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Evidence review

Insight

What is the impact of investing in power?

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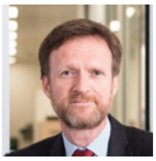
Foreword

CDC is delighted to publish this evidence review on power generation by Professor Anton Eberhard and Gabrielle Dyson. The importance of electricity in contributing to economic growth is well recognised by economists, investors and practitioners globally. However, the development needs and challenges in Africa and South Asia are constantly evolving and becoming increasingly complex. This is being driven by the need to provide adequate electricity to support employment opportunities for the rapidly growing population; the emergence of disruptive technologies challenging traditional grid-based systems; and the need to deploy renewables at scale whilst supporting baseload technology to deliver grid stability.

This review groups evidence from 2003 onwards of the impact of electricity services on development outcomes in emerging economies. Broadening the scope of earlier reviews on development impact from the electricity sector, it considers interventions that span transmission and distribution investments, utility-scale generation, off-grid individual supply systems and mini-grids, as well as ancillary technologies that support emerging supply models. The aim is not to compare or contrast different modes of intervention, but rather to assess the evidence of their impact in macroeconomic, microeconomic, social, and environmental areas to help investors like us to maximise impact across investments.

Anton Eberhard has established himself as a world class energy expert. He is Professor Emeritus at the University of Cape Town's Graduate School of Business and the founding Director of the University's Power Futures Lab, which conducts economic and policy research on energy sector structure, governance and investment in Africa and other developing regions. He is the author of more than 100 peer reviewed publications including Africa's Power Infrastructure: Investment, Integration and Efficiency; and Independent Power Projects in sub-Saharan Africa.

Gabrielle Dyson specialises in energy economics and policy analysis for sustainable development, and has collaborated with University of Cape Town's Power Futures Lab since 2018. Founder of Paris-based social science research consulting group, kōtare.network, she previously consulted on renewable energy economics and finance from Washington, DC. She has advised government agencies and international organisations on energy and environmental policy in dozens of developing and small island countries.



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Summary of key findings

Electricity infrastructure is a major development challenge, with over one billion people lacking electricity access in developing countries, mostly in sub-Saharan Africa. Energy is an essential component of economic growth and development: it is a primary input to any economic activity, across all scales and sectors, including for households.

This report maps the evidence on development impact from electricity, revealed through an extensive literature review. We review over 80 key studies and dozens more contextual papers on the varying impact of electricity infrastructure, from utility-scale investments to off-grid lighting programmes, focusing on developing or emerging (industrialising) economies.

The table below lists 22 impact types, each alongside a question explaining its pertinence to the study. The final column represents the quantity of data and prevailing findings about each impact in the body of literature. This column shows where overall positive findings are observed (based on an incidence of over 70 per cent positive relationship from the electricity intervention assessed in the literature), where findings tend to be mixed or inconclusive, and where they find no relationship.

1 billion

Electricity infrastructure is a major development challenge, with over one billion people lacking electricity access in developing countries, mostly in sub-Saharan Africa.

Evidence on impact of power sector development

	Impact	How does receiving access or improved quality of electricity intersect with …	Strength and quantity of evidence
Macroeconomic indicators	GDP growth	Stimulating GDP growth? We found the causality of relationship between electricity use and GDP growth can work in either or both directions.	Mixed findings, or not significant; well documented
	Jobs and labour market	Creating jobs directly, indirectly, or by induction through economic growth?	Significant positive; well documented
	Productivity	Increasing business productivity and competitiveness?	Significant positive; well documented
Microeconomic impact	Household energy consumption	The amount of energy a household consumes?	Significant positive; moderate body of evidence
	Appliance ownership	The number of appliances a household or business owns?	Significant positive; moderate body of evidence
	Energy cost or spending	Reducing overall energy expenses?	Mixed findings, or not significant; well documented
	Household income and expenditure	Increasing incomes or expenditure?	Significant positive; well documented
	Housing stock, land value	The quality of housing, its value, or overall asset wealth?	Mixed findings, or not significant; small body of evidence
	Migration to community	Increasing in-migration to an (electrified) community or reducing out-migration?	Mixed findings, or not significant; small body of evidence
	Entrepreneurship, businesses and employment	Allowing customers to engage or increase economic activities and entrepreneurship?	Mixed findings, or not significant; well documented
	Time allocation	Saving or rearranging time for new activities e.g. income-generation, leisure, chores?	Significant positive; well documented
	Distributional effect and poverty reduction	Reducing poverty and inequality by reaching the poorest consumers?	Mixed findings, or not significant; moderate body of evidence
Community and individual wellbeing	Health outcomes, knowledge, accidents	Improving healthcare, reducing health problems, increasing awareness of health issues, reducing accidents?	Significant positive; well documented
	Household air pollution	Reducing indoor air pollution and associated irritation or disease?	Significant positive; well documented *
	Education, children's use of lighting	Improving children's educational outcomes, increasing study hours and years of schooling?	Significant positive; well documented
	Gendered uses: women's work, time, and decision-making power	Improving women's equality and empowerment by enabling greater participation in non-household work, giving greater decision-making power, improving leisure time?	Significant positive; moderate body of evidence
	Life satisfaction, stress, and mental wellbeing	Improving life satisfaction and mental wellbeing, or relieving stress?	Significant positive; small body of evidence
	Sense of safety	Increasing perceived safety in the community and at home?	Significant positive; moderate body of evidence
	TV watching/ownership	Increasing access to entertainment and information through television?	Significant positive; moderate body of evidence
Environmental improvements	Greenhouse gas (GHG) emissions	Avoiding or reducing GHG emissions by increasing renewable generation capacity in the energy mix, or replacing dirty-fuel technologies?	Significant positive; moderate body of evidence
	Local pollution	Local e-waste pollution (such as by replacing dry-cell battery use or contributing to additional e-waste)?	Significant positive; small body of evidence
	Deforestation and local livelihoods	Reducing deforestation by incentivising lower-impact agricultural activities, or reducing need for fuelwood?	Significant positive; small body of evidence

* Including inferred improvement due to reduced kerosene use.

Direction of findings: positive, negative or inconclusive

- Significant positive impact or relationship (>70% of studies)
- Mixed findings, or not significant
- Significant negative or null relationship (>50% of studies)

Quantity of evidence

- Well documented (over 14 results)
- Moderate body of evidence (over 9 results)
- Small body of evidence (fewer than 9 results)

Note: the size of the circle does not represent the size of the effect or impact, but rather the number of studies reviewed that produce a finding in this category.

01

Introduction

1.1 How important is electricity for economies, both at system-wide and local scales?

Energy use is inextricably related to economic growth and development, which are strongly correlated at national levels (Lemma et al. 2016; Cabraal, Barnes, and Agarwal 2005). Energy is a primary input to any economic activity, across all scales and sectors from domestic uses to large industrial production and transformation of goods. Energy scarcity, by consequence, constrains economic growth. The exploitation of fossil fuels and electricity in past centuries has removed that constraint in industrialised economies. But many developing countries still lack a sufficient level of modern energy services to meet demand and improve economic productivity, growth, and livelihoods.

Electricity has an almost infinite number of uses, most notably offering:

- Flexible and efficient means to power productive industry such as manufacturing and agriculture, as well as commercial uses and service industries
- Higher quality, more efficient lighting, at far lower cost per lumen than fuel-powered lighting
- Entry to modern information and communication technologies, including mobile telephone and internet services made possible through electricity powering telecommunication and fibre networks
- Potential to improve food security by enhancing agricultural productivity and local sustainable food production
- Potential to replace dirty solid or liquid fuel cookstoves with electric-powered cooking (Lombardi et al. 2019)

For rural, unelectrified contexts, electricity from a grid or off-grid renewable source offers a cleaner and more flexible alternative to fuel energy.[1] At the point of the end-user, electricity emits zero pollution emissions. Fuel for cookstoves or kerosene lamps causes air pollution (which results in health and environmental harms) and costs either time or money to source (Booth 2014). In many cases, gathering fuel also produces environmental harms such as deforestation and biodiversity impacts.

Energy use is inextricably related to economic growth and development, which are strongly correlated at national levels.

1 Renewable sources of energy generally include solar, wind, hydroelectric, and geothermal. Fuel energy refers to generation from fuel oil, kerosene, or coal. Biomass—including wood and charcoal—is a renewable resource derived from vegetation, which can power electricity generators or cookstoves under a similar principle to thermal fuel (often with associated local air pollution).

Over the next decades, most growth in energy demand is predicted to occur in low-income countries (Wolfram et al., 2012). Sub-Saharan Africa, in particular, is expected to experience higher economic growth, and expansion of electricity systems and consumption (see Figure 1). Demand projections suggest that total installed generation capacity needs to reach 292 gigawatts (GW) in 2030 across the region (Multiconsult and AfDB 2018). The IEA's sustainable development scenario projects that for Africa (including North Africa) installed power capacity would need to reach 497 GW, about 20 per cent more than a business-as-usual growth path. Nonetheless, most Africans will continue to depend on biofuels for energy in coming decades (Calvin et al. 2016). This heightens the need for policy and investments to consider efficient and sustainable designs for the future power networks and generation technologies of least-developed countries.

