lines coming online, if there is a specific period at which supply is suddenly activated. In other cases, synthetic controls may be used to compare localities where energy improvements take place with those where they do not, if there are frequent observations before improvement. In addition, effects of new large-scale infrastructure may be manifest in improvements in the quality and reliability of supply, which may have more spatial variation in changes, depending on how power is dispatched/prioritized. This variation may help to allow the use of traditional large-n techniques, such as fixed effects models.

Studies reviewed have found limited evidence of significant effects of energy sector reforms. The direction of findings often runs in expected directions, but many results are not significant (Bensch et al. 2016). It is not fully clear from the studies to date if this is a matter of "type II" error, in which studies did

not have sufficient sample sizes or adequate designs to detect actual effects, or if it is an actual lack of effects to date, because reforms are often partial or offset by implementation details. Many reforms, such as privatization, are not universally applied to all energy sector actors simultaneously, but instead are applied to individual firms or administrative units. This means there is scope to work with variability within relevant subsectors as a basis of identification using traditional impact evaluation techniques. Based on results to date, a more refined and focused theory of change, which better defines the contexts and time frames under which effects are expected for specific outcomes and groups, should be used to target a new set of studies on reforms.

Projects that expand household electricity supply/connectivity have clear and direct potential for application of traditional impact evaluation methods. Where grid expansion affects large areas simultaneously, or placement bias is likely to be strong, encouragement designs and/or pipeline randomization of connection fees incentives/subsidies can help to introduce random variation in connectivity rates for estimating unbiased treatment effects.

Even when this is not possible, quasi-experimental methods may also be applicable if connectivity is phased in and remains partial during the analytical period (see Box 2 for an example). If there are eligibility criteria with clear cutoffs for grid expansion or supported or subsidized connections, regression discontinuity design may be employed. In the absence of such criteria, fixed effects or DiD models may be applied. It may also be noted that these types of connectivity effects also often embed the effects of larger-scale infrastructure that generates and transmits electricity.

Energy projects increasingly seek to alter energy supply and use behavior. Demand-side energy efficiency measures may include tariff reform, information campaigns, or support to efficient appliances, while renewable energy is often backed by a range of incentives on both the supply and consumer side. These types of interventions are amenable to impact evaluation using randomized techniques, since the incentive assignment can be easily altered. As energy use captures key outcomes that may be characterized rapidly using administrative or billing data, such impact evaluations may also be rapid and low cost.

“Big data,” or large data sets derived from administrative and commercial sources, offer increasing potential for energy sector impact evaluation. For instance, data on electricity consumption patterns and expenses may be retrieved from electricity providers through power meters and electricity bills. In countries where public data are reliable and can be accessed, evaluators

may also explore options for using administrative tax revenue data or data on business registrations to explore the effect of improved energy supply on business activity. In addition, remote sensing-derived data relevant to energy, such as luminosity and pollution levels, are available with increasing precision, frequency, and resolution, so as to enable new types of analysis. To enable more use of big data for impact evaluation, international agencies, research bodies, and other groups involved in impact evaluation may need to forge new data sharing agreements with utilities in the energy sector.

10. Conclusions

Energy sector programming is becoming increasingly complex and depends ever more on a broadening array of behavioral assumptions. This makes impact evaluation more and more relevant to informing the design of future programming. Fortunately, big data are also becoming more easily available to enable new forms of impact evaluation, and promising examples of randomized and otherwise innovative impact evaluations are expanding for the sector.

At the same time, impact evaluation coverage remains limited, with evaluations focused mostly on a few interventions and outcomes. There is room to better explore the effects of interventions from the level of energy suppliers and power producers all the way through to households. There is ample opportunity to generate new evidence on intermediate channels, effects on a wider range of actors, such as service providers and firms, as well as unevaluated outcomes, such as air quality.

To do so, the suite of methods applied may be expanded. Present studies are dominated by use of DiD and IV methods. In a number of cases, the "parallel trends assumption" for DiD techniques may not fully hold, and many instruments often struggle to fully satisfy the exclusion restriction. With big data, more use of multivariate panel (fixed effects) models may allow more consideration of continuous treatments, such as increased hours of electricity. Where small-n, large-scale infrastructure, or policy reform comes online at a specific period for specific regions, interrupted time series and synthetic controls may also offer new estimation options to help understand effects, especially for outcomes with high frequency data.

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APPENDIX 1:
EXAMPLE CASE STUDIES OF ENERGY SECTOR IMPACT EVALUATIONS

Case studies are included to demonstrate different types of empirical approaches, data sources, and questions addressed. Each case study is based exclusively on the published paper referenced at the end of its description. Equations, key notations, tables, figures, and their respective notes are drawn from each summarized study.

Case Study 1

Country : El Salvador
Source : Barron, M. and M. Torero. 2014. Short Term Effects of Household Electrification: Experimental Evidence from Northern El Salvador. Job market paper.

Brief Overview

This randomized evaluation examines how access to electricity affects incomes, health, and education, and explores the mechanisms through which change occurs. Using a randomized encouragement design, the study allocates discount vouchers for a randomly selected subset of households offered to connect to the electricity grid, thereby introducing exogenous variation in take-up. It finds significant effects of electrification on indoor air pollution, higher test scores for schoolchildren, increased household income from increased nonfarm work, and increased ownership of electronic appliances.

Intervention Evaluated

The study was conducted in the course of a grid extension and intensification program in northern El Salvador. Households were offered to connect to the electricity grid, with the government financing installation costs except for the cost of within household installation and a connection fee of $100 related to safety certification.

The study primarily examines (a) the impact of connecting to the electricity grid on socioeconomic outcomes; but in doing so, also examines (b) the impact of discount vouchers on households' decision to connect to the electricity grid; and (c) the impact of connection on neighbors' likelihood to do the same, i.e., the spillover effect. The units of assignment, treatment, and analysis for this study are the household.

Outcomes and Theory of Change Evaluated

The study focuses first on the effects on intermediate outcomes: indoor air pollution, time use, and electronic appliance ownership. It subsequently explores how each of these outcomes affect more advanced outcomes related to health, education, and income.

Although the theory of change is not explicitly described, the paper both discusses and tests the causal channels through which electrification affects final welfare outcomes at household level.

Methods Used

Because the location of electricity grids is not random, it is generally challenging to identify a valid comparison group that can help evaluators undertake convincing counterfactual analysis of the household gains from connecting to electricity. The study overcomes this by using a randomized encouragement design. By allocating discount vouchers to a subset of households that were being offered to connect to the electricity grid, the study introduces exogenous variation in the connection cost and take-up.

This approach relies on the fact that the connection-related fee of $100 was a substantial amount for most households—equivalent to a fifth of an average annual per capita income according to the study authors, which meant that discounts of 20% and 50%, respectively, were expected to be effective in influencing the probability of connecting for a subset of households.

Nevertheless, only 20% of those encouraged through vouchers responded to treatment (also referred to as a compliance rate of 20%), which means 80% will either connect or not regardless of treatment status. Because low compliance affects the predictive power of voucher allocation on connection, the authors choose to examine the effect of voucher allocation on the outcomes of interest, rather than directly measuring the effect of electricity connection on outcomes. These, in turn, are considered as "intent-to-treat" (ITT) estimates, and are local to those induced into the connection by the subsidy.

The empirical approach includes three steps (or models). First, the average effect of the vouchers across all the follow-up surveys is estimated. Second, to examine dynamic effects, the authors interact vouchers and survey rounds. Finally, these models are replicated by pooling both types of voucher together.

Spillover effects are also estimated. As reported by the authors, "to estimate the role of spillovers on adoption, [the study] use[s] the number of household i's neighbors that received a voucher in a given radius of household i (0–100 meters, 100–200 meters, 200–300 meters), controlling by the number of eligible neighbors in that radius" (Barron and Torero 2014, 10).

Treatment and Control Groups

The treatment and control groups were identified through random allocation of vouchers to households living in subdistricts that were scheduled to become electrified: 200 low-discount vouchers (20% discount) and 200 high-discount vouchers (50% discount) were randomly allocated, with a remainder of 100 households acting as controls (N=100).

The random allocation of vouchers introduces exogenous variation in the connection fee and thus overcomes the problem of selection bias stemming from household self-selection in connection to the grid.

Data Analyzed

The data used are derived from a household survey implemented for the purpose of the study, which the authors describe as collecting "standard information" on demographics, health, education, housing characteristics, energy use, income, consumption, and other factors. In addition, the study adds a "detailed module on time allocation for up to four household members: the male head, the female head, and up to two school-age children" (Barron and Torero 2014, 10).

The baseline household survey was undertaken in late 2009 covering 4,800 households across northern El Salvador. Four follow-up surveys were collected in 2010, 2011, 2012, and 2013. To explore the effects on indoor air pollution, the study also collected data on overnight fine particulate matter ($PM_{2.5}$) concentration from a subset of households in each survey round.

Sample Size

The sample consists of a total of 500 households located in subdistricts that were expected to become electrified during the first year of the program.

Key Findings

Probability of take-up

Receiving a discount voucher increased the probability of households connecting to the electricity grid by 11% to 19% in the case of individual vouchers. No significant difference is observed in the effect of vouchers with large and small discounts respectively, which may indicate (a) that demand for electricity

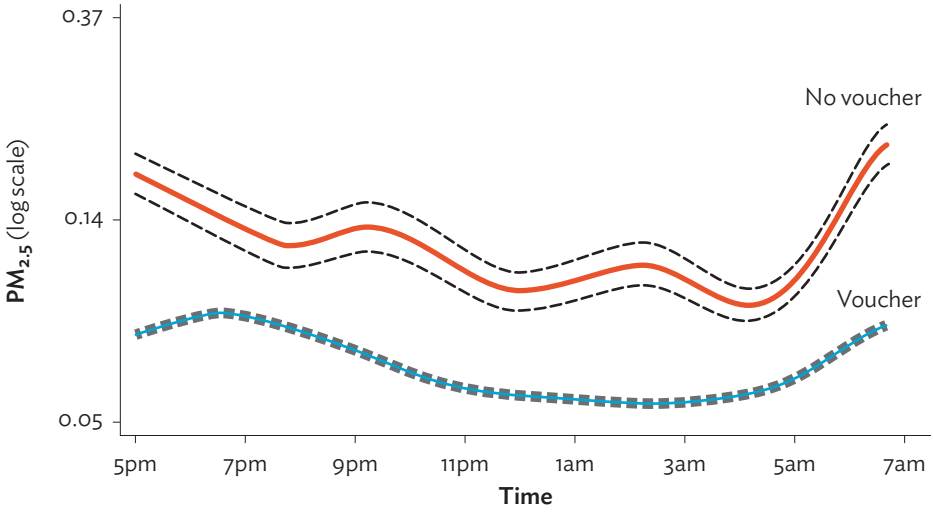
connection does not vary within this price range (is inelastic); or (b) that the effect of vouchers stems not primarily from the financial incentive but from other factors such as increased awareness of the possibility to connect; or (c) the voucher may be a tool for nudging households into taking action to connect.

Indoor air pollution and child health

The study finds important effects of electrification on indoor air pollution. Overnight $PM_{2.5}$ concentration is 63% lower for voucher recipients, and reductions of 37%–44% in acute respiratory infections incidence among children under the age of six are observed. Case Study Figure 1.1 illustrates the differences in $PM_{2.5}$ concentration between treatment and control groups in the experimental sample.

$PM_{2.5}$ reductions appeared to result from reduced use of kerosene for lighting. The study found large reductions in kerosene expenditures in electrified households and no substantial effect on other traditional lighting sources, such as candles.

Case Study Figure 1.1: Voucher Allocation and $PM_{2.5}$ Concentration by Minute of the Day, Local Polynomial Estimates
(Experimental Sample)



PM = particulate matter .
Source: Barron and Torero (2014).

Education

The study finds positive effects of electrification on investment in education, as children in school increased study time at home, and had higher math scores. As a placebo test, the authors show that there is no effect on years of schooling (Case Study Table 1.1).

