Evidence paper

International Growth Centre

# Energy and environment

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## Table of contents

# 1. Introduction

Economic development requires sharp increases in the consumption of energy (Figure 1). The reliability and cost of energy is a critical determinant of the competitiveness and growth of small and large businesses, and of the well-being of households. At the same time, the energy required for firms to grow and individuals to prosper creates externalities at the local level and globally.

The inequality gap across countries in terms of energy consumption is even wider than that of income inequality. The average American uses over 12,000 kWh of energy per year, the average Indian less than 1,200 kWh, and the average Ethiopian a paltry 70 kWh – only enough for each citizen to power a 30-watt bulb for seven hours a day. Ethiopia simply cannot grow out of poverty with a single bulb for each citizen – and hence has recently undertaken a massive electrification campaign. More than a billion people, largely in South Asia and sub-Saharan Africa, live without reliable and affordable energy. An energy policy that promotes economic development must therefore, first of all, improve access to electricity for households and firms.

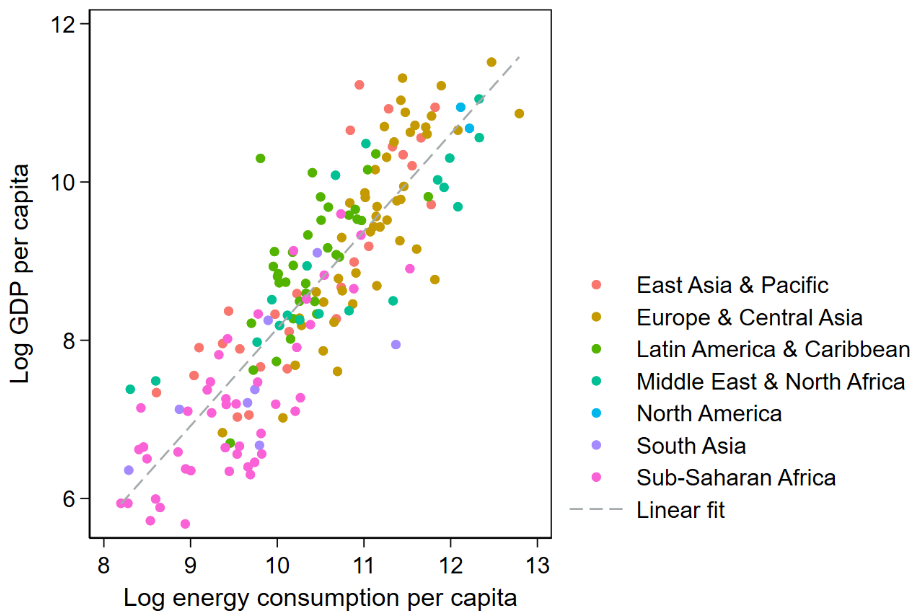


**Figure 1: The relationship between energy consumption & income (Data: WDI, 2015)**

Economic growth since the first and second industrial revolutions has been driven by industrialisation, transportation, and electrification, all powered by fossil fuel combustion. This growth path has had harmful and damaging by-products from the start (Beach and Hanlon, 2017), and these externalities are now holding back economic growth. Rapidly industrializing countries like China and India face some of the worst air pollution in recorded history (Jacobson, 2015, WHO 2016). The direct economic impact of these externalities is illustrated by recent research showing that workers in China were, on average, 6% more productive on low pollution days (Chang et al, 2016). Most of the increase in energy consumption in the coming decades will come from developing countries (Dasgupta, 2010; Wolfram et al, 2012). If the majority of that growth comes from fossil fuels, it will create damaging consequences to health, productivity, and ecosystems in those countries and around the world (IPCC, 2014).

The implications of energy policy for local pollution and climate change are obvious. But the implications of these growth-related externalities for energy policy are also important. Climate change and local pollution disrupt energy supply and increase the demand for power for adaptive purposes. On the supply side, extreme weather such as heavy rainfall, high winds, heat waves, and tropical storms can cripple energy infrastructure assets – from generation to transmission and distribution. This can cause long and damaging outages and impose severe economic costs (Zamuda et al., 2018). And even when it does not damage assets, climate change can disrupt the generation capacity of power systems. One such example is hydropower. While total rainfall trends will likely vary from region to region, the variability and frequency of extreme conditions is expected to increase across the world. This could pose a major challenge for developing countries, such as eastern and southern Africa, which depend heavily on hydro capacity, much of which depends on the stability of rainfall patterns (Conway et al., 2017). On the demand side, both global and local externalities from energy consumption will have implications for energy usage. Households in the developing countries, which will experience some of the biggest temperature and pollution increases, will require more electricity to power appliances such as air conditioners and purifiers. The agriculture industry in particular is likely to require more energy for irrigation in response to less frequent and more unpredictable rainfall.