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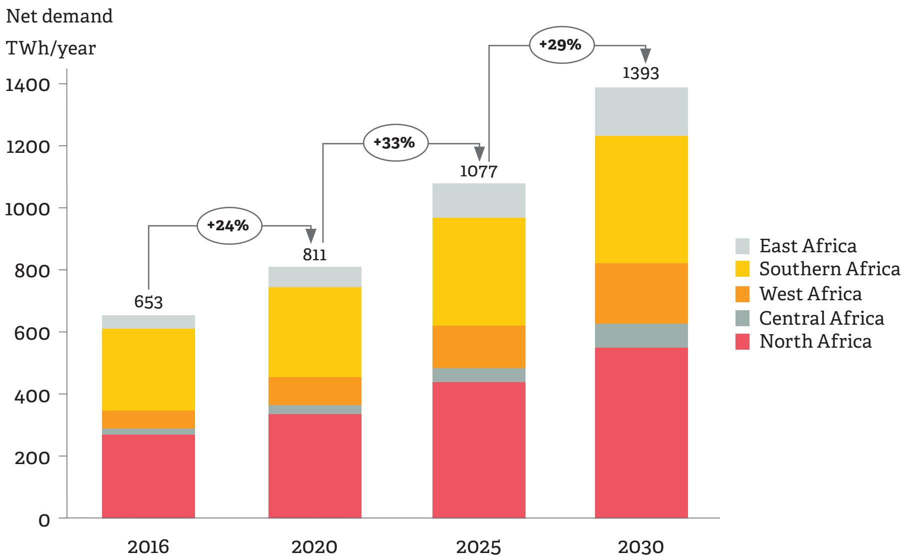

Figure 1: Forecasted net electricity demand in Africa, by region to 2030 (Source: Multiconsult and AfDB 2018. Roadmap to AFDB's New Deal on Energy for Africa. Report to the African Development Bank)

1.2 How can investments in the electricity value chain lead to developmental impact?

Investments can target five different segments of the electricity sector:

- **Utility-scale independent power projects to build generation capacity** (utility scale typically refers to a generation plant above 5 or 10 megawatts (MW), depending on local context)
- **Transmission grid projects** to extend or boost capacity to transport high-voltage electricity from large production centres to important load centres, as well as interconnections that can open up cross-border power trade
- **Distribution grid projects to strengthen local networks and build connections** to new customers in a district, including households, industries, and enterprises
- **Off-grid projects** to allow production and distribution of electricity at a local village or individual customer level, before (or in parallel to) the arrival of a centralised electricity grid in the area
- **Technology investments that underpin or support** the quality, reliability, and viability of the above segments, such as battery storage, smart meters, and prepayment or mobile payment mechanism.

Generation and transmission projects have several direct outcomes: they broadly increase the capacity of the system to meet existing, latent, and projected demand, which improves the availability and reliability of electricity, and reduces downtime. Contingent on technologies, cost structure, and factors such as regional trade potential, generation and

Adding generation capacity in a developing country can have significant effects on the quality and reliability of grid services.

transmission investments are essential to shape a cleaner energy mix. They do this by integrating greater shares of renewable energy and lower-emission generation. The financial viability of electricity systems depends on efficient, well-maintained, least-cost generation and transmission; new projects can alleviate the utility's financial burden by lowering overall costs and reducing losses (including by allowing them to retire more expensive generation plants). Adding generation capacity in a developing country can have significant effects on the quality and reliability of grid services. With sufficient generating power, the utility can operate with fewer outages. Similarly, investments in transmission and distribution infrastructure can shore up grid reliability, which affects household and industry energy use, expenses, and other areas including productivity and leisure.

Distribution investments, first and foremost, extend electricity connections to new customers, and strengthen or maintain the existing grid capacity, offering individuals and businesses access to modern energy. The quality of electricity delivered through a distribution network essentially relies on the capacity and reliability of transmission and generation segments to supply the power, although distribution businesses can also generate power themselves. Distribution connections have a complex relationship with the system's financial viability, however. While connecting new customers can increase a utility's revenue and growth, newly-connected customers seldom present sufficient demand to be profitable to the system.[2] Sometimes, new connections pose an overall burden to the utility's financial viability, notably when the cost of extending the grid is not recovered by subsidised connection fees (Lee, Miguel, and Wolfram 2019). The growth of grid-tied rooftop solar PV also poses new challenges for distributors who have to recover the cost of network infrastructure with lower grid electricity sales.

As solar PV and battery prices fall, businesses and higher-income households may choose to go off-grid, especially where grid electricity is expensive and unreliable.

Off-grid projects offer electricity services to new customers that the main utility can't or won't serve—generally remote or poor populations that receive few modern infrastructure services. As solar PV and battery prices fall, businesses and higher-income households may also choose to go off-grid, especially where grid electricity is expensive and unreliable. Solar home systems can be especially attractive to replace diesel generators (or gensets), which are expensive yet widely used among high-income households and businesses in regions with low electricity reliability (Akpan, Essien, and Isihak 2013; Energy Sector Management Assistance Program 2019). Off-grid projects span a range of technological solutions and business models, from pico-solar products, individual solar household systems, micro/mini-grids, and systems for productive uses for local commercial or industrial uses, such as agriculture and food processing (Mandelli et al. 2016). Off-grid solutions can be designed to power basic loads, such as lighting and phone charging—the prevailing uses for newly-connected rural customers in developing countries—but bolstering the capacity of micro/mini-grids can address higher order household applications like televisions, fans, and refrigeration, as well as cooking with electric stoves (Lombardi et al. 2019; Taneja 2018). Mini-grids can also serve productive loads, including to power agricultural applications, local industrial installations, small manufacturing, and micro-enterprises (Pueyo and DeMartino 2018).

Advanced metering and payment technologies are improving billing efficiency, customer service and utility bill collection rates throughout grid distribution systems.

Technological innovations—or enablers—allow various grid-and off-grid systems to support technical and financial outcomes. In particular, battery storage help off-grid renewable-powered systems to provide extended hours of electricity and ensure predictable supply. Storage systems strengthen grid stability against the variability introduced by high levels of renewable penetration. Costs of battery technologies for small and large applications are falling across technologies (Few, Schmidt, and Gambhir 2019). Other technological innovations have an impact on the consumer-provider relationship. Advanced metering and payment technologies are spreading throughout grid distribution systems to improve billing efficiency, customer service, and utility bill collection rates. Smart meters increase the accuracy and efficiency of consumption metering; mobile payment offers customers convenient and accessible payment methods; and prepaid meters reduce

2 In remote, poor regions that receive access to the grid, consumers typically have little access to markets and low buying power to invest in new appliances needed to increase electricity consumption, and may have little knowledge about the benefits of using electricity for lighting, cooking and other applications

bill collection costs and losses for utilities, while allowing poor customers to manage consumption costs in smaller chunks. 'Internet of Things' (IoT) technology can be used to facilitate data collection in off-grid systems to analyse appliance use, model future demand growth, and develop efficient, affordable appliances to meet users' needs (Bisaga et al. 2017). Demand-side interventions are also important, such as programmes promoting energy efficiency investments, or load-shifting away from expensive peak periods. Other interventions include establishing markets for large electricity users to temporarily curtail demand to balance the power system, or to provide ancillary services for frequency and voltage control. These outcomes improve the financial sustainability of a power system and can also improve the affordability of electricity (Jack and Smith 2017, 2015).

In Section 2, we present a mapping of evidence revealed through an extensive literature review, covering macro- and microeconomic impact, individual, social and community impact, and environmental impact. Section 3 assesses the role of private investment in infrastructure, Section 4 reviews the enabling political factors and Section 5 proposes several avenues for further research. Appendix 1 explains the methodology for the evidence review.

02

Mapping evidence

In the following section, we overview the direct outcomes of electricity infrastructure development in different segments of the power system, such as improving quality and capacity of energy in a system, decarbonising the energy mix, and making a system more financially sustainable (section 2.1). We discuss the types of impact observed at macroeconomic level from power sector development (section 2.2), before examining microeconomic impact (section 2.3). We then present findings on the relationship of electricity service delivery with other measures of social wellbeing (section 2.4), and address the environmental impacts of electricity (section 2.5).

Assessing the impacts of electricity infrastructure investments requires an analytical framework and sufficient empirical evidence. We identify 63 evaluations of impact from the past 15 years through our literature search (in addition to 24 developing country analyses of macroeconomic growth and energy consumption assessed in a systematic review by Lemma et al. (2016)).[3]

In the course of this research, we categorise impact broadly following conventions adopted in the literature, according to four different—although unavoidably interrelated—categories. These distinctions are open to interrogation, due to their inter-reliance or mutual dependency, and integrated approaches are key; focusing on any single development indicator while neglecting or damaging another would be counterproductive in the long run. Nonetheless, simplifying such complex and wide-reaching questions is essential to facilitate understanding. We distinguish between typically **macroeconomic** questions (economic growth, employment creation, and improvements in overall productivity and skills) and **microeconomic** impact, which is observed at household or community level (increasing household income, expenditure, and consumption; reducing energy expenditures; changing time allocated to work and chores; increasing appliance ownership; affecting migration to the community; and so on). We observe a separate category for **individual**, **social**, and **community wellbeing** measures, which encompasses health outcomes, children's

3 See Appendix 1 for more detail of the literature search and analysis process

education, women's empowerment, access to entertainment, perceived sense of safety and life satisfaction. Finally, we treat **environmental** questions in a fourth category, which includes climate mitigation, resource use, and pollution and waste management.

2.1 Macroeconomic indicators

Electricity use—and energy more broadly—is highly correlated with various measures of economic performance. This section discusses evidence on the relationship between the power sector and economic growth, and follows with an overview of evidence on job creation and productivity.