Case Study Table 1.1: Time Allocation, Children 6–15 Years Old
(Seemingly Unrelated Regression)

Panel A: Main Activities								
	Time Studying	**Education, Other**	**Leisure**	**Labor/ Chores**	**Time Studying**	**Education, Other**	**Leisure**	**Labor/ Chores**
Any discount	0.154*	0.100	0.147	−0.426				
	(0.082)	(0.271)	(0.462)	(0.423)				
20% discount					0.157*	0.049	0.330	−0.630
					(0.090)	(0.295)	(0.503)	(0.460)
50% discount					0.151*	0.149	−0.029	−0.230
					(0.089)	(0.293)	(0.500)	(0.457)
Neighbors with discount, 100 meters	0.013	−0.138	−0.074	0.320	0.013	−0.136	−0.079	0.326
	(0.051)	(0.170)	(0.290)	(0.265)	(0.052)	(0.170)	(0.290)	(0.265)
Panel B: Effect on Education Outcomes								
	Math Skills	**Enrolled**	**Schooling**		**Math Skills**	**Enrolled**	**Schooling**	
Any discount	0.136***	0.057	0.160					
	(0.043)	(0.044)	(0.240)					
20% discount					0.142***	0.082*	0.220	
					(0.046)	(0.047)	(0.258)	
50% discount					0.130***	0.029	0.092	
					(0.046)	(0.047)	(0.262)	
Neighbors with discount, 100 meters	0.059**	-0.050*	0.274*		0.058**	-0.053*	0.266	
	(0.029)	(0.029)	(0.161)		(0.029)	(0.029)	(0.162)	

Notes: ***Panel A***: Columns 1–4 report the results of a Seemingly Unrelated Regression (SUR) system estimation of the activity indicated on the column on an indicator for having received any discount voucher. Columns 5–8 report the results of a similar SUR system with indicators for each discount level. The dependent variables are measured in hours. ***Panel B***: The dependent variables are math skill index (a dichotomous index of math skills described in the main text) an indicator for being enrolled in school, and years of schooling. Columns 1–3 form a system of equations, columns 4–6 form another system. ***Both Panels***: Regressions control for time and subdistrict fixed effects, number of eligible neighbors within 100 meters, and baseline household characteristics (dirt floor; household size; cooking with wood; sex, schooling, and literacy status of household head). Standard errors are reported in parentheses. Significantly different than zero at 90(*), 95(**), and 99(***) percent confidence.
Source: *Household Electrification Survey*. Reproduced from Barron and Torero (2014).

Income and assets

Electricity connection is found to increase per capita incomes by 34%, which for adult males appeared to be channeled by increased time spent on labor and less time spent on leisure and cultivation of own land (Case Study Table 1.2). Ownership of household assets, such as televisions and refrigerators, similarly increased, with the latter potentially reinforcing the health gains from improved air quality.

Case Study Table 1.2: Household Income, $1,000 per Year
(Ordinary Least Squares Estimates)

	Income per Capita		Low Income		High Income	
	(1)	(2)	(3)	(4)	(5)	(6)
Any discount	0.186**		−0.105*		0.070	
	(0.093)		(0.055)		(0.048)	
20% discount		0.199*		−0.109*		0.082
		(0.110)		(0.060)		(0.052)
50% discount		0.173		−0.101*		0.057
		(0.110)		(0.059)		(0.053)
Neighbors with discount, 100 meters	0.173**	0.171**	−0.019	−0.019	0.047	0.045
	(0.086)	(0.085)	(0.033)	(0.033)	(0.030)	(0.030)

Notes: Each column corresponds to an Ordinary Least Squares regression. "Income per capita" is measured in thousands of $ per year. "Low Income" is an indicator for households below the median. "High Income" is an indicator for households in the top quartile of the income distribution. Regressions control for time and subdistrict fixed effects, number of eligible neighbors within 100 meters, and baseline household characteristics (dirt floor; household size; cooking with wood; sex, schooling, and literacy status of household head). Standard errors are reported in parentheses. Significantly different than zero at 90(*), 95(**), and 99(***) percent confidence.
Source: *Household Electrification Survey*. Reproduced from Barron and Torero (2014).

Spillover effects

The study finds important spillover effects of voucher allocation: "Holding the number of eligible neighbors constant, an additional voucher allocated within 100 meters of household I increased the probability of connection by 4 percentage points" (Barron and Torero 2014, 15). The effect of vouchers on households farther away is not statistically significant.

Case Study 2

Country : South Africa
Source : Dinkelman, T. 2011. The Effects of Rural Electrification on Employment: New Evidence from South Africa. *American Economic Review*. 101. pp. 3078–3108.

Brief Overview

The study explores the impact of new access to electrification on employment growth in South Africa, focusing on an extensive expansion of the country's electricity grid that took place between 1996 and 2001 in KwaZulu-Natal (KZN) province.

By combining the use of an instrumental variables strategy and a fixed effects approach, the study finds significant positive effects on female employment rate and on hours worked for both men and women. The overall income effect is slightly more ambiguous, as there is no gain to female earnings while male earnings increase, despite limited effects on employment.

Intervention Evaluated

The study examines the effects of the rapid expansion of South Africa's electricity to rural households between 1996 and 2001. Within the 10-year period from 1993 to 2003, a full 470,000 households, or 28% of all households in KZN, became connected to the electricity grid and, according to the author, began receiving sufficient power to at least power basic appliances and maintain a minimum level of service. As electrification occurs via grid expansion, the unit of assignment is the village/district, whereas units of treatment and analysis are communities and households.

Outcomes and Theory of Change Evaluated

To capture the effects of new energy infrastructure on employment growth, the community-level employment growth rate is used as the primary outcome variable. To explore the mechanisms through which such infrastructure affects

rural labor markets, the study investigates what happens to (a) home production activities, (b) market employment, (c) market wages in areas that gain new access to electricity, and (d) migration flows.

The study also explores the extent to which effects "differ by gender, whether changes in methods of home production and changes in wages support a labor supply channel, whether there is any evidence for the labor demand channels, and the extent to which migration into and out of electrifying and non-electrifying areas can account for employment effects" (Dinkelman 2011, 3083).

Methods Used

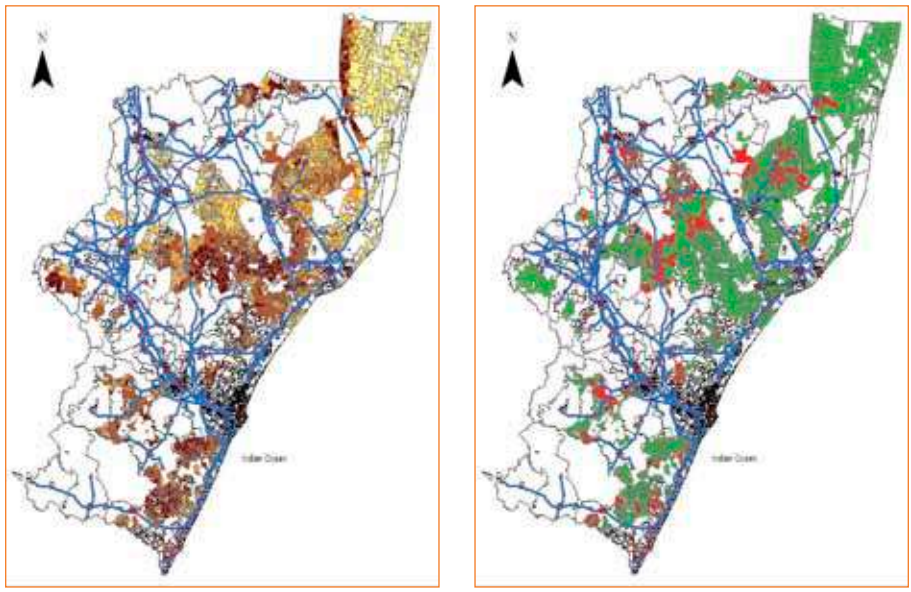
As for many other impact evaluations of infrastructure projects, the main methodological challenge is project placement bias, in which power facilities are located purposively. Whereas many infrastructure projects are placed in locations with higher potential for growth, for reasons detailed in the paper, South Africa's electricity infrastructure was likely to first reach more deprived areas with several years of declining economic activity.

To address the challenge of endogenous project placement, the study uses two empirical strategies. First, to estimate community-level employment growth rates the study employs an instrumental variable (IV) approach where land gradient is used as an instrument to generate exogenous variation in electricity project allocation to communities.

Because higher land gradient raises the cost of grid connection, steeper areas are less likely to become electrified. To be a valid instrument of course, land gradient must not independently affect employment. The author's identification assumption is that "conditional on baseline community characteristics, proximity to local economic centers and grid infrastructure, and district fixed effects, land gradient does not affect employment growth independently of being assigned an electrification project" (Dinkelman 2011, 3091). Case Study Figure 2.1 illustrates the spatial distribution of land gradient and electricity.

Second, a fixed effects strategy is used to estimate the effects of electrification on a set of labor market outcomes including employment, hours of work, wages, and earnings using only within-district variation in electrification.

Case Study Figure 2.1: Spatial Distribution of Gradient and of Electricity Project Areas in KwaZulu-Natal, South Africa



Notes: Shaded communities are in the analysis sample (N = 1,816). Thick lines depict electricity grid lines in 1996, triangles are electricity substations in 1996, and stars represent towns. Gradient is shown in the figure on the left: steeper areas are shaded dark, flatter areas are shaded light. Electricity Project areas are depicted in the figure on the right: project areas are shaded dark, lighter shaded areas are electrified after 2001 or not at all.
Source: Reproduced from Dinkelman (2011).

Treatment and Comparison Groups

The treatment group consists of communities in KZN that were electrified between 1996 and 2001. Comparison groups are non-electrified communities.

Data Analyzed

A number of data sources are used for the main analysis of the employment effects of electrification:

(1) A panel data set of community aggregate variables constructed from 1996 and 2001 South African census data;
(2) Spatial data collected from the construction company on the location of electrification infrastructure in KZN province at baseline;

(3) Administrative data on project placement across the province between 1990 and 2007;
(4) Measures of geography such as community land gradient and distance between each community and the nearest electricity substation, road, and town at baseline; and
(5) Finally, a micro census data set for 1996 and 2001 is used for parts of the analysis.

For the fixed effects analysis, a large data set is constructed from cross-sectional household surveys completed in 1995, 1997, 1999, and 2001 containing individual-level data on employment, hours of work, wages, earnings, demographics, and household fuel sources.

Sample Size

The full sample consists of 1,816 communities in KZN province, of which 365 are treatment communities, and 1,451 are not. For the fixed effects analysis, pooled information from four cross sections of South Africa household survey data is used. For the purpose of this study the sample includes only respondents living in rural areas of KZN, with a sample size of at least 900 respondents per year.

Key Findings

The study found positive effects of electrification on employment. In particular, female employment rose by between 9 and 9.5 percentage points which, according to the author, translates into an additional 15,000 women entering the labor force. Male employment also rose in treatment areas, although insignificantly, and to a lower degree. Case Study Table 2.1 shows the increase in the female employment rate. Fixed effects estimations also find that the number of hours women worked also increased as follows: "in districts with the [largest] average increase in electrification over the period (15%), women worked about 8.9 more hours per week, a 3.5% increase from baseline" (Dinkelman 2011, 3099).

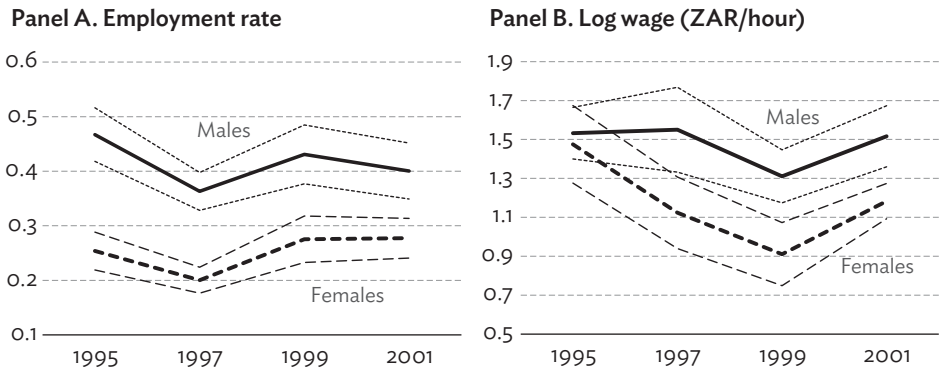
Case Study Table 2.1: Effects of Electrification on Employment: Census Community Data

	Δ_t Female Employment Rate							
	OLS regression coefficients				IV regression coefficients			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Eskom project	−0.004	−0.001	0.000	−0.001	0.025	0.074	0.090*	0.095*
	(0.005)	(0.005)	(0.005)	(0.005)	(0.045)	(0.060)	(0.055)	(0.055)
Anderson-Rubin 95% confidence intervals								
								[0.05; 0.3][0.05; 0.3]
Poverty rate	0.029***	0.033***	0.031***		0.027**	0.032**	0.031**	
	(0.011)	(0.010)	(0.010)		(0.012)	(0.013)	(0.013)	
Households headed by women	0.042**	0.051***	0.047**		0.014	0.036	0.033	
	(0.019)	(0.019)	(0.020)		(0.031)	(0.026)	(0.026)	
Adult sex ratio	0.019**	0.017**	0.020***		0.033**	0.029**	0.032***	
	(0.009)	(0.008)	(0.007)		(0.014)	(0.012)	(0.012)	
Baseline controls?	N	Y	Y	Y	N	Y	Y	Y
District fixed effects?	N	N	Y	Y	N	N	Y	Y
Δ_t other services?	N	N	N	Y	N	N	N	Y
N communities	1,816	1,816	1,816	1,816	1,816	1,816	1,816	1,816

Notes: Robust standard errors clustered at subdistrict level. Eskom project is instrumented with mean community land gradient. See Table 3 for full list of control variables. The last two columns provide confidence intervals from the Anderson-Rubin test for the coefficient on Eskom project. The test is robust to weak instruments and implemented to be robust to heteroskedasticity. *** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level.
Source: Dinkelman (2011).