Current energy policy in developing countries neither achieves its growth objectives nor addresses the negative externalities caused by energy usage. A pro-development energy policy is, therefore, one that maximises energy access while limiting the external costs of energy use—both locally, within developing countries, and globally. This tension—between access and growth on one side and externalities from energy consumption on the other—is the centre of IGC's research agenda on energy.

Our focus is on three main questions. First, how will the last billion get access to energy, and what benefits will it bring for their welfare and livelihoods? Second, how can environmental regulation check the local harms from energy consumption in countries with weak enforcement capacity? Third, what are the most effective ways for developing countries to slow the growth of greenhouse gas emissions associated with increased energy consumption and adapt to the effects of climate change?

This paper reviews the literature on these questions and outlines the areas we think have the greatest potential for research progress in the next five years. A few cross-cutting themes emerge when considering these questions. We touch here on two of these, as they help to organise our thinking in a wide range of disparate areas.

One recurring theme is that the progress of technology has opened a new kind of pro-development energy policy that relies on renewable energy to a much greater degree. The cost of renewable electricity generation has come down enormously over the past several years (IRENA 2018), which has increased its role in new-generation investment in developing countries and opened up new kinds of off-grid power supply substitutes for traditional grid electrification for some poor populations (Burgess et al. 2019). Renewable energy can reduce both local and global externalities from energy use, and is therefore an essential element of any pro-development energy policy. However, the shift to renewables brings with it a greater variability in electricity supply, with associated costs (Joskow, 2011). This could put a particular strain on power systems that are smaller or only partly integrated across space. Research is needed to help guide how renewable energy should be procured and integrated into power systems in developing countries.

A second recurring theme is that the energy sector is a political system as much as an economic one. Energy economics gives clear, standard prescriptions for how energy policy should work—eliminate subsidies, price at a marginal cost, regulate natural monopolies, and so forth—that are politically all but impossible in many countries. Instead we see, as a rule, that energy is wildly mispriced, and many segments of the energy sector are loss-making. Energy, rather than being priced at social cost, is often priced below private cost and used as a tool for redistribution. The broader point is that energy markets are often immature in developing countries, and so governments play a much larger role in energy's distribution than in developed countries; the result is that it is impossible to analyse these markets and consider reforms without accounting for political economy considerations.

We conclude by emphasising that to make progress in designing a pro-development energy policy, it is not enough for researchers to reiterate the standard prescription, or to measure and decry just how inefficient current policies are. Rather, a research agenda that aims to have influence in the real world must explore the constraints on energy policy that arise from equity, redistributive, and political concerns, market failures, and governance failures. It may then use those findings to propose reforms that are not only desirable but practical.

## 2. Access to inexpensive and reliable energy

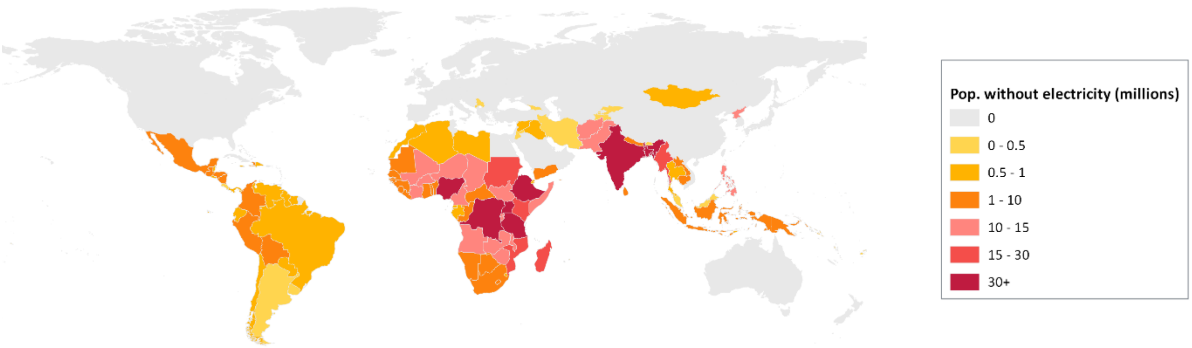


**Figure 2: Population, in millions, without electricity (Data: WDI, 2015)**

A billion people, mostly in sub-Saharan Africa and South Asia, do not have access to electricity (Figure 2). From the map, it is clear that the much of world's population without electricity is concentrated in areas of extreme poverty – in middle income countries such as India and Nigeria and in fragile states like the Democratic Republic of Congo and Sudan. Reaching universal access by 2030 will require an average annual investment between $45-60 billion (World Bank, 2019a). And for electricity access to be as reliable as the 24-hour supply that is taken for granted in developed countries, even more resources would be needed. Thinking about the return to such investments naturally raises many of the questions for research with respect to energy access.