Economic growth

The correlation between economic growth and energy use—and in particular electricity consumption and access—has been closely studied to unearth the pathways and causal links at work. Energy is essential for production and transport of materials, goods, and people, presenting either a defining constraint or opportunity for economic growth and development. As discussed above, electricity offers more efficient, productive, and flexible uses for industries than other forms of energy. With rising national income, the share of electricity in total energy tends to increase; this is also observed among individual consumers, who tend to consume higher quality energy in the form of electricity as household income rises (Csereklyei, Rubio Varas, and Stern 2016; Benthem and Romani 2009). But it remains difficult to make a conclusive universal claim on the direction of this relationship. While the availability of reliable, competitively priced electricity can spur economic growth in some contexts, in others, economic growth is found to stimulate electricity demand. Three recent papers in the grey literature review analyse the causality between energy and GDP (Stern et al. 2017; Lemma et al. 2016; Attigah and Mayer-Tasch 2013). They underline the importance of investigating how the quality of electricity supply affects economic outcomes.

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While the availability of reliable, competitively priced electricity can spur economic growth in some contexts, in others, economic growth is found to stimulate electricity demand.

Lemma et al. (2016) identify 42 econometric studies that test these hypotheses across developing country contexts. They show a wide range of conclusions varying by time period and country, and finding no prevailing hypothesis. The paper presents four hypotheses to describe this relationship: 'neutrality' (no causal link exists between the two, meaning any correlation is a result of external factors); 'conservation' (economic growth has a unidirectional causal effect on increasing energy consumption); 'growth' (increasing energy consumption has a unidirectional causal effect to increase economic growth); and 'feedback' (a bidirectional causal link exists between energy consumption and economic growth, suggesting that variation in energy consumption will affect the rate of economic growth, and vice versa). Of the studies reviewed, which examine 114 individual cases of energy and economic growth in dozens of low and middle-income countries—over three-quarters support the existence of some kind of causal relationship between the factors. This includes 29 per cent for 'conservation' hypothesis; 23 per cent for 'growth'; and 26 per cent for 'feedback'. Attigah & Mayer-Tasch (2013) similarly review the literature showing mainly positive impact of electricity use and quality for firm productivity, but find these effects to be highly specific to the country and economic context of the study.

In Africa, for example, Wolde-Rufael (2006) examines the causality of the relationship for 17 countries in a 30-year time span, and finds different causal relationships across the sample: five countries exhibit no causal relationship; in nine others he finds a causal relationship in one or other direction; and the remaining three countries show evidence of a bidirectional relationship. A later analysis of the same question, including labour and capital, offers evidence to reject the neutral hypothesis for 15 of the 17 African countries, implying energy is a significant factor in economic growth for those cases, albeit secondary to labour and capital (Wolde-Rufael 2009).

Stern, Burkes, and Bruns (2017) highlight the likelihood of publication bias affecting the number of statistically significant findings on energy use and economic growth, and caution against drawing overarching conclusions.

Changes in electricity use could have various causes that in turn imply various effects on GDP. For example, improving energy efficiency would reduce electricity use—before any eventual rebound effect on consumption (Allcott and Greenstone 2013)—and also increase GDP. By contrast, increasing electricity prices would reduce consumption, while also reducing GDP. At the same time, changing energy prices can affect GDP along various pathways, such as by affecting firm operating costs and, by extension, productivity, or by incentivising substitution of inputs to production or investments in manufacturing, agriculture, and other industries. These pathways should be examined separately to establish causality.

Evaluations of DFI electricity investments in developing countries have shown significant impact on GDP, and the effect is especially great in low-income countries with small, costly electricity grids. After 70 MW of grid generation investments in Senegal, GDP rose 1.7 per cent due to the lower cost and greater availability of power, which reduced economic constraints and allowed job creation (Steward Redqueen 2017). Uganda's GDP increased by 2.6 per cent as a result of improvements in the electricity system, including the commissioning of a 250 MW hydropower plant (Steward Redqueen 2016b). By contrast, a lower-middle income country with a more developed electricity system, Uruguay, saw GDP increase by €3.3m ($3.7m, a tiny fraction of GDP), and electricity prices reduced by 1.3 per cent as a result of adding 50MW of power on the grid (Steward Redqueen 2016a).

Electricity has a significant impact on GDP and effect is especially great in low income countries with small and costly electricity grids.

Jobs and labour markets

Power sector development indirectly contributes to generating employment through supplying lower-cost, efficient, and reliable electricity (Steward Redqueen 2016a; Datta et al. 2012; Dalberg 2012). Recent evaluations estimate that electricity infrastructure investments directly generate new jobs due to construction and operation, but the greatest employment effect is through supporting the creation of jobs due to increased business productivity. Estimated multipliers for jobs created range from 6.5 jobs/MW in Uruguay, 226 jobs/MW in the Philippines, to 761 jobs/MW in Senegal (Steward Redqueen 2017, 2016a).

This can imply major effects on employment. In the aforementioned case of Senegal, almost 70,000 jobs were estimated to be created or induced by the development of 90 MW of added capacity on the grid. Another Private Infrastructure Development Group (PIDG) investment in Uganda contributed over 9,600 jobs (Scott et al. 2013), while improvements in the country's power sector from 2011 to 2014 are calculated to have allowed over 200,000 jobs to be created (Steward Redqueen 2016b). Job creation due to power capacity addition is much greater in low-income than higher-income countries, as might be expected from the diminishing marginal gain on overall generating capacity and reliability (MacGillivray et al. 2017).

Power sector development indirectly contributes to generating employment through supplying lower-cost, efficient, and reliable electricity to power economic activities.

Productivity

Improving electricity infrastructure by increasing generation and transport of energy typically has powerful effects on economic output. This is particularly the case in sectors highly dependent on reliable power supply, notably manufacturing, trade, transport, and services. Outages reduce operating time and production for economic activities that rely on electricity, and may impose additional burdens such as restart costs, equipment damage, and spoilage of materials in the course of production (Steward Redqueen 2016a). Many developing countries suffer from unreliable power because of insufficient grid capacity and chronically under-maintained transmission (Lee, Miguel, and Wolfram 2017). Improving electricity supply reliability in these contexts can significantly stimulate productivity, catalyse industrialisation, and reduce production costs (Andersen and Dalgaard 2013). However, the extent of negative impact from deficient energy infrastructure varies across countries, sectors and company sizes. For example, in India, Muneeza M. Alam (2013) finds that electricity-intensive rice mills adapt production in the case of outages, reducing their output losses by purchasing more production inputs. However, steel mills cannot make such adaptations and suffer greater productivity losses. Cissokho

Many developing countries suffer from unreliable power service because of insufficient grid capacity and chronically under-maintained transmission.

(2019) finds that power outages have significant negative impact on small and medium enterprises in Senegal, but those firms that can afford to invest in a generator can offset the impacts.

When faced with power outages or poor reliability, firms adopt various coping mechanisms to mitigate the higher short-term costs of production. Investing in standalone backup fuel generators is a common recourse when the increased costs from self-generation are preferable to forgoing production until electricity comes back on (Akpan, Essien, and Isihak 2013; Fisher-Vanden, Mansur, and Wang 2015). Allcott, Collard-Wexler, and O'Connell (2016) find that reliability problems and power shortages reduce manufacturing output in India by five per cent on average, but firms with backup systems are not as affected as those without. Unable to benefit from economies of scale in self-generation, smaller firms are the most impacted. Alternatives to self-generation include investing in more electricity-efficient technologies such as those that allow faster production when power is available, or substituting intermediate impacts to their production by buying semi-finished goods (side-stepping power-intensive manufacturing steps) (Lee, Miguel, and Wolfram 2017).

Supplying electricity to previously-unconnected regions has been found to stimulate the level of competition and firm turnover, favouring more productive firms (Kassem 2018). In India, increasing electrification is found to increase manufacturing productivity by 14 per cent, alongside more factories and higher output among smaller firms (Rud 2012). And to the extent that electricity infrastructure investments reduce electricity prices, this stimulates growth of economic activity (Steward Redqueen 2016b). However, these effects are also contingent on economic and cultural contexts.

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2.2 Microeconomic impact

Most evidence examining the impact of electricity at a microeconomic level studies electrification of remote, rural communities, which tend to be the last remaining populations yet to receive modern electricity access (Aklin et al. 2017; van de Walle et al. 2017; Akpan, Essien, and Isihak 2013; Rom, Günther, and Harrison 2017; Sharma et al. 2019; Lee, Miguel, and Wolfram 2019). But similar to macroeconomic dynamics, the causal relationship between electricity use and economic development in rural areas and at household level is complex and depends on contextual details that can be difficult to capture in data, much less generalise between countries and regions (Riva et al. 2018).

Consumption of energy and other goods, costs, and ownership of appliances

While overall household consumption tends to increase over time after gaining access to electricity (Khandker et al. 2014; Peters et al. 2014; van de Walle et al. 2017), consumption growth is not linear in newly-electrified communities, especially when it comes to energy use. Consumers change habits incrementally over time depending on various factors, including their income-generating activities, household economy, education, and social norms (Bisaga and Parikh 2018; Gertler et al. 2013). Rural electrification is usually followed by low consumption rates and limited electricity demand. This therefore requires energy efficient measures and the introduction of affordable appliances. (Khandker, Barnes, and Samad 2013; Lee, Miguel, and Wolfram 2019). New rural power consumers in Africa, in particular, tend to continue using traditional forms of energy for cooking and also lighting while introducing electricity, a practice known as energy stacking. Overall energy costs may not decline significantly for such consumers, especially as usage habits change and electricity consumption grows to power new appliances (Lee, Miguel, and Wolfram 2016). Alkon, Harish, and Urpelainen (2016), analysing consumption data in India, find that both poor and wealthy households spend more on energy when high quality energy is available in the form of cleaner fuels and electricity.