Despite such increases in female employment, the study also finds that female wages decreased, leaving no gains to average female earnings despite increased employment, whereas male earnings increased even in the absence of changes to male wages. Case Study Figure 2.2 shows development of employment and wage rates by gender. The author discusses potential reasons for the observed results, but does not provide strong conclusions on the mechanisms through which electrification affects employment growth.

Case Study Figure 2.2: Employment Rates and Hourly Wages over Time by Gender



KZN = KwaZulu-Natal, ZAR = South African rand.
Notes: Figures show fraction of adult African men and women employed and average hourly log wage rate (in ZAR) for the employed, using data from October Household Surveys 1995, 1997, 1999, and the September Labour Force Survey 2001. Sample includes individuals living in rural KZN. Dashed lines are 95% confidence intervals. The unit of observation is the individual.

Source: Dinkelman (2011).

Case Study 3

Country : India
Source : van de Walle, D., M. Ravallion, V. Mendiratta, and G. Koolwal. 2013. Long-Term Impacts of Household Electrification in Rural India. *World Bank Policy Research Working Paper Series*. 6527.

Brief Overview

The study explores how household electrification affected consumption, labor supply, and schooling in rural India between 1982 and 1999. Using difference-in-differences (DiD) and instrumental variables (IV) estimations, the authors find long-term economic welfare gains from household electrification. Electrification is found to have significant effects on consumption and earnings, with the latter occurring through changes in market labor supply. Positive effects on schooling are found for girls, but not for boys. In addition, the study finds evidence of separate, positive spillover effects of village-level electrification on consumption for unelectrified households.

Intervention Evaluated

The study examines the impact of India's electricity grid expansion to rural areas between 1982 and 1999. Whereas only 18% of rural households were electrified in 1982, the number had risen to almost 70% 20 years later with most households connected, in the words of the study authors, "through a wired connection to above-ground power lines, which in turn are connected to village transformers linked via a feeder line to power substations further away on the grid." (van de Walle et al. 2013, 15).

Outcomes and Theory of Change Evaluated

The study focuses mainly on three sets of outcome variables:

(1) Consumption, measured as real per capita consumption
(2) Labor supply, measured as number of days spent on main and secondary occupations

(3) Schooling, measured as (a) the share of children aged 5–18 who are in school, and (b) the average years of completed schooling divided by the maximum number of years

The study separately explores the internal effects of household electrification from the external effect of village electrification.

The unit of analysis is the household, while units of assignment and treatment are the village.

Methods Used

The study applies both a DiD and an IV approach. Distance in kilometers from the village to the nearest power-generating plant within the state is used as an instrument for becoming connected to the electricity grid. The identifying assumption for the IV estimation is that "access to electricity depends in part on physical proximity to power-generating plants, which in turn are assumed not to influence outcomes independently of electrification or control variables, including other exogenous geographic variables" (van de Walle et al. 2013, 22).

To "address concerns about the validity of the exclusion restriction," the authors allow "a complete set of district fixed effects, as well as control variables for village characteristics to be included in regression estimates" (van de Walle et al. 2013, 22). The fixed effects absorb confounders that are time invariant.

Treatment and Comparison Groups

Predicted electrified villages are considered the treated group, as compared with unelectrified locations. For each round, a dummy variable for household electricity use was constructed as the "treatment" variable. A continuous variable was created for village-level electrification, indicating the duration of time since the village became connected to the electricity grid.

Data Analyzed

The study uses the 1982 and 1999 rounds of the India Rural Economic and Demographic Survey, which was nationally representative of rural India, and form a panel of 6,008 households across 242 villages in 15 states. Both survey rounds collected household-level data on sociodemographic variables, health, and labor supply as well as income sources, access to infrastructure,

consumption expenditure and assets, agricultural production, land ownership, and other attributes. Village-level data were also collected during both rounds, on attributes, such as male and female wage rates, infrastructure, prices, and population characteristics.

Sample Size

The sample consists of a panel of 6,008 households in 242 villages in 15 states. A village-level survey is also used.

Key findings

The authors find long-term economic welfare gains from household connection to electricity, and report positive external effects of village connection to the grid for households without electricity themselves.

Consumption

The study finds that electrification positively affects household consumption, in particular on food and fuel spending. In addition, for households not connected to the grid, village electrification increases annual consumption growth rate by 1 percentage point, whereas no such effect is seen for households that already have access to the grid. The DiD and IV estimates for consumption and labor supply are shown in Case Study Table 3.1.

Labor and wages

The analysis also finds that grid electrification increases labor supply, leading to extra work by both men and women in the form of regular wage work for men and casual wage work for women. The study does not however, find evidence of any impact of village electrification on real wage rates.

Education

Significant effects are observed on girls' schooling, as measured both by enrollment and average years of schooling for each age (Case Study Table 3.2). Notably, no such effect is found for boys.

Case Study Table 3.1: Impacts of Household and Village Electrification on Consumption and Labor Supply

Outcomes	Simple DD	IVE: Allowing for External Village Effect, Endogenous Electrification and with Controls	
	Change in Household Electrification	Change in Household Electrification	Years of Village Electrification *Times* Household Not Electrified
Consumption			
Total consumption expenditure per capita (log)	0.161***	0.067**	0.010**
	(6.55)	(1.99)	(2.11)
Food expenditure per capita (log)	0.081***	0.096***	0.002
	(3.34)	(2.89)	(0.39)
Fuel expenditure per capita (log)	0.172***	0.213***	-0.007
	(3.00)	(3.90)	(-0.70)
Nonfood, nonfuel expenditure per capita (log)	0.271***	0.054	0.017**
	(7.87)	(1.26)	(2.49)
Of which: Clothing and footwear	0.209***	0.081	0.007
	(4.95)	(1.41)	(0.85)
Entertainment	0.972***	0.553	0.034
	(3.00)	(1.39)	(0.49)
Ceremonies	1.138***	-0.705*	0.180**
	(2.71)	(-1.83)	(2.57)
Travel	0.297	0.060	-0.168***
	(1.51)	(0.24)	(-3.08)
Education	0.181	-0.057	0.040
	(0.67)	(-0.15))	(0.80)
Health	0.192	-0.016	-0.020
	(1.56)	(-0.10)	(-0.79)
Domestic help	0.448***	0.684***	0.023
	(2.93)	(2.65)	(0.70)
Repairs to housing	0.207	-0.031	-0.019
	(1.40)	(-0.19)	(-0.80)
Owns a kerosene stove (1=yes; 0=no)	0.137***	0.194***	0.009
	(6.63)	(6.06)	(1.54)
Labor supply (days per year)			
Days of regular wage work women	-0.582	-4.722	0.225
	(-0.53)	(-1.68)	(0.82)
Days of regular wage work men	10.881***	16.599**	0.883
	(3.45)	(2.60)	(1.34)
Days of casual wage work women	-5.184**	6.116*	0.008
	(-2.00)	(1.70)	(0.02)
Days of casual wage work men	-18.443***	-10.424*	-1.141
	(4.64)	(1.91)	(-1.32)
Days of agricultural self-employment by women	2.441	-0.176	-1.132*
	(1.03)	(-0.05)	(-1.89)
Days of agricultural self-employment by men	10.363***	-2.134	-1.134
	(3.27)	(0.52)	(-1.64)
Days non-agricultural self-employment by women	-1.975**	-2.234	0.463**
	(2.32)	(-1.19)	(2.30)
Days non-agricultural self-employment by men	2.146	3.409	0.641
	(0.87)	(0.73)	(1.46)

Notes: DD = "difference-in-difference". IVE = Instrumental variables estimates of a panel data model treating the acquisition of electricity as endogenous and using the 1982 electrification and geographic proximity to power generating plants as IVs. Controls and district effects included. See text for further details. *** = 1%, ** = 5%, * = 10%.

Source: van de Walle et al. (2013).

Case Study Table 3.2: Impacts of Household and Village Electrification on Schooling Outcomes

Schooling Outcomes	Simple Difference in Difference	IVE: Allowing for External Village Effect, Endogenous Electrification and with Controls	
	Change in Household Electrification	Change in Household Electrification	Years of Village Electrification *Times* Household Not Electrified
Share of children 5–18 in school	0.033	0.082**	0.001
	(1.58)	(2.56)	(0.30)
Share of girls 5–18 in school	0.042	0.094**	0.008*
	(1.53)	(2.05)	(1.80)
Share of boys 5–18 in school	0.020	0.073	-0.013*
	(0.70)	(1.52)	(-1.81)
Mean school years as share of max possible years	0.046**	0.026	0.002
	(2.66)	(1.00)	(0.69)
Min school years as share of max possible years	0.066***	0.037	0.004
	(3.21)	(1.15)	(0.13)
Max school years as share of max possible years	0.029	-0.010	0.005
	(1.32)	(-0.30)	(1.02)
Girls mean school years as share of max possible years	0.058**	0.092**	0.005
	(2.42)	(2.29)	(0.94)
Girls mean school years as share of max possible years (hh w/ boys and girls)	0.038	0.127**	0.002
	(1.33)	(2.21)	(0.30)
Girls min school years as share of max possible years	0.061**	0.096**	0.004
	(2.37)	(2.18)	(0.83)
Girls max school years as share of max possible years	0.067**	0.102**	0.004
	(2.47)	(2.28)	(0.73)
Boys mean school years as share of max possible years	0.039	0.002	-0.004
	(1.63)	(0.05)	(-0.80)
Boys mean school years as share of max possible years (hh w/ boys and girls)	0.044	0.028	-0.007
	(1.25)	(0.43)	(-0.107)
Boys min school years as share of max possible years	0.062**	0.041	-0.001
	(2.53)	(0.98)	(-0.27)
Boys max school years as share of max	0.014	-0.034	-0.004
	(0.55)	(-0.85)	(-0.87)

hh = households.

Notes: Instrumental variables estimates of a panel data model treating the acquisition of electricity as endogenous and using past acquisition and geographic proximity to power generating plants as IVs. Controls and district effects included. See text for further details. The restriction passes in all cases.

Source: van de Walle et al. (2013).