First, what is the return on such public investments in electricity, both for the households that will be reached and these societies as a whole?

Second, what energy market features specific to developing countries affect the efficiency and equity of the energy sector? Here we mean supply-side market design, such as procurement rules, importing of fuels (e.g., natural gas), and policy around renewable energy integration.

Third, what is the role of the state in energy markets, and how do institutional and political reforms shape the return on energy investments?

The first question is characterised by the most high-quality research to date—but, we will argue, there are still a number of large gaps in the evidence. The second and third questions are characterised by a long history of discussion around developed-country markets, but relatively little evidence from developing countries. Moreover, historical experience may be a poor guide to creating policy in these areas today, since technological change—namely, the advent of low-cost renewable energy—has made many tenets of market design obsolete.

Throughout our discussion, we will draw mainly on examples from the electricity sector. However, we consider all of the questions above to be general, and to apply to the use of energy in other domains, such as transportation or household uses like cooking and heating.

### a. Energy access and economic growth

To some observers, the right approach with respect to access to electricity is simply "whatever it takes": Set a goal for universal access and spend what is needed, out of public funds, to get there.

The research to date on access to electricity and growth has yet to agree on the basic question of the value of universal access for the rural poor that would justify such a strategy. There have been a few recent field experiments on this exact question. The demand for grid electricity connections in Kenya is far below the cost of providing such connections (Lee, Miguel, and Wolfram 2019). The demand for grid electricity in India does not cover its cost among a poor rural population, and households do not value improvements in the quality of supply very much (Burgess, Greenstone, Ryan, and Sudharshan 2019). Households, however, are extremely sensitive to price, and they have been found to rapidly take up both grid electricity when it is subsidised or off-grid electricity when it comes down in price.

Policy makers will respond that a "whatever it takes" strategy is still justified, because electrification benefits society as a whole, and that these benefits are not internalised in household demand. Indeed, longer-run estimates at a higher level of aggregation show large productivity benefits to electrification over the span of decades (Lipscomb et al. 2013). Policy makers taking a farsighted view may well be right that low demand among the poor today should not deter large-scale investments in growing economies. But, having reviewed the literature, we feel that we do not have the evidence to reliably measure—much less forecast—the external returns to large-scale electrification or other large energy investments.

Many governments, moreover, are intent on universal electrification as a right regardless of its benefits. The most policy-relevant question is not, therefore, whether citizens should be given access to electricity; rather, it is what the timing, future supply, and tariffs for areas to be connected should be. This is especially important given that electrification will influence households' and firms' location choices; any policy mistakes will shape the allocation of economic activity around them (Dinkelman and Schulhofer-Wohl 2014).

Additionally, the question of universal electrification is now more complicated than ever due to technological change. The uses of power are expanding: more rural households now own mobile phones than lightbulbs. Potential sources of power for the poor have come to include more renewable options as technological innovations have made them viable alternatives (Aklin, Bayer, Harish, and Urpelainen 2017, Grimm, Lenz, Peters, and Sievert 2016). These developments mean that modern energy still shapes household behaviour, even in areas lacking any kind of modern energy.

The central question of how energy consumption relates to growth faces, to begin with, an empirical challenge because causality clearly runs both ways. More wealth means more opportunities to consume energy, while more energy means more opportunities to create wealth (Ozturk 2010). Consider the historical examples of England's industrial revolution or the United States' Rural Electrification

Administration. In both cases, energy allowed the adoption of technologies that boosted labour productivity, leading to economic growth (Jorgenson 1984, Lucas 2002, Crafts 2004). It could be, however, that these areas being electrified had greater growth potential than the settings where today's micro-level studies are being conducted. We simply cannot assume that there is a clear correlation that will allow us to identify how electricity causes growth across the board. Many areas of development economics have addressed this endogeneity problem by running experiments of various interventions on well-defined outcomes, such as test scores in the case of education. In contrast, however, electrification is potentially related to a wide range of development outcomes, including labour productivity, firm and farm profits, educational investments, and health outcomes. A broader set of tools is necessary for the complete picture.