Appliance ownership is an important constraint to consumption, which is in turn constrained by household income, as well as habits, education, and access to other infrastructure services. Consumers must prioritise immediate survival needs—notably water, sanitation, lighting, and food—before turning their attention towards higher-order aspirations that require higher electricity

Appliance ownership is an important constraint to consumption, which is in turn constrained by household income.

consumption, such as appliance ownership for entertainment or time saving (Parikh, Chaturvedi, and George 2012). The consumption patterns between rural and urban areas after electrification are likely to differ dramatically due to gaps in knowledge of appliances, as well as access to markets, among rural populations. Rural households in India gradually invest in new appliances over time as they become accustomed to electricity use and save sufficient income, but the rate of purchase is slow (Richmond and Urpelainen 2019).[4]

Household incomes, expenditure, and housing values

Evidence from 18 studies finds electrification has significant effects on household incomes, notably in the long run, and sometimes with spill-over effects at a village level (Dinkelman 2011; IOB 2014; Peters et al. 2014; Khandker et al. 2014; Lipscomb, Mobarak, and Barham 2013; Barron and Torero 2014; Barman et al. 2017; Arnaiz et al. 2018; van de Walle et al. 2017). Household incomes can grow progressively thanks to the economic opportunities afforded by electricity, including access to wage labour and new or increased entrepreneurship, such as working in the evenings. Larger systems that can provide for evolving consumption, such as through the grid or a local mini-grid, are more likely to significantly impact incomes in this way. Recent evaluations of solar home systems and pico-solar systems find low to moderate evidence of income growth (Sharma et al. 2019; Samad et al. 2013; Grimm et al. 2017; Aklin et al. 2017).

Household incomes can grow progressively thanks to the economic opportunities afforded by electricity, including access to wage labour and new or increased entrepreneurship, such as working in the evenings.

A handful of studies find varied effects on land value and migration in and from electrified communities. Changes in housing stock or asset value following electrification would suggest increased household income and expenditure. Parikh et al. (2015) show that providing electricity and other infrastructure services in Indian slums acts as a driver to increase land value and upgrade households—but less so for women-majority households, possibly due to women's lower education and employment levels. Also in India, Burlig and Preonas (2016) find that the national rural electrification programme has no significant effect on improving or investing in housing stock. In Brazil, Lipscomb, Mobarak, and Barham (2013) find large positive effects of electrification on average housing values after grid expansion from new hydropower dams. If an electrified community experiences growing incomes coupled with productivity and wage labour availability, it would be reasonable to observe growing in-migration rates. Despite increased land values, however, the study in Brazil finds no evidence of increasing in-migration to electrified communities. This finding is mirrored by an evaluation of electrification in Tanzania (Chaplin et al. 2017). Qualitative evidence in Bangladesh suggests increased migration to electrified communities (Barkat et al. 2002), while reduced rates of out-migration from villages is observed following electrification in South Africa (Dinkelman 2011).

Larger systems that can provide for evolving consumption, such as through the grid or a local mini-grid, are more likely to significantly impact incomes.

In their recent controlled trial of grid electrification in rural Kenya, Lee, Miguel, and Wolfram (2019) find that claims for increased household welfare might be overstated. The cost per connection for grid electrification is found to overshadow poor rural customers' willingness to pay for electricity—a cost that is not expected to be recovered for many years following electrification. This adds weight to arguments for providing a first-step access through low-cost individual solar solutions and building demand before developing larger supply systems in rural areas. Peters, Harsdorff, and Ziegler (2009) suggest that complementary services such as business development and customer awareness campaigns are essential in ensuring uptake of electricity among potential new customers in a grid extension (in rural Benin).

Entrepreneurship, time allocation and workforce participation

Local productivity, work hours and labour force participation can benefit from availability of electricity in the community, both at industrial scale and in off-grid contexts (Rud 2012; Kassem 2018; Harsdorff and Bamanyaki 2009); but findings on this impact are mixed overall. Women's labour productivity and opportunities seem to especially benefit from electrification across multiple contexts to varying extents and in varying ways (see section 2.3). But electricity does not automatically lead to improved profits or creation of new enterprises. The impact on entrepreneurship, work and time allocation vary widely across contexts and even among similar modes of electricity provision.

The impacts on entrepreneurship, work and time allocation vary widely across contexts and even among similar modes of electricity provision.

4 Richmond and Urpelainen (2019) find that for every additional year after electrification in Indi, a household is likely to own 1.1 per cent more total appliances..

A handful of studies consider the effects of electrification on businesses and working time in India. Khandker et al. (2014) find that grid electrification allows rural businesses to stay open for longer and to harness more productive uses of energy. On the other hand, Burlig and Preonas (2016) find the Indian national rural electrification programme has mitigated effects on employment or labour markets. Millinger, Mårlind, and Ahlgren (2012) find users reallocate time to more productive activities thanks to electrification from solar mini-grids, but businesses do not show evidence of growth. An evaluation of mini-grid systems in India also finds no significant effect on business creation and profits, nor on time use among customers (Aklin et al. 2017).

Significant evidence from rural Kenya also offers a complicated picture. With grid extension, business performance improves in the long term (Vernet et al. 2019), and people spend more time in income generating activities (Lee, Miguel, and Wolfram 2019). But for off-grid systems, the results are contradictory. An evaluation of solar home systems finds that solar lights enable longer operating hours and higher profits in existing micro-enterprises (Harsdorff and Bamanyaki 2009), while another study offers evidence that micro-grids enable business growth (Kirubi et al. 2009). A more recent result on Kenyan business performance tells a different story: local businesses exhibit neither higher productivity nor income growth after connecting to a solar mini-grid (Pueyo and DeMartino 2018; Harsdorff and Bamanyaki 2009).

Larger villages gaining electricity access in Rwanda and Benin also show evidence of business growth (IOB 2014; Peters, Vance, and Harsdorff 2011). Greater time availability in Rwanda allows consumers to run more home-based businesses in one study (Peters et al. 2014), while another finds only weak effects on business growth, and no significant change to people's time availability (Lenz et al. 2017).

Off-grid studies also shed light on the effect of mini-grids and solar home systems on business behaviour and personal time use. Micro-hydropower systems in Bolivia and the Philippines enable businesses to invest in new electric-powered machinery and operate during night-time hours (Arnaiz et al. 2018). Even solar lighting devices can improve business performance, for example in Ghana (Obeng and Evers 2010). Conversely, microenterprises in Nepal that connect to micro-hydro mini-grids show no significant difference in profitability compared to non-connected enterprises (which rely on diesel for energy) (Banerjee, Singh, and Samad 2011). Similar results are found in Nigeria (Akpan, Essien, and Isihak 2013).

Some studies mentioned do not show a significant productivity improvement at a local level, while others do. The variation in results should be interrogated through multiple angles, including methodological differences, study design and specific field of study. In some cases, selected study timeframes may not afford sufficient time to reveal the studied impact, especially in the case of small-scale interventions and off-grid sector. Cultural and economic contexts could also account for variations in specific cases (e.g. perhaps electricity supply helped improve business efficiency, allowing entrepreneurs to increase output efficiency, but did not stimulate demand or market growth, therefore no significant change in productivity). The studies mentioned discuss their findings and consider underlying causes in more detail.

Distributional effect and poverty reduction

Many studies examine measures of indirect poverty reduction as a result of electricity provision, especially through business growth and job creation in the community. As discussed in previous sections, there is good evidence showing growth in businesses and jobs after various kinds of electricity service are offered.

Several studies also directly consider measures of poverty reduction. This includes the change in number (or proportion) of poor households in the group following the intervention, as well as the distributional effect of access to electricity in a population group: whether it benefits the poorest as well as wealthier members. One study assesses improvements in working conditions and access to goods and services as indicators of poverty reduction. Although rural electrification investments and programmes ostensibly target very poor, low-income populations, the benefits that accrue from community electrification investments are liable to be distributed unevenly among the target community as well as between communities of different income levels (Adusah-Poku and Takeuchi 2019). Poorer households face steeper affordability barriers that impede their uptake of electricity schemes. For instance, Khandker, Barnes, and Samad (2012) find in Bangladesh that when a village is electrified, higher-income households benefit significantly more than their poorer counterparts due to prohibitive connection fees.

Poorer households face steeper affordability barriers that impede their uptake of electricity schemes.

2.3 Social, community and individual wellbeing

In addition to—or in tandem with—economic impact, access to electricity affects various indices of individual, social and community wellbeing, including health, education, entertainment, and gender equality.

Health outcomes, access to information, and air pollution

Electrification affects health outcomes for individuals and their wider communities through improving access to services, access to information, and reduced risks. Many health facilities in rural areas have inadequate power supply to serve basic needs (Dholakia 2018), and spend large amounts on diesel generators to power basic equipment needed—in Rwanda, diesel generators cost three times more to run than grid electricity (Lenz et al. 2017). Once electrified, they can offer improved services with cooling for medicines, and can attract more qualified personnel thanks to the improved quality of living afforded by electricity. In Tanzania, for example, connecting to the grid was observed to increase the share of households receiving health information, thanks to enhanced radio and television connectivity (Chaplin et al. 2017).

Electrification affects health outcomes for individuals and their wider communities through improving access to services, access to information, and reduced risks.

Electricity reduces respiratory disorders and the risk of fire in displacing kerosene lamps and cookstoves. Millions of unconnected households across sub-Saharan Africa and South Asia still use kerosene lamps for lighting, with well-known adverse impact on health (Mills 2016; Obeng et al. 2008). Fuel-based lamps can also trigger accidents, causing burns and even major fires (Lenz, Montenbruck, and Sievert 2018). However, strong trends are taking shape to replace kerosene with battery-powered LED torches, in advance of more sophisticated electrical solutions such as solar home systems.