APPENDIX 2:
LIST OF ENERGY SECTOR IMPACT EVALUATIONS

Table A2.1: Overview of Energy Sector Studies

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
1	Rural grid electrification	South Africa	Dinkelman, T. 2011. The Effects of Rural Electrification on Employment: New Evidence from South Africa. *American Economic Review*. 101 (7). pp. 3078–3108.	Instrumental variables (IV), Fixed effects (FE)	Employment: hours of work, wages	The study explores the effect of access to electricity on employment growth in South Africa, focusing on an extensive expansion of the country's power grid between 1996 and 2001. Combining the use of an IV strategy and an FE approach, the study finds significant positive effects on female employment rate and on hours worked for both men and women. The overall employment effect is slightly more ambiguous, as female wages decrease, with no gain to female earnings, whereas male earnings increase despite limited effects on employment and wages.
2	Rural grid electrification	Bhutan	Asian Development Bank (ADB). 2010. ADB's Assistance for Rural Electrification in Bhutan– Does Electrification Improve Quality of Rural Life? Manila.	Propensity score matching (PSM)	Income, health, and schooling	This analysis estimates the impact of two ADB-funded rural electrification projects in Bhutan: The Sustainable Rural Electrification Project and the Rural Electrification and Network Expansion. The study aimed to evaluate the impact of electricity on quality of life. In the absence of baseline data, the study applies PSM using data collected specifically for the study, involving 1,276 electrified and 822 unelectrified households. Results suggest that (i) electrified households had higher incomes, (ii) children in the electrified households completed more years of schooling, and (iii) electrification reduced smoke-induced health problems.
3	Rural grid electrification/ discount vouchers	El Salvador	Barron, M. and M. Torero. 2014. Short Term Effects of Household Electrification: Experimental Evidence from Northern El Salvador. Job Market Paper.	Randomized controlled trial (RCT)	Indoor air pollution, time use, and electronic appliance ownership—and how each of these affect health, educational outcomes, and income	The paper examines how access to electricity affects incomes, health, and education, and explores the mechanisms through which changes occur. Using a randomized encouragement design, the authors allocate discount vouchers to a subset of households to connect to the electricity grid, thereby introducing exogenous variation in take-up. It finds significant effects of electrification on indoor air pollution, higher test scores for schoolchildren, greater household income from more nonfarm work, and increased ownership of electronic appliances.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
4	Rural grid electrification/ discount vouchers	El Salvador	Barron, M. and M. Torero. 2015a. Household Electrification and Indoor Air Pollution. *MPRA Paper.* No. 61424.	RCT	Indoor air pollution	This is a separate paper based on the experiment described in Barron and Torero (2014). It ,and combines detailed data on particulate matter ($PM_{2.5}$) concentration with an experimental design. The study finds a 67% reduction in overnight $PM_{2.5}$ concentration among households in the intention-to-treat group, largely driven by lower use of kerosene for lighting. Improved air quality is found to lead to fewer incidents of acute respiratory infections.
5	Rural grid electrification/ discount vouchers	El Salvador	Barron, M. and M. Torero. 2015b. Electrification and Time Allocation: Experimental Evidence from Northern El Salvador. *MPRA Paper.* No. 63782.	RCT	Time use	This separate paper based on the experiment described in Barron and Torero (2014) focuses on time use. It finds that electrification leads to significant increases in (i) the time children spend on schooling, (ii) women's participation in generating income, and (iii) the likelihood of women operating own businesses. The study finds that the magnitudes of the changes are of economic importance.
6	Access to electricity (rural electrification)	Honduras	Squires, T. 2015. The Impact of Access to Electricity on Education: Evidence from Honduras. Job Market Paper.	IV	Educational attainment, child labor	This study investigates access to electricity and its effect on whether children complete their education or drop out of school. To remove concerns of endogeneity, an IV approach is used, with distance along the distribution grid to the nearest substation as an instrument for the year of electrification. The study finds that access to electricity improves the labor market, which in turn increases the likelihood of children dropping out of school early to pursue more job opportunities. Children are also found to more likely stay home while their parents work.
7	Rural grid electrification	India	van de Walle, D., M. Ravallion, V. Mendiratta, and G. Koolwal. 2013. Long-Term Impacts of Household Electrification in Rural India. *World Bank Policy Research Working Paper Series.* 6527.	IV, FE, Difference in differences (DiD)	Consumption, labor supply, and schooling	The study explores the impact of household electrification on consumption, labor supply, and schooling in rural India between 1982 and 1999. Using DiD and IV estimations, the authors find long-term economic gains through the positive impact of household electrification on consumption and earnings as well as through changes in market labor supply. Electrified households have positive effects on schooling for girls, but not for boys. The study also finds additional positive effects of village-level electrification on unelectrified households.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
8	Rural electrification through Pico-PV kits comprising a small 1W panel, a 40-lumen lamp, a mobile phone charger, and a radio charger	Rwanda	Grimm, M., J. Peters, and M. Sievert. 2013. Impacts of Pico-PV Systems Usage Using a Randomized Controlled Trial and Qualitative Methods. Evaluation report commissioned by the Operations Evaluation Department of the Ministry of Foreign Affairs of the Netherlands. The Hague.	RCT	Energy and lighting usage, time use, health, and energy expenditure	This study applies an RCT to evaluate take-up behavior and impacts of a "Lighting Africa-certified Pico-PV kit" in remote rural areas of Rwanda. The study randomly distributed 150 kits containing a 1-watt solar panel, a 40-lumen lamp, a mobile phone charger, and a battery package, to be used in radios. The kits were found to increase nighttime studying for children, although overall study time did not change. Kits were found to reduce kerosene usage and improve air quality, although no change in respiratory symptoms were observed. Potential negative effects include environmental damage from inappropriate disposal of batteries.
9	Rural grid electrification/ Household and commune connection	Viet Nam	Khandker, S., D. Barnes, and H. Samad. 2013. Welfare Impacts of Rural Electrification: A Panel Data Analysis from Viet Nam. *Economic Development and Cultural Change.* 61 (3). pp. 659–692.	FE	Household income/ expenditure and education	Using panel survey data on 41 communes in rural Viet Nam, the study employs a fixed effects approach to test the relationship between rural electrification and welfare outcomes. It finds that grid electrification significantly increases household income and expenditure and school attendance, particularly for girls. The study also finds a separate effect of commune-level electrification for the poor and for schooling of girls.
10	Rural electrification	Nicaragua	Grogan, L. and A. Sadanand. 2012. Rural Electrification and Employment in Poor Countries: Evidence from Nicaragua. *World Development*. 43. pp. 252–265.	IV	Employment, time use	The study employs an IV approach to examine the impact of electrification on time use and employment using data from the Nicaraguan Living Standards Measurement Survey, the Census, and geographic information system data. Land gradient and 1971 pre-civil war population density are used as instruments for electricity connection in 2005. Results show a significant effect on women's propensity to work outside the home, which is particularly large for women under 35.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
11	Rural grid electrification/ discount vouchers	Ethiopia	Bernard, T. and M. Torero. 2015. Social Interaction Effects and Connection to Electricity: Experimental Evidence from Rural Ethiopia. *Economic Development and Cultural Change*. 63 (3). pp. 459–484.	RCT	Electricity connection	This uses data from a randomized experiment, which provided discount vouchers for connecting to the electricity grid to randomly assigned households in villages that were scheduled for electrification under Ethiopia's Universal Energy Access Scheme. The household survey for measuring impact of that program included GPS coordinates, which allowed researchers to demonstrate large spillover effects on the likelihood of connection among neighbors within a 100-meter range (but not beyond).
12	Rural electrification	Rwanda	Bensch, G., J. Kluve, and J. Peters. 2011. Impacts of Rural Electrification in Rwanda. *Journal of Development Effectiveness*. 3 (4). pp. 567–588.	DiD, PSM	Lighting usage, children's study time at home, energy expenditures, and income	The study uses PSM and a DiD approach to explore effects of electrification on lighting, study time, energy expenditure, and income. The authors present positive effects on lighting usage. Effects on income and children's home studying are significant using PSM, but become insignificant if accounting for regional differences.
13	Replacement of refrigerators and air conditioners with energy-efficient models	Mexico	Davis, L., A. Fuchs, and P. Gertler. 2012. Cash for Coolers. *NBER Working Paper*. No. 18044.	DiD	Electricity consumption	The paper examines the effects of an appliance replacement program on electricity consumption. The program allows households to replace their old refrigerators and air conditioners with energy-efficient models. The study matches data on program participants with electricity bills for all residential electricity users in Mexico. The empirical strategy employs a DiD approach using nonparticipating households matched to participants based on location. Results show a significant reduction in electricity use from refrigerator replacement, whereas replacing air conditioners has the opposite effect. This suggests a "rebound" effect in which usage is higher because of the lower cost to operate energy-efficient items.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
14	Changing pricing of electricity from a flat-rate tariff to a metered tariff	India	Meenakshi, J. V., A. Banerji, A. Mukherji, and A. Gupta. 2013. Does Marginal Cost Pricing of Electricity Affect the Groundwater Pumping Behaviour of Farmers? Evidence from India. *3ie Series Report*.	DiD	Total number of hours pumped and agricultural output	This study examines the effect of a switch from flat rate electricity costs to metering on groundwater pumping and agricultural output in West Bengal. Using a DiD approach, it finds lower water usage in one of the three agricultural seasons, but no effects on production or output.
15	Rural grid electrification	Benin	Peters, J., C. Vance, and M. Harsdorff. 2011. Grid Extension in Rural Benin: Micro-Manufacturers and the Electrification Trap. *World Development*. 39 (5). pp. 773–783.	PSM	Performance of micro manufacturing enterprises	The study uses PSM to examine the effect of electricity on monthly profits of 146 micro manufacturing firms in Northern Benin. The findings suggest a positive effect on firms that were created after electrification, whereas no significant effect is observed for the full sample, including older firms that predated the project.
16	Provision of free-of-charge CFL light bulbs	Ethiopia	Costolanski, P., R. Elahi, A. Lim, and R. Kitchlu. 2013. Impact Evaluation of Free-of-Charge CFL Bulb Distribution in Ethiopia. *World Bank Policy Research Working Paper*. 6383.	IV	Energy consumption	The study examines how CFL bulbs distributed free of charge to electricity consumers in Ethiopia affected energy usage. Using a combination of fixed effects and IV on a panel data set of 2,000 electrified households, the study finds a significant reduction in electricity consumption. The findings indicate a greater effect among the poorest for whom the savings constituted a larger share of total energy consumption. A rebound effect was observed with energy savings decreasing after 18 months.
17	Connection to piped natural gas	Argentina	Goytia, C., R. Pasquini, and P. Sanguinetti. 2011. Public–Private Co-operation for Gas Provision in Poor Neighbourhoods of Buenos Aires. *UNU-WIDER Working Paper*. No. 2011/23.	Natural experiment, IV	Improvements in dwelling, health, and happiness with respect to the dwelling	The study evaluates the impact of a program that provided natural gas to low-income households in informal settlements in Buenos Aires. Because a technical aspect of the rollout inadvertently led to a two-phase implementation, the program can be viewed as a natural experiment, with first phase beneficiaries comprising the treatment group, and the second phase households as controls. The study finds positive effects on housing quality and satisfaction, as well as a significant decrease in flu, fever, and other respiratory diseases.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
18	Electrification through solar home systems (SHSs)	Bangladesh	Wang, L., S. Bandyopadhyay, M. Cosgrove-Davies, and H. Samad. 2011. Quantifying Carbon and Distributional Benefits of Solar Home System Programs in Bangladesh. *World Bank Policy Research Working Paper.* 5545.	PSM	Kerosene use and avoided carbon emissions	Using a nationally representative household survey of 21,000 households in rural Bangladesh, the study seeks to examine and quantify the carbon benefits of a program supplying subsidized solar home systems (SHS). PSM is used to match owners of solar home systems to nonowners in the same village. Recognizing the presence of potential endogeneity, the study finds substantial carbon benefits of SHS, mainly through lower kerosene usage.
19	Rural grid electrification	Bangladesh	Khandker, S., D. Barnes, and H. Samad. 2009. Welfare Impacts of Rural Electrification: A Case Study from Rural Bangladesh. *World Bank Policy Research Working Paper.* 4859.	PSM, IV	Income, expenditure, and educational outcomes (years of schooling and daily study time)	Using a nationally representative household survey of 21,000 households in rural Bangladesh, the study examines the impact of rural electrification on household income, expenditure, and schooling outcomes. Taking advantage of specific pricing arrangements for electricity connections in Bangladesh by which connection cost increases sharply for households more than 100 feet from electric poles, the distance serves as an instrument for an IV approach. The study finds positive effects on all major outcomes of interest: income, consumption, schooling completion, and study time.
20	Energy conservation program	Brazil	Gerard, F. 2013. What Changes Energy Consumption and for How Long? New Evidence from the 2001 Brazilian Electricity Crisis. *Resources for the Future Discussion Paper.* No. 13-06.	DiD	Residential electricity consumption	The study examines the impacts of a government energy conservation program, which was carried out during an electricity crisis in Brazil in 2001. The program set in place electricity quotas for individual users, and included elements of encouraging conservation, providing bonuses for using less than the quota, and fining or closing of supply for exceeding quotas. Using 15 years of monthly administrative reports for every electric utility in Brazil, as well as monthly billing data for millions of electricity users, the study follows a DiD strategy comparing outcomes over time for participating and nonparticipating utilities. The program is found to substantially reduce electricity consumption over many months, with a slightly lower reduction in the long run.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
21	Access to electricity and quality of electricity supply (hours of daily supply)	India	Rao, N. 2013. Does (Better) Electricity Supply Increase Household Enterprise Income in India? *Energy Policy*. 57. pp. 532–541.	IV, PSM	Incomes of nonfarm enterprises	Using a nationally representative sample of 42,000 households, the study explores the impact of electrification and electricity supply on the income of non-farm enterprises in India. The study employs PSM and an IV approach where village electrification rate is used as an instrument for household electrification. It finds a significant income gain from being electrified, and evidence suggesting positive impact when using the continuous measure of daily hours of supply.
22	Tariff schedule for natural gas	Argentina	Bastos, P., L. Castro, J. Cristia, and C. Scartascini. 2011. Does Energy Consumption Respond to Price Shocks?: Evidence from a Regression Discontinuity Design. *IDB Working Paper Series*. 234.	RDD	Residential energy utilization	This analysis takes advantage of the introduction of a new tariff scheme for natural gas in Argentina, to explore the effect of gas price on residential energy consumption. This identification strategy allows the use of a regression discontinuity design to compare changes in usage for households just above and below the tariff cutoff. The findings show significant, sizable, and immediate decline in residential energy consumption from the price shock.
23	CFL adoption	Pakistan	Chun, N. and Y. Jiang. 2013. How Households in Pakistan Take On Energy Efficient Lighting Technology. *Energy Economics*. 40. pp. 277–284.	IV	Demand for lighting services, brightness capacity	The article uses an IV approach to examine the impact of households' adoption of compact fluorescent light bulbs (CFLs) on demand for lighting services. Respondents' CFL knowledge and the price ratio of CFL to incandescent light bulbs in the area are used as instruments for CFL adoption. The study finds that limited knowledge of the life span of CFLs negatively influences the decision to switch to CFL, as does higher CFL bulb prices. Adoption of CFL is found to result in energy savings, but less than expected, as a large proportion of potential energy savings are offset by households keeping the light on longer or making rooms brighter.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
24	Rural grid electrification and quality of electricity supply (hours of daily supply)	India	Chakravortya, C., M. Pelli, and B. Marchand. 2014. Does the Quality of Electricity Matter? Evidence from Rural India. *Journal of Economic Behavior & Organization.* 107. pp. 228–247.	IV	Household income	The study focuses on how electricity and quality of supply affect household income in rural India. It uses "district-level density of transmission cables" as an instrument for household electrification status and finds that being connected to the grid increases nonagricultural income significantly, but an even larger effect is found when connection is accompanied by higher quality supply, as defined by the daily number of hours during which the household actually receives supply.
25	Rural electrification	Peru	Dasso, R. and F. Fernandez. 2015. The Effects of Electrification on Employment in Rural Peru. *IZA Journal of Labor & Development.* 4 (6).	DiD, FE	Labor market outcomes, including employment and earnings	This study examines the effects of a rural electrification program on a set of labor market outcomes in Peru. Using large official household survey data sets collected annually over a 5-year period, the study employs a DiD approach with pooled data on almost 250,000 individuals, and a fixed-effects approach for a 3-year panel of 12,000 individuals. Results show positive effects on employment, which differ by gender. Electrification is found to increase the number of hours worked for men and lower the likelihood of having multiple jobs, whereas electricity increases employment generally and nonagricultural sector work specifically for women.
26	Electrification	Indonesia	Grimm, M., R. Sparrow, and L. Tasciotti. 2015. Does Electrification Spur the Fertility Transition? Evidence from Indonesia. *Demography*. 52. pp. 1773–1796.	DiD, IV	Fertility	The article evaluates the effect of electrification on fertility in Indonesia. Using a combination of annual national socioeconomic household survey data, village census data, Demographic and Health Survey data, and national data on power plant location, the study employs a DiD approach, as well as an IV approach. Proximity to power plant is used as an instrument for district electrification with versions using all versus older power plants only explored. Overall results reveal a strong effect of electrification on fertility, such that 19%–25% of the country's fertility reduction over the period may be attributed to electrification. The main identified channels are access to television and reduced child mortality.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
27	Access to rural electricity via solar-powered home systems	Peru	Arraiz, I. and C. Calero. 2015. From Candles to Light: The Impact of Rural Electrification. *IDB Working Paper Series*. No. 599.	PSM	Energy expenditure, time use, schooling, business activity	This paper examines the effects of access to electricity via solar home systems (SHS) on household well-being in rural Peru. It employs a PSM approach with matching being carried out both at community and household levels, based on a combination of program administrative data, cross-sectional household survey data, and community data. The study finds reduced energy expenditure on traditional lighting sources and women spending less time on farm activity and more time on household chores and home business activity. SHS ownership also increased the time spent by children studying and the number of years of schooling.
28	Rural grid electrification	India	Barnes, D. and H. Binswanger. 1986. Impact of Rural Electrification and Infrastructure on Agricultural Changes, 1966–1980. *Economic and Political Weekly*. 21 (1). pp. 26–34.	First differencing/ DiD	Agricultural productivity, rural service industries	The study examines the impact of rural electrification on agricultural development in India between 1966 and 1980. Using survey data on 108 villages collected in 1966 and 1980, the author employs a DiD approach to measure rural electrification not as a binary variable, but as a continuous variable on the number of years that the village has been connected to the electricity grid. The findings show a positive impact on agricultural productivity, which occurs through electric pumps.