Education and children's use of light

Evaluating children's study time is among the most commonly-measured outputs of electricity impact evaluations: 29 of the 70 studies in the sample report on this metric. The vast majority, 83 per cent, find a positive impact on the time children spend studying in the evenings (Lipscomb, Mobarak, and Barham 2013; van de Walle et al. 2017). For example, Barron and Torero (2014) use experimental methods to study the time allocation effects of grid electrification in El Salvador, finding significant increases in children's study time (as well as positive effects on health outcomes due to reduced kerosene pollution). Examining the night-time activities of users after gaining off-grid solar lighting in Senegal, Bensch, Peters, and Sievert (2013) also find children study for longer; similar results are found from solar lamps through a randomised trial in Kenya (Hassan and Lucchino 2016).

83%

Evaluating children's study time is among the most commonly-measured outputs of electricity impact evaluations. The vast majority, 83 per cent, find apositive impact on the time children spend studying in the evenings.

These findings are challenged by three recent randomized trials: one, on pico-solar lamps in Uganda, finds that despite additional time spent studying, children's test scores decrease after the intervention; an evaluation of micro-grids (for lighting and phone charging only) in India finds no benefits for children's study time; nor does a grid programme in Kenya (Furukawa 2014; Aklin et al. 2017; Lee, Miguel, and Wolfram 2019).

Gendered use of energy and women's empowerment

Clean and efficient energy services tend to benefit women disproportionately. Homes remain typically women's domains especially in rural areas of developing countries, where agricultural work is often a male domain (Cabraal, Barnes, and Agarwal 2005). Strong evidence supports the link between energy poverty in the household and women's health burdens, education, and access to information (Winther et al. 2017). Conversely, electricity access has been shown to reduce women's time spent in 'drudgery' or domestic work in South Africa through grid electrification (Dinkelman 2011), and in Bolivia and the Philippines through micro-hydro mini-grids (Arnaiz et al. 2018). Gaining access to electricity tends to increase access to information and entertainment, which can ultimately empower women to engage more politically and in household and local-level decision-making (Matinga and Annegarn 2013). Much of this evidence is produced in South Asia, examining grid electrification both in rural areas and in urban slums (Millinger, Mårlind, and Ahlgren 2012; Khandker et al. 2014; Samad et al. 2013; van de Walle et al. 2017; Parikh et al. 2015). In Central America, women see a significant boost to workforce participation after their community receives electricity, especially in non-agricultural employment (Barron and Torero 2014; Grogan and Sadanand 2013; Dasso and Fernandez 2015). A randomised experiment investigating the socio-economic effects of solar micro-grids in India found no effect on women's employment or social status (Aklin et al. 2017).

Clean and efficient energy services tend to benefit women disproportionately.

Whilst productive uses of electricity can help alleviate household chores and even free up time for leisure, the idea of 'productivity' in energy use embeds its own gender bias. Its primary focus is on 'male' forms of production—as industry and commerce—which in many contexts exclude women (Pueyo and Maestre 2019). Controlling for gender differences in household labour, Salmon and Tanguy (2016) find that while men enjoy economic benefits from electrification, their gains can come at the expense of their wives' working time. In India, Parikh et al. (2015) find that women tend to benefit less than men from labour market improvements in urban slums that receive upgraded electricity, sanitation and road infrastructure services. While improving infrastructure improves outcomes for women's health and education, their wages and labour market participation do not significantly change. Scholarship on gender differences in electricity use has also overlooked the importance of businesses in offering labour opportunities and income generation for women, where women's interest in electricity is predominantly understood to be in the home. Rural marketplaces can reflect this bias, often catering directly to men's needs. The benefits of electricity for domestic productivity and time-saving are routinely incorporated into measures of electrification. But given that men predominantly serve as household decision-maker, off-grid electricity service providers and markets continue to cater to them. For instance, leisure items (such as TV and radio) are often given higher priority on the supply side than time-saving appliances like electric cookstoves.

Life satisfaction, wellbeing, sense of safety, and entertainment

In a handful of studies, regardless of income gain or even the size of the system, individuals report lower stress levels and greater life satisfaction following an electricity intervention or investment (Scott et al. 2016; IOB 2014). These effects stem from households' growing access to entertainment through television and radio (Bernard and Torero 2009; IOB 2014), as well as the new opportunities to socialise among family and neighbours in the evenings. Not only quantity but quality matters, too, when it comes to evaluating satisfaction. A survey of over 8,000 Indian households finds that households report greater satisfaction with longer hours of lighting (Aklin et al. 2016). Four studies relating to grid and off-grid electrification programmes in sub-Saharan Africa report increased measures of life satisfaction, in Kenya (Vernet et al. 2019; Lee, Miguel, and Wolfram 2019) and Rwanda (Peters et al. 2014; IOB 2014). Solar home systems in Bangladesh are found to lead to improved quality of life and socialising (Urmee and Harries 2011). Mini-grids enable households to grow their perception of status in Bolivia and the Philippines, as well as to improve their sense of safety in the community (Arnaiz et al. 2018).

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Electric lighting is also found to also improve the sense of safety in studies from rural Senegal (Bensch, Peters, and Sievert 2013), Tanzania (Chaplin et al. 2017), Rwanda (Lenz et al. 2017), Uganda (Steward Redqueen 2016b), and South Africa (Matinga and Annegarn 2013). Studies in India and Sri Lanka also report improved sense of safety among participants following electrification through the grid or off-grid systems (Khandker et al. 2014; Sovacool 2013).

2.4 Environmental and climate factors

Electricity production and heating contributes the largest share of greenhouse gas emissions by sector, globally, almost entirely due to fossil fuel generation. Coal-fired electricity generation accounts for 30 per cent of global carbon dioxide emissions—most of which is now found in Asia, where average plants are only 12 years old (decades younger than their economic lifespan) (IEA 2019). Increasing electricity production in India, for example, makes up half of the country's emissions growth from 2017 to 2018. In Africa, 39 per cent of emissions can be attributed to anthropogenic sources, grouping energy, industrial, and waste sectors (Valentini et al. 2014). Nonetheless, poor African and Asian countries produce a fraction of the carbon emissions generated by their developed country peers (see Figure 2). The entire African continent produces little over a third of the emissions of the EU-28 countries—although the population of Africa is over twice as large.

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African emissions from energy use are forecast to rise rapidly due to economic growth, though this will be strongly influenced by political and technological choices (Calvin et al. 2016). Global warming, hastened by greenhouse gas emissions, is widely considered a primary threat to livelihoods, food security, and political stability, most particularly across the developing world (Tumushabe 2017; Busby et al. 2018; Raleigh and Urdal 2007). Retiring fossil fuels as technologies for generation and process heating, combined with sustainable decarbonisation across other economic sectors, are essential to keep global temperature rise within 1.5 degrees. This includes limiting the development of new fossil fuel generation plants worldwide. In particular, wealthy countries (which historically produced and continue to exacerbate the conditions leading to climate deregulation) must urgently cut their GHG emissions to achieve this (OHCHR, 2019; Oxfam, 2015). Reducing emissions in the energy sector through cost-effective investment in renewable energy generation offers a huge opportunity to mitigate global warming while contributing to meet global development goals.

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Rising temperatures and decreasing water availability as well as growing severity of storms, flooding, and sea level rise also make the energy sector vulnerable to the destabilising effects of climate change (Gerlak, Weston, McMahan, Murray, & Mills-Novoa, 2018). This is already evident in falling levels of hydropower capacity due to increasing droughts in African countries, and in frequent power outages during heatwaves in major manufacturing centres in Asia (Verisk Maplecroft, 2018b). Increasing temperatures burden electric grids with higher loads (Dirks et al., 2015). Grids are especially vulnerable in the event of natural disasters, with risks ranging from damaged infrastructure to supply chain interruption.

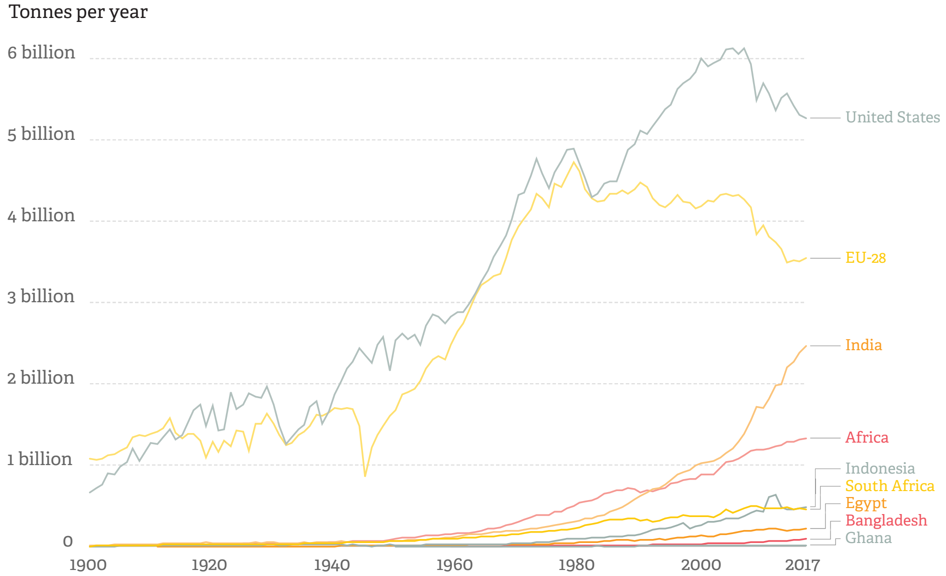

Figure 2: Annual carbon dioxide emissions by country/region (tonnes per year) (Source: Our World in Data, 2018 (from Global Carbon Project, Carbon Dioxide Information Analysis Centre))

Systemic and global environmental questions

Various technologies for electricity generation and supply contribute to mitigating or avoiding greenhouse gas emissions (collectively referred to as carbon or CO2-equivalent emissions). At utility-scale, low-carbon generation additions to a system can directly replace high-carbon thermal generation capacity, notably when the latter is expensive or will be retired. Renewable mini-grids (solar, micro-hydro, bio-mass) are deployed across rural and urban areas, offering potential to serve productive uses of energy as well as household uses (Alstone, Gershenson, and Kammen 2015; Energy Sector Management Assistance Program 2019), and displacing fuels used to power small industrial machinery. In regions with low electricity coverage or poor reliability, higher-income households and businesses often have recourse to running diesel generators (Akpan, Essien, and Isihak 2013; Barkat et al. 2002), which can be replaced by the grid or off-grid systems. At household level, mini-grids, solar home systems, and pico-solar lights replace polluting kerosene used for lighting and—in time—can replace fuel-based heating and cooking (Harrison, Scott, and Hogarth 2016; Lombardi et al. 2019; Apple et al. 2010; Shahsavari and Akbari 2018). Rural electricity systems are also increasingly likely to replace battery-powered torches, which are spreading across Africa to replace kerosene lamps (and use non-rechargeable dry-cell batteries) (Harrison, Scott, and Hogarth 2016).

Various technologies for electricity generation and supply contribute to mitigating or avoiding greenhouse gas emissions.

Local renewable sources combined with storage can diversify the energy mix, which enhances overall energy security and mitigates climate and political risks. Reducing hydropower dependency is especially important in regions that depend heavily on hydroelectric generation, and in those that face climate-related hydrological risk (Trotter, Maconachie, and McManus 2018).

Electrification through renewable power also poses operational challenges for grid management as well as increased need for baseload capacity. Solar and wind generation varies according to weather and climate conditions, with consequences for meeting demand (IRENA 2019). In the small power systems prevalent in sub-Saharan Africa, a relatively small addition of renewable generation can pose a greater challenge to grid stability than in more developed systems, where existing baseload capacity can absorb a higher share of intermittent power. Droughts in many African countries relying on hydropower have highlighted the need for reliable baseload generation to complement renewable technologies. This need can be met using high-efficiency combined-cycle gas generation to replace highly polluting coal or fuel-oil capacity. At scale, new battery storage technologies are low-emission options to convert intermittent renewable power into baseload.

Electrification through renewable power also poses operational challenges for grid management as well as increased need for baseload capacity.

Integrating demand-side flexibility and energy efficiency measures to increase response to variability in renewable energy generation are increasingly important pillars of energy strategy and climate policy. For example, smart devices and storage can be used to provide greater control over demand, as well as electrifying new sectors such as transport. In Nepal, predictions show that transitioning to electrified transport implies a 13 per cent reduction in emissions within three decades as well as a corresponding increase in electricity capacity (Shakya and Shrestha 2011). Energy efficiency will be the largest single contribution to meeting global climate change mitigation goals in the energy sector, causing over 40 per cent of reductions in emissions (IEA, 2018). Energy efficiency policies have already been successful in African countries, especially in more established systems, such as in South Africa and Egypt.[5] Ghana implemented a successful efficiency programme from 2012 to 2015, saving 2.4 GWh per year by replacing inefficient refrigerators and air conditioners (UNDP, 2014; Ghana Ministry of Power, 2015). This also saved customers significant costs on electricity bills, avoided associated carbon emissions, and freed up generation capacity to serve newly-connected households.

Energy efficiency will be the largest single contribution to meeting global climate change mitigation goals in the energy sector, causing over 40 per cent of reductions in emissions.

5 In the commercial and industrial sector, South African utility Eskom offers energy audits to advise customers on developing energy management action plans to increase efficiency. Local municipalities also have to develop energy efficiency strategies for demand-side management under the National Energy Efficiency Strategy of South Africa (2005). See http://www.eskom.co.za/sites/idm/EnergyAdvisory/Pages/EnergyAdvisory.aspx

Local environments, livelihoods, and deforestation

Electricity infrastructure investments can contribute to climate change adaptation, in addition to mitigating emissions. At household and community level, the availability of modern electricity services reduces dependency on fossil fuels. Electrical appliances like fans and air conditioning units have major benefits for resilience to climate change, although households must be able to afford them in addition to receiving electricity supply. Electricity access, moreover, facilitates livelihood adaptation to more sustainable activities that are less vulnerable to climate change. For example, electricity can enhance agricultural practices, such as with irrigation pumps (Rud 2012). Food processing can also benefit from electrification, including through using refrigeration. However, few studies explicitly discuss climate adaptation through electrification.

Electricity infrastructure investments can contribute to climate change adaptation, in addition to mitigating emissions.

At a local household or business level, gaining a new electricity connection can displace ambient pollution indoors by replacing kerosene lanterns (Obeng et al. 2008). At close range, the smoke causes respiratory damage, as well as producing intense greenhouse gas emissions (per lumen, compared to other light sources) (Rom, Günther, and Harrison 2017). LED torches powered by dry-cell batteries are also increasingly used in unelectrified areas to substitute kerosene lamps. However, disposal of their non-rechargeable batteries tends to occur directly into the local surroundings, such as in pit latrines or open fields. This creates serious chemical waste and poses a risk of groundwater pollution. Providing grid or off-grid systems—at any scale, from pico-solar and above—directly replaces such solutions and reduces pollution (Bensch, Peters, and Sievert 2017). However, e-waste management at the appliance's end of life, notably for pico-solar lamps and other battery-powered off-grid systems, remains a problem in developing countries (Few, Schmidt, and Gambhir 2019). Programmes to sell or distribute such technologies should consider these questions and put in place systems to manage them.

The productivity effects of improved energy delivery can have corollary impact on resource allocation and exploitation, including industrial inputs and organisation. A study in Brazil, for example, found that deforestation decreased in response to increasing electrification of agricultural inputs through hydropower plants (Assunção et al. 2016). Supplying electricity for agricultural inputs incentivises farmers to favour crop production activities (rather than cattle farming). Crops require less land use and therefore reduce net deforestation when cropping is favoured. In addition, electrification can reduce community dependency on wood and charcoal for fuel, which causes deforestation in some regions, notably East Africa, and contributes to air pollution in homes (Alfaro and Jones 2018). In this context, reliable and adequate electricity supply is especially relevant as a solution for the clean cooking sector (Batchelor et al. 2019).

03

Catalysing private investment in infrastructure with development finance

Development finance, guided by the principle of additionality, is directed towards accelerating private financing in essential sectors in developing markets. The cost of delivering access to sustainable energy to all the world's poor requires a mobilisation of over $1 trillion annual investment (SE4All, 2015). Private capital is increasingly flowing to developing and frontier markets, but in the latter, it remains insufficient to meet infrastructure needs, notably in the power sector (Collier, 2013). This creates a barrier to energy development across much of sub-Saharan Africa (Aly et al. 2019).

Development finance institutions' (DFI) investment strategies, exemplified by CDC's portfolio, target projects with high potential development returns (in terms of estimated outputs and outcomes for economy, government revenues, and infrastructure services) as well as higher investment risk (Dalberg 2017). DFIs can assume part of the risk directly through providing equity, concessionary debt or with security instruments such as guarantees and political risk insurance. This shapes a more palatable investment for private lenders, presenting a lower risk profile than a utility project in a frontier market would otherwise exhibit. DFI interventions are valuable in mobilising capital from other private investors: from 2012 to 2015, DFIs mobilised an additional $24 billion of private capital for projects in Africa (Benn, Sangaré, and Hos 2017). Out of the total funds mobilised globally, 25 per cent was allocated to the energy sector.

This strategy operates in two stages, by:

- Maximising the additionality of DFI funds, by ensuring an investment truly represents added value to the particular context, rather than substituting for, or competing with, another possible source of private investment
- Producing a demonstration or catalytic effect, by illustrating the feasibility and viability of a project in the sector and country in question. Investments aim not only to have successful implementation, but to offer encouragement for other investors to follow (Dalberg 2017).

$1 trillion +

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$24 billion

From 2012 to 2015, DFIs mobilised an additional $24 billion of private capital for projects in Africa. Out of the total funds mobilised globally, 25 per cent was allocated to the energy sector.

DFI loans that offer preferable financing terms to commercial lenders, or by financing a risky project where other lenders may not be willing to commit funds, contribute added value (Dalberg 2012). In some cases, DFI funds are so critical that a project may not be financed in their absence. DFI participation may represent a less critical component to some more mature projects with more experienced developers. Conversely, difficult projects can have the opposite effect, creating perceptions that the enabling environment is insufficient and creates overly burdensome transactions. On the other side of the transaction, a hobbled or failing DFI project can paint a negative image of private participation in project financing from the perspective of the government. The need to protect bilateral relationships with governments is a strong incentive for upholding project agreements, meaning that in some cases the mere presence of a DFI investor can add a 'halo effect,' where the risk of default on the project is lowered. DFIs are disinclined to threaten the stability of broader country lending programmes and political relationships, to avoid the need to trigger sovereign guarantees or more severe consequences for future lending or development assistance.

Investments from DFIs can spark a change in the 'investment climate' by introducing international private capital where previously it was scarce. The entry of other foreign investors to a transaction can also encourage companies to consider the market for investment.

Investments from DFIs can spark a change in the 'investment climate' by introducing international private capital where previously it was scarce.