29	Energy-based livelihood training programs	India	PricewaterhouseCoopers (PWC). 2017. Impact Assessment of TA 7831: Enhancing Energy-Based Livelihoods for Women Micro-Entrepreneurs.	PSM	Female empowerment, income, time use, perceived safety	This evaluates the impacts of training women members of self-help groups on several economic and social outcomes using PSM and regression analysis. The overall results show that participation in the training programs has a positive effect on incomes and propensity to save and take out loans but no significant pattern on transition to low-carbon fuels and on ownership of labor-saving electrical appliances. Training conducted is not found to have an impact on time use, but has significant effects on women's perception of safety and household decision-making.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
30	Rural grid electrification	Peru	Aguirre, J. 2014. Impact of Rural Electrification on Education: A Case Study from Peru. Mimeo. Research Center. Universidad del Pacifico (Peru) and Department of Economics, Universidad de San Andres.	IV	Educational attainment	This paper evaluates the effects of rural grid electrification on education. IV analysis is applied to baseline demographic data from the Survey on Rural Household Energy Use 2013, which comprise 987 households in rural areas (both electrified and not electrified). The evaluation shows a positive effect of rural household electrification on the number of study hours of schoolchildren in rural households.
31	Electricity supply duration	India	Allcott, H., A. Collard-Wexler, and S. O'Connell. 2016. How Do Electricity Shortages Affect Industry? Evidence from India. *American Economic Review*. 106 (3). pp. 587–624.	IV	Input choices, revenue, productivity	The article examines the impact of electricity shortages on India's manufacturing industries, including their input choices, productivity, and revenue. The study used 1992–2010 weather, power sector and manufacturing data from the National Climate Centre, the India Energy Data Repository, and the Annual Survey of Industries. The evaluation employs IV techniques and finds that energy shortages reduced an average manufacturing plant's revenue, producer surplus, and productivity.
32	Rural electrification	Bangladesh	Barkat, A., S. Khan, M. Rahman, S. Zaman, A. Poddar, S Halim, N. Ratna, M. Majid, A. Maksud, A. Karim, and S. Islam. 2002. *Economic and Social Impact Evaluation Study of the Rural Electrification Program in Bangladesh. Dhaka, Bangladesh: Human Development Research Centre.*	Post-test-only control group operations research design, with–without scenario	Household consumption, irrigation, industry, and commercial activities	This study evaluates the social and economic impacts of Bangladesh's rural electrification program. It adopts a post-test-only control group operations research design to estimate the impacts of the program on households' standard of living, industrial development, commercial activities, and agricultural production in Bangladesh. The study finds significant effects of the program on nearly all outcomes investigated.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
33	Rural electrification	Peru	Dasso, R., F. Fernandez, and H. Nopo. 2015. Electrification and Educational Outcomes in Rural Peru. IZA Discussion Paper Series. No. 8928.	IV, FE	Enrollment, attendance, expenditures	The study investigates the effects of electrification on educational outcomes by taking advantage of the rapid expansion of rural electrification in rural areas of Peru. Using household survey panel data from 2007 to 2012, the results show that (i) electrification does not have any effect on boys' school enrollment, attendance, or education-related expenses; (ii) although girls living in treated districts are more likely to be enrolled in school, this does not translate into higher attendance rates; and (iii) households in treated areas spend more money on younger girls' education. Using school-level panel data from 2007 to 2010, math and reading test scores show that electrification is associated with reduced student learning. However, longer treatment exposure among treated schools improves scores in reading for boys and girls and improves performance in math among only boys.
34	Electricity supply duration	People's Republic of China (PRC)	Fisher-Vanden, K., E. Mansur, and Q. J. Wang. 2015. Electricity Shortages and Firm Productivity: Evidence from China's Industrial Firms. *Journal of Development Economics*. 114. pp. 172–88.	FE	Firm productivity, production costs	This study tests four hypotheses regarding how firms respond to electricity shortages (decreased productivity, self-generation, outsourcing inputs, investment in energy-efficient technologies). It uses a fixed-effects model on firm-level data for production, electricity, and material inputs. The results indicate that electricity shortage (scarcity) affects firms' production decisions and significantly increases outsourcing behavior.
35	Solar lamps	Uganda	Furukawa, K. 2013. Do Solar Lamps Help Children Study? Contrary Evidence from a Pilot Study in Uganda. Working Paper. Brown University.	RCT	Children's learning outcomes, study productivity	This RCT on 204 households in Uganda evaluates whether access to solar lamps/reliable lighting enhances the health and learning of children more than dim kerosene candles. This paper concludes that while factors such as health and study time increased because of reliable lighting, school performance (test scores) decreased.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
36	Rural electrification	Indonesia	Gibson, J. and S. Olivia. 2009. The Effect of Infrastructure Access and Quality on Non-Farm Enterprises in Rural Indonesia. *World Development*. 38 (5). pp. 717–26.	DiD	Employment in and income from nonfarm enterprises	This paper uses the DiD method to evaluate the effect of quality and access to rural infrastructure on income and employment of nonfarm enterprises/economy. The study focuses on data from 4,000 households in rural Indonesia. The results suggest that both the poor quality and lack of access to infrastructure are constraints to nonfarm enterprises in Indonesia's rural areas.
37	Electricity access	Tanzania	Burlando, A. 2014. Power Outages, Power Externalities, and Baby Booms. *Demography*. 51. pp. 1477–1500.	DiD/Fixed effects	Fertility	This study applies a two-way fixed effects model on birth records from Zanzibar to assess whether a month-long blackout in 2008 caused a significant increase in childbirth. It finds a significant increase across electrified villages, regardless of the level of electrification; in comparison with unelectrified villages, which had no increase. The authors suggest that there may be spillover effects driving fertility increases in electrified villages with very low levels of household electrification.
38	Access to electricity	Africa	Grimm, M., R. Hartwig, and J. Lay. 2012. How Much Does Utility Access Matter for the Performance of Micro and Small Enterprises? Working Paper. Washington, DC: World Bank.	IV	Economic growth and/or performance of micro and small enterprises in the informal sector	The analysis uses a detailed cross-sectional micro data set on informal production units (IPUs) in West African capital cities to evaluate the impact of utility access on their performance. An IV approach is used to reduce the endogeneity bias of utility access, and results were disaggregated by business sector or by country. The findings include that utility access did not have significant effects on the performance of these IPUs, with the exception of tailors in Ouagadougou, which were positively impacted.
39	Access to electricity, rural electrification	Morocco	Khandker, S. R., V. Lavy, and D. Filmer. 1994. Schooling and Cognitive Achievements of Children in Morocco. Discussion Paper 264. Washington, DC: World Bank.	FE	Schooling/overall educational attainment, cognitive achievements	This study evaluates whether Morocco's public investments, including on electricity, positively affect educational outcomes. Regression analysis using FE models was used to analyze existing survey data on living standards and literacy and evaluate effects. The study finds that investments in Morocco's rural areas that improve infrastructure such as roads, access to electricity, and irrigation as well as its educational system all positively affect school enrollment, attendance, and educational attainment.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
40	Rural electrification	India	Khandker, S. R., H. Samad, R. Ali, and D. Barnes. 2014. Who Benefits Most from Rural Electrification? Evidence in India: Policy Research Working Papers. *The Energy Journal.* 35. pp. 75–96.	IV	Labor supply, schooling, household and per capita income and expenditure, poverty reduction	The authors employed an IV method, as well as a quantile regression model, to quantify the effects of rural electrification on a set of household-level characteristics in India. Data from the 2005 India Human Development Survey were used for the analysis. The study finds that electrification positively affects income, expenditure, time allocation for fuel collection, schooling, and poverty incidence. The study also evaluated the effects of electricity interruption/power outages and found that these reduced the gains from rural electrification.
41	Access to electricity	Rwanda	Lenz, L., A. Munyehirwe, J. Peters, and M. Sievert. 2016. Does Large Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. *Ruhr Economic Paper*. No. 555.	DiD	Poverty alleviation, households, microenterprises	The study evaluates the effects of Rwanda's electricity access program on socioeconomic outcomes. The data used are from surveys conducted from 2011 to 2013 of 974 households with and without electrification. A DiD approach is used to control for unobserved time invariant differences in households with and without electricity. The study finds that access to electricity increased electric appliance usage in households, but not in health centers, decreased by 3% the share of energy expenditure in total expenditures, increased access to information, and had no effect on income-generation potential or on investment in education. In industries, electrification is found to have led to some changes in production processes and outputs and induced the creation of new firms.
42	Electrification (hydropower plants)	Brazil	Lipscomb, M., A. Mobarak, and T. Barham. 2013. Development Effects of Electrification: Evidence from Topographic Placement of Hydropower Plants in Brazil. *American Economic Journal: Applied Economics*. 5 (2). pp. 753–66.	IV	Labor productivity	This paper estimates the development effects of electrification across Brazil, using hydrological simulations of hypothetical electricity grids over the period of 1960–2000 as instruments for actual electrification. It finds that electrification had effects on household income, the education score on the Human Development Index, increases in formal employment, reduction in illiteracy rates, and increased number of years in schooling.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
43	Electrification	Ghana	Peters, J., M. Sievert, and C. Vance. 2013. Firm Performance and Electricity Usage in Small Manufacturing and Service Firms in Ghana. In Productive Use of Energy (PRODUSE): Measuring Impacts of Electrification on Micro-Enterprises in Sub-Saharan Africa, edited by L. Mayer-Tasch, M. Mukherjee, and K. Reiche. Eschborn.	Ordinary least squares (OLS), IV	Microenterprise performance	The relationship between electricity use and performance of service and manufacturing micro and small enterprises in Ghana, specifically the effect that electrification has on profits is evaluated using cross-sectional data from 236 firms in a two-stage least squares (2SLS) IV approach. The paper finds that firms connected to the grid had substantially different economic activities from non-connected firms. No substantial differences were found in labor input and work hours, but firms with connection had higher capital input. The study also did not find any significant effect on income of electricity use.
44	Access to electricity	India	Rud, J. 2012. Electricity Provision and Industrial Development: Evidence from India. *Journal of Development Economics*. 97 (2). pp. 352–67.	OLS, IV	Industrialization, manufacturing output	The study quantifies how much investments in electricity provision affect industrial development. IV methods are used on data pertaining to industrial development and performance. The funds that increase in electrification lead to a significant increase in manufacturing firm production such as that across states in India. The findings suggest that a 14% increase in manufacturing output can be gained by one standard deviation increase in electrification.
45	Rural electrification	Nigeria	Salmon, C. and J. Tanguy. 2014. Rural Electrification and Household Labor Supply: Evidence from Nigeria. *TEPP Working Paper*.	Copula-based bivariate hurdle model and IV	Labor supply, household time allocation	This paper evaluates the effect of rural electrification on household time allocation and participation in labor markets. It utilizes IV methods on matched husband-wife data from the 2010–2011 General Household Survey to analyze spouses' time allocation for labor force participation. The paper finds that electrification increases the work hours of spouses who were currently working, but it had no significant effect on spouses' chances of gaining employment.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
46	Solar home system	Senegal	Bensch, G., J. Peters, and M. Sievert. 2012. Fear of the Dark? How Access to Electric Lighting Affects Security Attitudes and Nighttime Activities in Rural Senegal. *Ruhr Economic Papers.* No. 369. Essen: RWI.	CEM	Lighting consumption and activities after nightfall (study) and security attitude	Using 2009 household data from rural Senegal, the study explores how ownership of a solar home system affects lightning usage and nighttime activity. Via the application of CEM, it finds significant positive effects on lighting usage along with increases in nighttime studying for schoolchildren, and suggestive evidence of increased perceived safety at night.
47	Rural electrification thru micro hydro mini grids	Rwanda	Bensch, G., J. Kluve, and J. Peters. 2011. Impacts of Rural Electrification in Rwanda. *Journal of Development Effectiveness.* 3 (4). pp. 567–588.	PSM	Hours of lighting usage, time primary schoolchildren dedicate to studying at home, energy expenditures, and income per working-age adult	Comparing household-level data from matched electrified and non-electrified communities, this study quantifies the effects of electrification on intensity of lighting usage, amount of time spent on studying, and energy expenditures and income in rural Rwanda. It finds a significant increase in intensity of lighting usage in electrified households. Effects on income, study time, and energy expenditures were also observed, but these become insignificant if regional differences are taken into account.
48	Television and radio exposure	Indonesia	Olken, B. 2009. Do Television and Radio Destroy Social Capital? Evidence from Indonesian Villages. *American Economic Journal: Applied Economics*. 1 (4). pp. 1–33.	FE (district level)	Participation in social groups and trust	The author measures the effects of television and radio, which were enabled by electrification, on social capital. Using data from two different sources on the number of television and radio signals that a household can receive, the study finds that increased access to television and radio signals is associated with reduced participation in social groups. More time spent watching television and/or listening to radio are found to lead to fewer types of social organizations present in a community, but not worse governance outcomes.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
49	Incomplete privatization of the electric sector	Peru	Alcázar, L., E. Nakasone, and M. Torero. 2007. Provision of Public Services and Welfare of the Poor: Learning from an Incomplete Electricity Privatization Process in Rural Peru. *Research Network Working Paper*. No. R-526. Washington, DC: Inter-American Development Bank.	PSM	Direct: accessibility, service quality Indirect: type of energy source, time devoted to nonagriculture activities, time devoted to economic and noneconomic activities	The paper exploits an incomplete privatization of Peru's electricity sector to examine the impact of public versus private provision of electricity. Using a nationally representative electricity and energy survey, the study performs PSM and finds that quality of electricity provision improves under privatization, which in turn affects household time use. Households with privatized supply of electricity spend more time on nonfarm activities, less time on household work, fewer hours working, and longer time on leisure. The results also suggest a substitution effect away from agriculture.
50	Private sector involvement, regulation	Latin America and the Caribbean (19 countries)	Andres, L., J. L. Guasch, and S. L. Azumendi. 2009. Regulatory Governance and Sector Performance: Methodology and Evaluation for Electricity Distribution in Latin America. *In Regulation, Deregulation, Reregulation: Institutional Perspectives,* edited by C. Menard and M. Ghertman. pp. 111–150. Cheltenham, UK and Northampton, Mass.: Edward Elgar Publishing.	FE	Supply, electricity price and/or tariff, electricity generation costs, inefficiencies, revenue or price and cost ratios, quality	This study explores the link between regulatory governance and energy sector performance. The authors developed an aggregate index and run different fixed effects models to explain the contributions of change in ownership and different characteristics of the regulatory agency to the performance of the utilities using two unique databases—the World Bank Performance Database and the Electricity Regulatory Governance Database. Analysis show that mere existence of a regulatory agency, regardless of the utilities' ownership has a significant effect on sector performance.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
51	Unbundling	PRC	Du, L., Y. He, and J. Yan. 2013. The Effects of Electricity Reforms on Productivity and Efficiency of China's Fossil-Fired Power Plants: An Empirical Analysis. *Energy Economics*. 40. pp. 804–812.	DiD	Productivity (labor, capital, fuel) and efficiency	This study estimates the effects of electricity reforms on the productivity and efficiency of fossil-fired generation plants using industrial and economic census data. DiD partial factor productivity analysis shows electricity forms lead to a significant increase in labor and capital productivity and a weakly significant effect on fuel use. Total factor productivity analysis also shows significant (albeit lower) efficiency gains if substitution effect between labor and capital is considered, but gains become weakly significant if fuel expense is included.
52	Regulatory reforms	PRC	Du, L., J. Miao, and J. Shi. 2009. Assessing the Impact of Regulatory Reforms on China's Electricity Generation Industry. *Energy Policy*. 37 (2). pp. 712–720.	DiD	Production efficiency (inputs of labor, fuel, nonfuel materials)	Using administrative data, this article aims to measure the effects of regulatory reforms on production efficiency of fossil-fired generation plants in terms of labor, fuel, and nonfuel materials. It finds that regulatory reforms led to net efficiency improvements in use of labor (29%) and nonfuel materials (35%) but no effect on fuel input use.
53	Privatization, regulation	Latin America (14 countries)	Estache, A. and M. A. Rossi. 2005. Do Regulation and Ownership Drive the Efficiency of Electricity Distribution? Evidence from Latin America. *Economics Letters*. 86 (2). pp. 253–257.	FE	Number of employees (labor productivity)	This study analyzes the effects of alternative regulatory regimes on the labor productivity of electricity distribution firms in Latin America using fixed effects models. It finds that (i) incentive-based regimes lead to higher labor productivity than rate-of-return regulation, (ii) firms regulated under hybrid regimes have intermediate labor productivity, and (iii) privatized firms operating under rate of return have similar labor productivity as public firms.
54	Deregulation and vertical unbundling	PRC	Gao, H. and J. Biesebroeck. 2014. Effects of Deregulation and Vertical Unbundling on the Performance of China's Electricity Generation Sector. *The Journal of Industrial Economics*. 62 (1). pp. 41–76.	DiD and IV	Production efficiency (labor, material)	The paper estimates the effects of deregulation and vertical unbundling on the performance of the electricity generation companies in terms of labor and material input efficiency. Using firm-level data (1998–2007) from the National Bureau of Statistics, it finds a reduction in labor (7%) and material use (5%) 2 years after reforms were implemented, and that findings are robust to many specification checks.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
55	Electricity sector privatization	Argentina	Gonzalez-Eiras, M. and M. A. Rossi. 2008. The Impact of Electricity Sector Privatization on Public Health. In *Privatization for the Public Good? Welfare Effects of Private Intervention in Latin America*, edited by A. Chong. pp. 43–63. Washington, DC: Inter-American Development Bank; Cambridge: Harvard University, David Rockefeller Center for Latin American Studies.	DiD	Incidence of low birth weight and child mortality rates (diarrhea and food poisoning)	The effects of electricity sector privatization on food contamination and nutritional deficiencies were investigated in this study. Results show that privatization improves nutritional intake, as a result of greater electricity coverage (and use of refrigerators) and reduce frequency of food poisoning due to fewer power interruptions. At the same time, it does not find significant effects on birth weight and child mortality rates.
56	Privatization	Latin America (10 countries)	Guasch, J. L., V. Foster, and L. Andres. 2006. The Impact of Privatization on the Performance of the Infrastructure Sector: The Case of Electricity Distribution in Latin American Countries. *Policy Research Working Paper*. No. 3936. Washington, DC: World Bank.	FE	Electricity supply, prices and tariff, inefficiency, quality	This paper analyzes effects on performance indicators, such as output, employment, labor productivity, efficiency, coverage, and prices for 116 electricity distribution firms in 10 Latin American countries after privatization. The results suggest that changes in ownership caused significant improvements in labor productivity, efficiency, and product/service quality during transition period. However, the improvements appear modest in the post transition period of 2 years past the change in ownership