DFI investments mitigate project finance risks by design. Legal uncertainty and currency fluctuations all impact project viability, and are common in developing markets, compounding the perceived political risks. These weaken the bankability of long-term contracts such as concessions or PPAs, as well as threatening contractual arrangements for land acquisition. With the halo effect of DFI investment, private financiers can come on board to participate in a project. Figure 3 shows revealing data on how the level of DFI financing tracks total private sector investments in independent power producers (IPPs) in sub-Saharan Africa since 1994. Rolling average investment grows over time. This offers preliminary evidence of the importance of DFI participation to underpin—and 'crowd in'—private capital for project development in high-risk environments, showing that private investments are unlikely to occur in the absence of donor investments (and vice versa). However, the correlation alone cannot be understood to imply a causative effect.

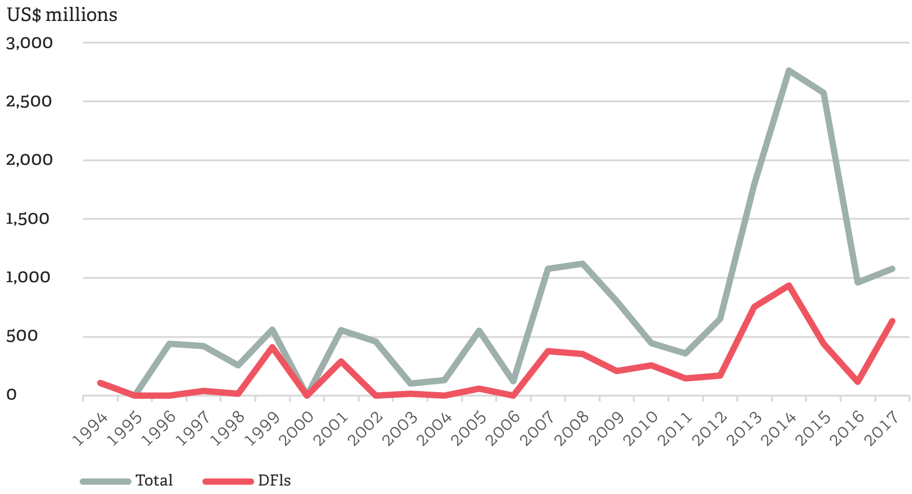

Figure 3: Charting DFI and total IPP investments in Africa, $ millions (Source: IPP database (2019, unpublished), Power Futures Lab, University of Cape Town)

There is little empirical evidence on whether DFI investments have a causal effect on encouraging future infrastructure investments. Measuring a demonstration effect is a delicate challenge, considering the long timeframes involved in developing, implementing, and establishing a project as viable. The complex array of factors surrounding investment in any market make any causal argument difficult to reveal. A case of a hydropower transaction carried out in Nepal by GuarantCo (a PIDG company) finds that the transaction helped familiarise local financial institutions with other large hydroelectric power developments in the country and raised interest among other international private lenders and DFIs for investing in the sector (Lion's Head Global Partners 2018). In addition, it improved local actors' understanding of international private lenders' environmental and social impact requirements. The involvement of KfW (the German development bank) in supporting successive IPP procurement rounds in Uganda demonstrated that private investment in small hydro, biomass and solar plants is viable. Indeed, today, Uganda has the highest number of IPPs in Africa (excluding South Africa). Spratt and Ryan-Collins (2012) review evidence for the demonstration effect of DFI infrastructure investments to crowd in private capital. Observed, anecdotal evidence from DFIs shows that making a commercially successful investment in a frontier market can prove a higher risk-return ratio than might otherwise be expected by investors, and improve investors' perceptions of that market.

04

Enabling environment and political factors

The extent to which improving infrastructure can have an impact on people's lives and the wider economy depends on political economy and institutional factors. (Eberhard et al. 2017b; Aly et al. 2019). The quality of regulation, governance and policy have a major impact on a project's success, particularly in terms of distributional and gender effects (Cook 2011; Peters, Sievert, and Toman 2019; Barman et al. 2017; Pueyo and Maestre 2019; Eberhard and Gratwick 2011). Policies to promote electrification or investment in renewables are essential to enable sustained private investment in those areas (IOB 2013; Eberhard et al. 2017a; Thillairajan, Deep, and Mahalingam 2013).

Pro-poor policies and governance are important in tackling energy poverty. The level of democracy in sub-Saharan African countries seems to influence the distributional outcomes of electricity sector development, with more democratic contexts providing greater benefits for poorer populations than countries with more autocratic political environments (Trotter 2016). The presence of democratic institutions and institutional quality also determine the level of electricity consumption in Africa, supporting the argument for an integrated approach with good governance in electricity service provision (Ahlborg et al. 2015). The amount of poverty reduction that results from overall economic growth decreases when inequality is higher and development levels lower (Bacon and Kojima 2016). Reducing inequality should be a key lever in efforts to boost the poverty reduction that results from economic growth and increased energy consumption.

A country's institutional governance culture and policies are critical in deciding how to implement electrification programmes as well as infrastructure procurements more generally. Regulatory decisions and tariff policies contribute significantly to the impact of electricity on welfare, notably in ensuring affordability of electricity for poor populations (Pacudan and Hamdan 2019). They also contribute to cost recovery and the financial sustainability of grid systems (Bacon and Kojima 2016). The impact of interventions to improve electricity supply at a local level on women, such as in employment creation, income growth, health outcomes, and women's work opportunities, are also highly contingent on local political economy and social norms, including gender norms, institutions and education (Pueyo and Maestre 2019). For example, education, access to finance or credit, and institutional spaces are essential to empower women, alongside energy interventions to allow them to take advantage of productive uses of energy.

Access to credit is also key to increase the resilience of small and medium enterprises to grid outages and unreliable service (Cissokho 2019). Investing in energy-efficient technologies or backup systems offers essential protection against productivity losses, especially in manufacturing.

Private sector participation can benefit poor and rural consumers, although this is contingent on government support for interventions through public funding and targeted policies (Thillairajan, Deep, and Mahalingam 2013). Private investment works best in the context of improving availability and service quality, rather than increasing access. Extending grids to remote areas tends to increase transmission and distribution losses, creating a trade-off between access and quality. Private sector participation (PSP) to increase access in rural areas should focus on strengthening the quality of grids. This can bring greater impact through long-term forms of PSP such as concessions and divestitures, which are also more suited to attracting long-term private sector capital.

Private sector participation can benefit poor and rural consumers, although this is contingent on government support for interventions through public funding and targeted policies.

Achieving development outcomes with private finance requires an enabling market environment, including competition and regulation on price and quality. Eberhard and Gratwick (2011) propose a framework that identifies what contributes to success for IPP investments in Africa. At the country level, these include general country governance and investment climate metrics, such as specific policies and legislation that promote private investment in the electricity sector. Capable, independent electricity regulators with transparent and consistent licensing and tariff-setting practices have a significant effect on project outcomes. Up-to-date generation plans—especially when linked to timely initiation of competitive and transparent bidding processes and contracting of new power—also contribute. At the project level, various additional inputs can influence successful implementation, including the level of experience of project developers; the familiarity of equity and debt providers with developing country risk; and the bankability[6] of power purchase agreements. These can be strengthened by appropriate risk mitigation and security measures, such as escrow accounts, letters of comfort, partial or full guarantees, and political risk insurance.

Capable, independent electricity regulators with transparent and consistent licensing and tariff-setting practices have a significant effect on project outcomes.

An analysis of evidence in developing countries observes that interventions to increase transparency have mixed effects on infrastructure project outcomes (Thillairajan et al. 2012). The analysis concludes that private investment alone is insufficient to bring about positive development outcomes. The transparency of a power sector transaction in many cases has concrete, positive effects on its implementation outcomes, including efficiency, access, and costs. In electricity infrastructure services, about 28 per cent of papers find a significant positive result after a studied transparency intervention across a range of dimensions (access, cost, efficiency, price, and quality). In contrast, only 13 per cent of studies found a negative effect, though the majority of studies found no significant impact. Compared to telecom and transport sectors, the electricity sector shows a smaller share of positive outcomes produced by transparency interventions. This may imply that interventions to improve governance and reduce corruption in the electricity sector are ineffective or poorly implemented, or possibly that electricity infrastructure is less susceptible to corruption and rent-seeking than other infrastructure (therefore less likely to show positive benefits from initiatives to improve governance). Project financing and development must be accompanied by robust regulatory institutions alongside efforts to increase transparency, such as thorough competitive procurement processes. Poor, rural and illiterate populations are most likely to benefit from increased access and quality as a result of governance interventions. The transparency of infrastructure procurement can be measured through proxies such as corruption levels and rule of law, as well as other regulatory or project-level interventions.

6 A project considered acceptable to institutional lenders for financing, for example offering sufficient collateral, future cashflow, and probability of success.

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Directions for future research

Considerable evidence has been produced to investigate how electricity access and quality affect livelihoods, wellbeing, and related economic and development impact. But several key dimensions of this question have received less attention:

- **The long-term distributional effect** of electrification models on bottom-of-pyramid (lowest-income) consumers. For example, what design characteristics of an investment or programme ensure it benefits those with greatest need (not accrue merely to consumers with higher buying power)?
- Related to this, **the factors affecting affordability of modern energy** to those bottom-of-pyramid consumers, and design aspects to incorporate sophisticated understanding of affordability.
- The **different impact on, and use of electricity by women and men**, considering the structural and contextual factors that shape these differences (Bradshaw 2018). This is important to provide understanding, for example, of how electrification investments, programmes, and businesses might integrate gender-sensitive approaches into their model. This includes targeting women customers, appointing women decision-makers and designers, and designing complementary frameworks and interventions to benefit women's empowerment through electricity use.

Such work requires serious qualitative engagement with local data, complementing quantitative methods, to understand the contextual factors affecting consumers' decision-making and ability to take advantage of new technologies. In-depth interviews, case studies and participatory approaches are powerful tools to shed light on the tangible and intangible contextual factors shaping men and women's economic decisions. Social norms, gender, roles, and cultural or religious mores have important influence in these choices, which need to inform the design of business models and programmes for maximum impact and sustainability.

More attention could be given to the modalities and long-term effects of **investing in electricity infrastructure projects in high-risk geographies**. Understanding the conditions that contribute to a project's demonstration effects could contribute to a project design that more successfully encourages private capital flows by 'crowding in' future private sector investment. The way that private investors engage in a market after electrification occurs is also little understood, although perhaps too complex to measure. Innovative mechanisms to de-risk infrastructure investments in Africa are being tested, including insurance tools, bundling, and standardisation (Collier 2014). These can benefit from broader qualitative research on the effectiveness and persuasiveness of these tools for risk-averse private investors.

In the environmental dimensions, most work focuses on the potential for emissions mitigation through renewables. However, there are **trade-offs between reducing greenhouse gas emissions and other environmental impact** produced by different energy technologies, notably in terms of land use, watercourse changes, and biodiversity (key considerations of the water-energy-food-climate nexus). These are better understood in the case of hydroelectric dams, for instance, but little scholarship seems to exist on the trade-offs between land-use for solar PV and agriculture in developing contexts. Moreover, few studies explore how electricity might substitute or reduce land-intensive industries, which is an interesting area to consider in the context of natural resource stress. In addition, several studies mention the need for greater attention to waste management systems, especially in light of new battery-supported solar technologies spreading through rural areas.

In developing countries with small systems, more research and innovative technological approaches are needed to address **the repercussions of adding high shares of low-cost variable renewable energy for system stability and reliability**. What are the requirements for complementary flexible resources, storage, and ancillary services? What future power market reforms are needed to deliver adequate, reliable and competitively-priced electricity to support social and economic development? And what are the implications for the evolution of power markets? Few developing countries have fully competitive wholesale or retail power markets. Because of more challenging investment climates, private investment in new power generation is usually supported by long-term contracts. These may be competitively procured—competition for the market—while competition in the market is constrained. Rapid adoption of disruptive energy innovations, including greater shares of low-cost renewable energy and decentralised energy, where consumers can also be producers of electricity, may allow developing countries to leapfrog the more conventional power market designs of industrialised countries. We could see innovations in the evolution of markets for flexible resources and decentralised transactions.

Previous research has focused mostly on the impact of investments in power generation and on approaches to widen access to electricity. Relatively little work has looked specifically at the **impact of investments in transmission** (other than cross-border connections) **and distribution companies on development outcomes**, in part because relatively fewer privately-financed investments have targeted these sectors (African Development Bank, Association of Power Utilities of Africa, 2019). But new initiatives, such as CDC's Gridworks, are creating new opportunities to explore the impact of different investment and technical assistance projects in these sectors. Innovative approaches use debt covenants to incentivise improved performance. More direct approaches link equity investments to board appointments, or incorporate mechanisms to influence management appointments and offer performance monitoring and incentives.

Finally, the growing **viability of mini-grids and a range of off-grid options** in response to declining costs of renewable technologies and batteries, coupled with innovations in smart grid technologies and business models, offer new opportunities to understand how decentralised systems can achieve maximum impact. In particular, researchers are gathering larger data samples from off-grid companies to assess development impact.

The view from our partners

An immense challenge still lies ahead to provide power to over one billion people who still lack access to electricity – 60 per cent of whom are in sub-Saharan Africa. Eberhard and Dyson reemphasise the importance of electricity in generating employment opportunities and increasing household welfare and quite rightly, highlight the need to consider the most appropriate technology to fit the regional and country context. For sub-Saharan Africa, a combined approach of gas, hydro, wind, solar PV and battery energy storage systems will be essential to meet demand, balance grids, lower the cost of generation and displace higher emissions.
Mike Scholey – CEO, Globeleq

The World Bank estimates that the working age population in India increases by 1.3 million people every month. This means the country will need to create 8.1 million jobs a year to maintain its employment rate. The evidence review reiterates the need to continue to support the development of cleaner power to enable the Indian economy to achieve its full potential – creating the jobs required, improving the quality of life for the ever-growing middle-class whilst tackling the climate challenge.
Shivanand Nimbargi – CEO, Ayana Power

The evidence review highlights the transformational impact an IPP can have on developing a market for private sector investment in some incredibly hard places. As we develop Ruzizi 3 we hope to have this same impact in DRC and Burundi in particular, who have for so long struggled to mobilise capital. We are also glad to see the wide range of impacts electricity offers across macro, quality of life and climate indicators which provides development agencies and financiers a licence to operate.
Galeb Gulam – CEO, Industrial Promotion Services in East Africa, an agency of the Aga Khan Fund for Economic Development

This study shows strong evidence that investment in electricity infrastructure can create positive benefits for both people as well as the planet. It also highlights the need for greater investment into both grid and off-grid networks which are an essential part of the value chain necessary to provide access as well as improve grid efficiency and stability. As Gridworks focuses on improving the quantity and quality of power and the networks carrying that power, we will use this evidence to shape our strategy and maximise the positive outcomes of our investments.
Simon Hodson – CEO, Gridworks

55 per cent of Pakistan's generation mix relies on imported fuels which exposes the sector to fuel price volatility, contributes to import dependence and a build-up of CO_2 emissions. Eberhard and Dyson have reinforced the significant role cleaner power generation can have in facilitating economic growth and job creation, enhancing living standards and contributing to climate mitigation.
Kumayl Khaleeli – CEO, Zephyr

Appendix 1

Methodology for literature review and analysis

The methodology adopted a broad evidence review strategy including a wide literature search and expert consultation, with the following components:

- Identify a study question and component questions (A1.1)
- Follow a search strategy or strategies (A1.2)
- Apply inclusion/exclusion criteria (A1.3)

A1.1 Study question

The study took as a starting point the following question and component questions:

What are the **effects of investments** in programmes, businesses, infrastructure, or technological solutions that **provide electricity access or improve electricity service in low-income and lower-medium income countries**, either on the electricity grid or at off-grid level? Specifically, what are the effects on:

- Microeconomic factors, household incomes, business growth, workforce participation, economic activity?
- Community and household wellbeing, health outcomes, education, gender equality and empowerment?
- Macroeconomic factors, private sector activity, investment, growth?
- Local and global environment, including air and ground pollution, natural resource use/conservation, and greenhouse gas emissions?
- Future or ongoing private sector investment in similar technologies or projects in the country, stemming from DFI activities in a local market (demonstration effect)?

A1.2 Search strategies

Our search strategy adopted four broad pathways: database searches; expert consultations and interviews; and review searches and snowballing. The target literature is peer-reviewed, published academic and relevant grey literature (working papers and institutional reports).

Database search

In the first phase, we searched databases of prominent energy journals Energy Policy, Energy for Sustainable Development, and Nature Energy, as well as Google Scholar, using Boolean search strings (search terms divided by operators 'or', 'and').

Examples of search strings used:

- 'evaluation' OR 'impact' OR 'effects' AND 'electricity' OR 'energy' OR 'electrification' AND 'income' OR 'expenditure' OR 'environment' OR 'gender' OR 'women' OR 'markets' OR 'industrial' OR 'health' OR 'pollution' OR 'wellbeing' OR 'private sector' OR 'deforestation'
- 'evaluation' OR 'impact' OR 'effects' AND 'electricity' OR 'energy' OR 'electrification' AND 'time allocation' OR 'time use'.

Expert consultation

We held 10 interviews in person and via phone or video calls with 13 academic scholars and expert practitioners with 10 institutional affiliations, who work in various areas of electricity infrastructure research, investment, and impact measurement. Interviews were designed to provide specific new pathways of published research and grey literature, as well as contextual understanding of the review question. The following individuals were consulted (by chronological order):

- Alice Chapple and Harry Marin, PIDG
- Robert Towers, DFID
- Catherine Wolfram, University of California Berkeley, NBER
- Lissa Glasgo, Global Impact Investing Network (GIIN)
- Kat Harrison, Lean Data/Acumen

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- Dimitri Szerman, University of Mannheim, PUC-Rio, NBER
- Kristine Bos, Arif Mamun, and Duncan Chaplin, Mathematica Policy Research
- Elcin Akcura, IFC
- Priti Parikh, University College London.

Snowball and review searches

Finally, we identified recent reviews and meta-analyses of relevant literature examining aspects of our focus question. We included the literature reviewed in those papers, as well as studies that cited those. We followed up on literature and scholars recommended by interviewees and snowball-searched for literature stemming from those scholars, as well as from initial papers identified.

A1.3 Inclusion and exclusion criteria

The 63 studies selected for inclusion in the review include only evaluations and studies published since 2005 (with one exception from 2002).

Studies are included that examine the **effects of investments** in programmes, businesses, infrastructure, or technological solutions that *provide electricity access* or *improve electricity service* in *low-income* and *lower-medium income countries*, specifically concerned with the effects on:

- Microeconomic factors, household incomes, business growth, workforce participation, economic activity
- Community/household wellbeing, health outcomes, education, gender equality and empowerment
- Macroeconomic factors, private sector activity, investment, growth
- Local and global environment, including air and ground pollution, natural resource use/conservation, and greenhouse gas emissions
- Future private sector investment in similar technologies or projects in the country (demonstration effect).

The review encompasses econometric or statistical analyses, as well as mixed methods analyses, which consider counterfactual cases (notably using with/without, difference in differences, independent variable, propensity score matching). We code selected literature by year, study question, method, and finding according to 23 impact categories. Additional contextual literature is included that provides contextual social scientific and scientific analysis.

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