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
57	Electricity sector restructuring (unbundling)	India	Malik, K., M. Cropper, A. Limonov, and A. Singh. 2015. The Impact of Electricity Sector Restructuring on Coal-Fired Power Plants in India. *The Energy Journal.* 36 (4). pp. 287–312.	DiD	Operating reliability and thermal efficiency	This study measures the effects of electricity generation unbundling on the operating reliability and thermal efficiency of coal-fired power plants. Using data from the performance review of thermal power stations (covering around 80% of total installed generation capacity in the country), it finds that generating units that unbundled between 1996 and 2002 experienced a significant increase in service availability, due to reduced forced outages, with the largest effects being experienced 3 to 5 years after unbundling. No improvement is observed for thermal efficiency.
58	Privatization, unbundling	India	Panda, A. K. 2002. Restructuring and Performance in India's Electricity Sector. Unpublished doctoral dissertation. University of Southern California. Los Angeles, United States.	FE	Operational efficiency (plant availability, plant load factor, forced outage, number of employees per thousand consumers, and number of employees per unit of electricity sold) and financial performance (average unit cost of supply of electricity, average tariff collection, sales revenue as a ratio of cost, and the extent of cross-subsidization)	The impacts of electricity restructuring and privatization on operational efficiency and financial performance of the sector are analyzed in this study. Using available panel data sets, it finds that restructuring led to improvements in operational efficiency (plant availability and load factor, forced outage) and financial performance (average tariff collection and sales revenue as a ratio of cost). Restructuring also appears to lead to reduction in the extent of cross-subsidization. However, the cost of supply seems to be unaffected by restructuring. Government ownership is found to have adverse effects on costs, sales revenue as a ratio of cost, and labor efficiency.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
59	Privatization, unbundling, competition-enhancing policies	India	Sen, A. and T. Jamasb. 2012. Diversity in Unity: An Empirical Analysis of Electricity Deregulation in Indian States. *Energy Journal.* 33 (1). pp. 83–130.	Dynamic panel data estimators (FE)	Efficiency (plant load factor, transmission and distribution losses, gross generation); price (average price, average industrial price); pricing (ratio of industrial to domestic prices, ratio of industrial to agricultural prices); reinvestment (percentage energy deficit); and industrial consumption	This study evaluates the effects of various power-sector reforms on key economic variables related to the power sector, taking into account India's political landscape and regional diversity. Analysis shows that (i) reform measures lead to different economic outcomes, and (ii) outcomes initially tend to be adverse due to political economy factors at play but improvements become visible as time progresses.
60	Privatization, regulation	Latin America and the Carribean (18 countries)	Wren-Lewis, L. 2015. Do Infrastructure Reforms Reduce the Effect of Corruption? Theory and Evidence from Latin America and the Caribbean. *The World Bank Economic Review.* 29 (2). pp. 353–384.	FE	Productivity	This paper analyzes the effects of reforms—privatization and creation of independent regulatory agencies on corruption and governance at the sector level. The interaction is analyzed empirically using an FE estimator on a panel of 153 electricity distribution firms across 18 countries in Latin America and the Caribbean from 1995 to 2007. Results reveal that greater corruption is associated with lower firm labor productivity, but this association is reduced with the presence of an independent regulatory agency. These results are robust even when controlling for a large range of observables and using several different corruption measures. The association between corruption and productivity also appears weaker for privately owned firms compared with publicly owned firms, although this result is somewhat less robust.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
61	Rural electrification	Viet Nam	Gencer, D., P. Meier, R. Spencer, and H. T. Van. 2011. *Vietnam – State and People, Central and Local, Working Together: The Rural Electrification Experience*. Asia Sustainable and Alternative Energy Program (ASTAE). Washington, DC: World Bank.	DiD	Social, economic, welfare impacts (appliance ownership, household electricity consumption, adult education, children's education, income and expenditure patterns, poverty)	This study estimates the social, economic, and welfare impacts of a rural electrification program in Viet Nam. It was found that the program leads to positive outcomes such as job creation, increased household income, improvements in health and education, and improvements in overall quality of life.
62	Access to electricity	Uganda	Neelsen, S. and J. Peters. 2011. Electricity Usage in Micro-Enterprises – Evidence from Lake Victoria, Uganda. *Energy for Sustainable Development*. 15 (1). pp. 21–31.	PSM	Firm performance (composition of capital stock, hours of operation and monthly labor input, employment and remuneration hours, job creation, market access, firm profit, industry structure, product variety)	This paper explores the effects of electricity on firm performance and economic development in two fishing communities in Southern Uganda. Using quantitative firm-level data on 200 microenterprises complemented by qualitative case studies, the study finds that modern energy increases the importance of electricity using capital and alters the sectoral distribution of economic activities. In contrast, it finds no effects of electrification on firm performance, as measured by profits or workers' income. In fact, many entrepreneurs consider the direct gain from connecting to the grid to be small. However, qualitative analysis suggests that electrification has positive indirect impact on firm performance.

continued on next page

Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
63	Rural electrification	India	Burlig, F. and L. Preonas. 2016. Out of the Darkness and Into the Light? Development Effects of Rural Electrification. *Energy Institute at Haas WP*. 268.	RDD, DiD	Employment, income, poverty, asset ownership, school enrollment	This study estimates the effects of India's national rural electrification program. It employs a regression discontinuity design to identify medium-term impacts of electrification on a range of outcomes, including employment, income, poverty, asset ownership, and school enrollment. The study draws on combinations of existing data sets, including luminosity, household and village censuses, the Socioeconomic and Caste Census, and administrative educational data. The assignment variable is village size, in that only villages with more than 300 households were targeted by the national electrification program. A DiD estimation is employed as a secondary technique. The study finds a substantial increase in electricity use, but that effects are smaller than 0.26 standard deviations across all measures, and that many effects are smaller than in other literature.
64	Rural electrification	Philippines	Chakravorty, U., K. Emerick, and M. L. Ravago. 2016. Lighting Up the Last Mile: The Benefits and Costs of Extending Electricity to the Rural Poor. *Resources for the Future*. Washington, DC.	IV	Income, poverty, employment, agricultural income	This paper estimates short-term welfare gains from electricity expansion in the Philippines. The study uses spatial analysis to construct an instrument of the lowest-cost electricity transmission and distribution development locations. The instrument is then employed with rounds of the household income and expenditure surveys and annual poverty indicators aggregated to the village level to evaluate instrumented electricity development. Large effects on income are found, particularly agricultural income. The value of the effects is found to dwarf costs.
65	Rural electrification	Kenya	Lee, K., E. Miguel, and C. Wolfram. 2018. Experimental Evidence on the Economics of Rural Electrification. Working Paper. Berkeley University of California.	RCT (Randomized encouragement design)	Willingness to pay, welfare, income, health, education, employment	This field experiment takes place in 150 "transformer communities," which were randomly assigned into treatment arms consisting of no connection subsidy, a 100% connection subsidy, a 57% subsidy, and a 29% subsidy. Uptake results, household survey data, and community data were utilized to evaluate demand curves and compare them with costs. Willingness to pay was found to be below connection costs. The study also does not find meaningful impacts on economic, health, and educational outcomes.

continued on next page

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
66	Solar lanterns	Bangladesh	Kudo, Y., A. S. Shonchoy, and K. Takahashi. 2015. Impacts of Solar Lanterns in Geographically Challenged Locations: Experimental Evidence from Bangladesh. IDE Discussion Paper No. 502. Chiba, Japan.	RCT	Education, health, time use, energy use	This study is a randomized controlled trial in "Char" river islands of northern Bangladesh where no grid-based electricity is available. Approximately 900 schoolchildren from households with no lanterns were randomly assigned to receive a larger-capacity solar lantern, a smaller-capacity lantern, or were assigned to control. The study finds that solar lanterns significantly increased home study hours, especially in the night and before exams. Although school attendance rate also initially increased, the effects faded over time, and children's exam results did not improve. Marginal improvements on health-related indicators, such as eye redness and irritation were found. A decrease in annual biomass and kerosene fuel consumption was also observed.
67	Rural electrification	Bangladesh	Fuji, T. and A. S. Shonchoy. 2017. Fertility and Rural Electrification in Bangladesh. Research Collection School of Economics. Singapore Management University.	DiD, IV, PSM	Fertility	The study applies a household-level panel data set from Bangladesh to estimate the effect of access to electricity on fertility. The study estimates effects separately using DiD, village electrification status as an instrument, and propensity score matching. It finds that access to electricity reduces the change in the number of children by about 0.1 to 0.25 children over a 5-year period.
68	Electricity supply	Colombia	Fetzer, T., O. Pardo, and A. Shanghavi. 2016. More than an Urban Legend: The Long-Term Socioeconomic Effects of Unplanned Fertility Shocks. Technical Report 284. Department of Economics, University of Warwick.	DiD	Fertility	The study evaluates the effects of power supply on fertility. It does so by exploiting a nearly year-long period of power rationing that took place in Colombia in 1992 as a source of variation from which fertility effects can be estimated. It finds that power shortages can lead to higher fertility and that the increase in fertility was not offset over the following 12 years.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
69	Rural electrification	Colombia	Grogan, L. 2016. Household Electrification, Fertility, and Employment: Evidence from Hydroelectric Dam Construction in Columbia. *Journal of Human Capital*. 10 (1). pp. 109–158.	IV	Fertility, employment, education	The study evaluates effects of household electrification in Colombia on fertility, women's work behavior, and children's schooling. The study uses the distance between a municipality and the nearest hydroelectric dam as an instrument for electrification during 1973–2005. It finds that electrification reduces fertility, increases schooling, but does not find employment effects.
70	Rural electrification	Bangladesh	Samad, H. and F. Zhang. 2017. Heterogeneous Effects of Rural Electrification Evidence from Bangladesh. *Policy Research Working Paper 8102*. Washington, DC: World Bank.	Propensity score weighted DiD, IV	Time use, energy use, income	The paper uses panel data for 7,018 rural households in Bangladesh for 2005 and 2010 to quantify the heterogenous effects of electricity. It applies propensity score weighted DiD, as well as IV using distance to electricity poles as an instrument. The latter is applied cross-sectionally to 2005 data regarding power outages, whereas electrification uses the panel techniques. The study finds that power outages negatively impact many development outcomes, whereas the benefits of electrification take time to occur.
71	Off-grid electrification for irrigation	Benin	Burney, J., H. Alaofè, R. Naylor, and D. Taren. 2017. Impact of a Rural Solar Electrification Project on the Level and Structure of Women's Empowerment. *Environmental Research Letters*. 12 095007.	DiD	Women's empowerment	The study evaluates the impacts of a distributed photovoltaic irrigation project on women's empowerment in Benin. It applies a DiD design to evaluate effects on an index of empowerment. The study finds significant impacts on empowerment, especially in terms of economic independence.
72	Rural electrification	Guatemala	Grogan, L. 2018. Time Use Impacts of Rural Electrification: Longitudinal Evidence from Guatemala. *Journal of Development Economics*. 135.	IV	Gender-disaggregated time use, employment	This study estimates effects of household electric connections on time allocation of rural, indigenous Guatemalans during 2000–2011. It applies an IV model, in which electrification of a household is instrumented by electrification rates of the census segment and other covariates. The study finds that women increased paid employment time by 2–3 hours per day.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
73	Rural electrification	Brazil	Borges da Silveira Bezerra, P., C. L. Callegari, A. Ribas, A. F. P. Lucena, J. Portugal-Pereira, A. Koberle, A. Szklo, and R. Schaeffer. 2017. The Power of Light: Socio-economic and Environmental Implications of a Rural Electrification Program in Brazil. *Environmental Research Letters*. 12 (9).	DiD/FE	Human development index, education	The study evaluates the effects of rural electrification in the poorest regions of Brazil. A fixed effects model is applied to a municipal panel data set to estimate effects on the components of the Human Development Index. Significant effects on all index dimensions are found, with the strongest effect on education.
74	Rural electrification	Cambodia	Saing, C. H. 2018. Rural Electrification in Cambodia: Does It Improve the Welfare of Households? Oxford *Development Studies*. 46 (2). pp. 147–163.	DiD	Income, education	Socioeconomic surveys from 2004 and 2011 are aggregated to construct village panel data, to which DiD techniques are applied to estimate the impact of rural electrification on household consumption and children's education. The study finds that rural electrification increased household consumption by approximately 16.6%, and that higher-quintile households benefited more. It also had significant impacts on years of schooling.
75	Rural electrification	PRC	Ding, H. C. Qin, and K. Shi. 2018. Development through Electrification: Evidence from Rural China. *China Economic Review*. 50. pp. 313–328.	DiD plus PSM	Agricultural income, employment	The study estimates the effects of rural electrification on agricultural income and employment. It applies a combination of PSM and DiD techniques to a national data set for 2,459 PRC villages in 1992 and 2002. The study finds significant impacts on net agricultural income per capita of farmers.
76	Rural electrification	Ghana	Akpandjar, G. and C. Kitchens. 2017. From Darkness to Light: The Effect of Electrification in Ghana, 2000–2010. *Economic Development and Cultural Change*. 66 (1). pp. 31–54.	DiD	Energy consumption, fertility, education, employment, income	This study examines effects of electricity rollout between 2000 and 2010 on employment, the structure of the households, and other outcomes. It applies DiD techniques to 10% microsamples of the Ghana census. Electrification is found to lead to movements from agriculture toward wage-earning occupations, as well as a reduction in the use of wood fuels, a reduction in fertility, and larger schooling investments.

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Table A2.1 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
77	Solar lamps	Tanzania	Aevarsdottir, A. M., N. Barton, and T. Bold. 2017. The Impacts of Rural Electrification on Labour Supply, Income, and Health: Experimental Evidence with Solar Lamps in Tanzania. *International Growth Centre Working Paper*. E-89302-TZA.	RCT (Randomized encouragement design)	Income, employment, time use, savings, education, health, air quality, subjective well-being	This study applies a randomized encouragement design, in which subsidies were randomly allocated to 30 households in each of 60 schools for a solar lamp with a mobile phone charging point. The study finds that the lamps positively affect labor supply, household income, savings, air quality, health, and subjective well-being.
78	Solar microgrids	India	Aklin, M., P. Bayer, S.P. Harish, and J. Urpelainen. 2017. Does Basic Energy Access Generate Socioeconomic Benefits? A Field Experiment with Off-Grid Solar Power in India. *Science Advances*. 3 (5). E1602153.	RCT	Energy use, time use, employment, education, income	The study is an RCT in which villages were randomly selected to be offered a subsidized solar microgrid with sufficient electricity for lighting and mobile phone charging. The study finds that electrification rates in the treatment group increased by 29% to 36%, but that daily hours of electricity increased only by 0.99 to 1.42 hours. Although kerosene expenditure decreased, no significant changes in savings, expenditure, business creation, or time use are found.
79	Solar lamps	Kenya	Hassan, F. and P. Lucchino. 2017. Powering Education. http://www.poweringimpact.org/wp-content/uploads/2017/03/Paper_PE1.pdf.	RCT	Education, time use	This study distributed solar lamps to randomly selected 7th grade pupils in rural Kenya and collected data on educational outcomes at a quarterly frequency to estimate direct effects and spillovers. The study finds significant effects on math grades, both directly, and through spillover effects to classmates, as a result of more study time.
80	Solar lamps	Kenya	Rom, A., I. Günther, and K. Harrison. 2017. The Economic Impact of Solar Lighting: Results from a Randomised Field Experiment in Rural Kenya. ETH. Zurich.	RCT	Energy use, time use, education, income	This RCT randomly assigned households of 1,600 students into a treatment of a free solar light, a solar light offered at different prices, or into a control. It finds that households that purchase or receive a solar light reduce monthly kerosene costs by about 1% and 2.5% of their total cash expenditures. It finds no significant increase in study time of children or in productive time use by adults.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
81	Prepaid metering	South Africa	Jack, B. K. and G. Smith. 2016. Charging Ahead: Prepaid Electricity Metering in South Africa.	RCT	Electricity use	This study tests the effects of switching from postpaid billing to prepaid metering in Cape Town, South Africa. Over 4,000 monthly billed customers were randomly assigned to receive a prepaid electricity meter. Analysis of billing data shows that electricity use falls by about 13% as a result, and that the decrease continues for a year of subsequent measurement.
82	Information nudges and electricity pricing	India	Sudarshan, A. 2017. Nudges in the Marketplace: The Response of Household Electricity Consumption to Information and Monetary Incentives. *Journal of Economic Behavior & Organization*. 134. pp. 320–335.	RCT	Electricity use	This study is a randomized experiment of interventions to improve demand-side energy efficiency. Treatments include (i) weekly reports with peer comparisons of electricity use; (ii) reports augmented with monetary incentives to reduce consumption; and (iii) electricity price variation. The study finds that reports alone reduced summer consumption by 7% and that the impact of peer comparisons was equivalent to tariff increase of 12.5%. However, a combination of weekly reports and monetary incentives for electricity conservation eliminated the savings.
83	Rural electrification via solar home systems	Bangladesh	Asaduzzaman, M., Yunus, M., Haque, A., Azad, A., Neelormi, S., and A. Hossain. 2013. *Power from the Sun: An Evaluation of Institutional Effectiveness and Impact of Solar Home Systems in Bangladesh*. Bangladesh Institute of Development Studies.	PSM	Education, fertility, health, time use, female empowerment	Propensity score matching is applied to a cross-sectional data set from a survey of 1,600 households in villages where solar home systems (SHS) have been more widely adopted and 2,000 households in adjacent villages where SHS adoption rates are low. It finds that SHS adoption leads to increases in children's study time, with greater increases for girls than for boys. Adoption of SHS is found to have a negative effect on recent fertility and is found to influence positively women's mobility, general and economic decision-making, as well as time use for tutoring children, watching television, and socializing. Disease prevalence is found to be significantly reduced among SHS households.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
84	Rural electrification via micro-hydro systems	Nepal	Banerjee, S., A. Singh, and H. Samad. 2011. Power and People: *The Benefits of Renewable Energy in Nepal*. A World Bank Study. Washington, DC: World Bank.	PSM	Income, expenditure / consumption, health, education, female empowerment, time use, fertility	The analysis applies propensity score matching to a cross-sectional household survey to estimate the effects of micro-hydro electricity connections on a range of outcomes. It finds significant effects on nonfarm income, household expenditure, evening study time of children, girls' years of education completed, significant reductions in respiratory illnesses among women and children, reductions in gastrointestinal illnesses among girls, higher contraceptive usage rates, higher female time dedication to income generating, study, and leisure activities, and increased independence of female decision-making.
85	Electricity access	El Salvador, Ghana, Guatemala, Morocco, and Yemen	Guarcello L., S. Lyon, and F. Rosati. 2004. Child Labour and Access to Basic Services: Evidence from Five Countries. Understanding Children's Project Working Paper Series. January 2004.	PSM	School attendance, child labor	The study assesses the effects of water and electricity access on child labor and school attendance in five countries—El Salvador, Ghana, Guatemala, Morocco, and Yemen. It applies propensity score matching to existing household survey data sets to evaluate effects for rural and urban households, and finds consistently significant effects of electricity access on increasing school attendance for rural children in all countries, a significant effect also for urban children in Guatemala, and significant reductions in child labor in Morocco.
	Intervention	**Country**	**Study**	**Study Design**	**Outcomes**	**Summary Findings**
	Selected Ongoing Impact Evaluation from ADB					
1	Evaluate the use of digital technology in enhancing productivity and profitability of Simpa Network's Off-Grid Pay-as-You-Go Solar Project	India	Enhancing Rooftop Solar Power Business Using Digital Technology	RCT	Customer acquisition (number of new customers per month) and customer maintenance (revenue collected, proportion of defaulting customers)	
	Selected Ongoing Impact Evaluations from the Millennium Challenge Corporation					
2	Rehabilitation and extension of distribution system, customer connection financing scheme	Tanzania	Millennium Challenge Corporation (MCC). 2015. Evaluation of the Tanzania Energy Sector Project: Final Update of Design Report.	RCT	Connection rates, changes in community size, electricity use; liquid fuel use, health and economic well-being, perceived safety	

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
	Selected Ongoing Impact Evaluations from the Abdul Latif Jameel Poverty Action Lab					
3	Set of two solar-powered LED lights and one solar-powered mobile phone charging station	India	Robin Burgess, Michael Greenstone, Nick Ryan, Anant Sudarshan (ongoing) on Welfare Benefits of Decentralized Solar Energy for the Rural Poor in India	RCT	Fuel collection times, respiratory health, children's school attendance, and more	
4	One of four different offers to purchase the Angaza design solar power system	Kenya	William Jack, Tavneet Suri (ongoing) on Powering Small Retailers: The Adoption of Solar Energy under Different Pricing Schemes in Kenya	RCT	Not stated	
5	Deployment of rural solar micro grids, using smart metering technology to evaluate patterns of energy use and theft; power will be sold on a pay-as-you-go basis, with pricing varied randomly across households and time	India	Eric Brewer, Meredith Fowlie, Edward Miguel, Catherine Wolfram (ongoing) on Deployment of Rural Solar Micro Grid	RCT	Not stated	
6	Random assignment to neighborhood scheme with electricity usage linked to and monitored by a power meter for the entire neighborhood	India	Robin Burgess, Michael Greenstone, Nick Ryan, Anant Sudarshan (ongoing) on Light Up Bihar, India	RCT	Energy consumption and electricity supply and customer and business responses to having more supplied electricity, including productivity, operating hours, inventory, and income	

CEM = coarsened exact matching, DiD = difference-in-differences, FE = fixed effects, IV = instrumental variables, PSM = propensity score matching, RCT = randomized controlled trial.
Sources: Authors.

APPENDIX 3: SUMMARY DESCRIPTIONS OF MAJOR IMPACT EVALUATION METHODS

Note: This section draws on White and Raitzer (2017), which provides a more detailed explanation of the methods described.

Difference-in-Differences and Fixed Effects

The difference-in-differences (DiD) technique is based on the difference in the changes in the outcome between treatment and comparison groups over time. The method takes the trajectory of the comparison group as the counterfactual trajectory for the treatment group with the intervention of interest. That is, the change in the outcome that takes place in the comparison group is taken as what would have happened to the treatment group in the absence of the intervention. Therefore, subtracting the change in the outcome observed in the comparison group from that observed in the treatment group gives the measure of impact. The effects of all factors that do not change over time or that do not affect changes over time are thereby eliminated from the impact estimate. Many determinants of program placement or participation can be expected to be rather time invariant, hence the attractiveness of this approach. DiD provides an unbiased estimate of program impact if the "parallel trends" assumption holds, which is the assumption that the outcome variable follows the same trajectory over time in treatment and comparison groups without the intervention. Fixed effects models in two-way panel form (with individual and time period dummies) function similarly to DiD, but can incorporate additional control variables to reduce reliance on the parallel trends assumption, and can be applied to continuous intervention variables (for which the comparison is regarding amounts of the intervention, rather than presence versus absence of the intervention).

Synthetic Controls

Synthetic controls build on the concepts of DiD approaches, in that the difference in trends between the outcome and comparison group observations provides the estimate of impact. However, synthetic controls relax the parallel trends assumption and build the control by weighting the comparison group observations such that trends in covariates and outcomes of the synthetic control match those of treatment before the intervention. Under this method, a panel regression of outcomes on covariates (excluding treatment) is conducted, and a binary variable indicating the treatment status of individual observations is specified. An optimization procedure is conducted to identify weights for individual comparison group observations, such that the weighted synthetic control trends in covariates and outcomes match those of the treated units before treatment as closely as possible. Application of these weights to the comparison group observations during the treatment period allows for a synthetic control, or counterfactual that can be compared with the actual trend of treated groups. The technique requires a time series of observations before and after the intervention of interest for those with and without the intervention.

Propensity Score Matching and Weighting

The propensity score is the estimated probability of being in the treatment group given the observable characteristics from a regression model of participation. Estimated propensity scores can be used to underpin a range of impact evaluation methods, including propensity score matching (PSM), the most common technique; weighting estimators; and weighted regressions. PSM creates a comparison group from untreated observations by matching treatment observations to one or more observations from the untreated sample, based on observable characteristics. Treated units are matched to untreated units with a similar propensity score before making comparisons. Weighting techniques apply weights to balance observable characteristics between treated and untreated groups. Propensity score approaches cannot address selection on unobservables (or variables without measured values that can be incorporated into the regression model of participation), so they may give biased estimates if these are important. DiD can be combined with PSM to eliminate confounding by both time invariant and observable factors.

Regression Discontinuity Design and Interrupted Time Series

Regression discontinuity design (RDD) can be used when there is a threshold rule for program eligibility, such as the poverty line; villages either side of an administrative boundary; or a score used to rank potential subprojects according to an assignment variable with a cutoff value. The underlying assumption, which is tested as part of the procedure, is that units in proximity to either side of the boundary are sufficiently similar for those excluded from the program to be a valid comparison group. The difference in outcomes between those near either side of the cutoff boundary, as measured by the discontinuity in the regression line at that point, is attributable to the program, and so is the measure of impact. The validity of the technique is contingent upon the cutoff value of the assignment variable conditioning eligibility only for the intervention of interest and not other interventions.

Interrupted time series is a specific application of RDD in which the threshold is the point in time at which the program came into effect. This can be a particularly relevant method where intervention effectiveness is sudden, rather than gradual, such as the completion of a bridge or major power transmission connection.

Instrumental Variables and Endogenous Treatment Approaches

The instrumental variable (IV) technique is used to obtain consistent estimates by using one or more variables that affect exposure to the intervention, but not outcomes, as a proxy for the intervention. Natural experiments are the ideal conditions for the application of IV methods, as the exogenous condition determining access to the intervention becomes the instrument. IV is often implemented as two-stage least squares: (i) stage one regresses the endogenous variable (that measuring program participation) on the instruments and calculates the fitted value; and (ii) stage two, estimates the outcome equation, replacing the endogenous variable with the fitted values from the first stage. The impact estimate is the coefficient on the fitted values. Other variants of IV techniques include endogenous selection or switching regressions. The limitation of IV-based approaches is that appropriate instruments are difficult to find.

Impact Evaluation of Energy Interventions

A Review of the Evidence

This report aims to support impact evaluation in the energy sector by assessing what has been produced against what might be possible. It reviews 85 impact evaluations of energy interventions in developing countries, summarizes findings on outcomes, identifies evidence gaps, and proposes ways forward. A majority of studies has so far focused on rural electrification and improved cookstoves, while most investments are in power generation and transmission. After considering the body of evidence available, directions and approaches are proposed for future impact evaluations to best contribute new evidence regarding the sector.

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