Methodologically, there have been relatively few experimental studies to date, though the use of experiments is growing. There is promising recent research randomising access to decentralised electricity or grid electricity connections for off-grid households in rural areas of India and Kenya (see e.g., Burgess et al. 2019, Lee et al. 2019). Demand for grid connections in Kenya was found to be remarkably low, with limited electricity consumption post-connection and no meaningful medium-term impacts (Lee et al. 2019). An experiment varying the price and availability of off-grid technologies in India demonstrated significant price sensitivity on the part of consumers, whose willingness to pay for electricity (grid or off-grid) was heavily dependent on the availability of competing options (Burgess et al. 2019).

In the absence of experimental variation, most work has relied on instrumental variables, like distance to the grid or some aspect of topography (e.g., hilliness or land gradient) that makes electricity access more or less likely (Dinkelman 2011, Grogan and Sadanand 2012, Lipscomb et al. 2013, Grogan 2015).

At the micro level, there is a nascent but growing evidence base for effects of household electrification on a range of development outcomes. Electrification releases home production time and may operate as a labour-saving technology shock, increasing women's labour force participation (Dinkelman 2011). The extension of the potential workday through lighting can impact women's fertility and labour force participation decisions (Grogan 2015). Electrification can also improve both the quantity and quality of schooling investments by freeing up children's time to attend school during the day and allowing for reading time in the evening. It may also provide health benefits if it induces households to switch away from unsafe or polluting technologies such as biomass stoves or kerosene lighting (van de Walle et al. 2015). Evidence from a small experiment in El Salvador confirms significant reductions in exposure to particulate matter following electrification (Barron and Torero 2017).

Other microeconometric papers have used firms or farms (rather than households) as the unit of analysis. Unreliable electricity supply is viewed by firms as a significant obstacle to doing business and may cause negative aggregate growth effects (Straub 2008). Power shortages reduce the average output of Indian manufacturers by five percent, and considerably more so among small firms that lack backup generators (Allcott, Collard-Wexler, and O'Connell 2016). The effects vary across industries as some firm types are more adaptable to outages than others. Evidence from India finds weaker impacts of increased frequency in power outages among rice mills compared to steel mills, for instance (Alam 2013). A similar re-optimisation of production inputs in response to outages has been documented among Chinese manufacturing firms, helping them dampen the blow to productivity (Fisher-Vanden, Mansur, and Wang 2015). Electricity is conducive to investments in irrigation, boosting agricultural productivity in Brazil (Assuncao et al. 2015). In the Philippines, the cost of electrifying rural communities was recovered within a year, a result driven by large increases in agricultural income (Chakravorty, Emerick, and Ravago 2016). The overall picture, however, is less clear. Recent analysis of India's massive national rural electrification programme, *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY), shows muted effects. Exploiting variation from a population-based eligibility criterion for electrification, Burlig and Preonas (2019) find that despite visible increases in electric power availability, the medium-term impacts on a swath of economic outcomes—employment, asset ownership, housing stock, education, and more—are minimal.

At the macro level, electrification has been shown to precipitate industrialisation across Indian states (Rud 2012). Lipscomb et al. (2013) conduct analysis of the long-term effects of electrification in Brazil at the *municipio* (similar to US county) level, showing that development effects are mostly realised through increases in formal-sector employment and investments in post-primary education. Their estimated total rate of return to electrification substantially exceeds the estimates of internal rates of return using traditional cost-benefit analyses (e.g., Munasinghe 1987). This suggests that there are substantial external benefits to providing electricity access. Such benefits may derive from agglomeration externalities if firms and skilled workers mutually benefit from co-location. Brazil's experience demonstrates this; electrification clearly resulted in within-county urbanisation (Lipscomb et al. 2013).

Electrification also has spillover effects. Substantial "external" benefits to village electrification have been found in Vietnam and India (Khandker et al. 2013, van de Walle et al. 2015). Lighting in public spaces and the use of shared appliances may improve productivity and welfare for all households in a locality, regardless of their connection status.

Electricity also works differently depending on scale. If I get a television, I watch a movie; if my country gets television, it may change gender norms (La Ferrara et al. 2012). Electricity is therefore a network technology; my use and the value I attach to it directly depends on how others around me use or value it. Similarly, though operating through different channels, the provision of public services or external effects in firm productivity (Greenstone, Hornbeck, and Moretti 2010) may make the aggregate returns for a country investing in electricity very different to local or individual returns. There could also be decreasing returns: If electricity provision simply results in the equilibrium re-balancing toward electrified areas, then estimating firm, farm, or household productivity gains at the local level, without accounting for migration, will inflate growth effects. Dinkelman and Schulhofer-Wohl (2015) use the case of South Africa to demonstrate the importance of accounting for migration when evaluating the welfare gains of spatial programmes. They develop a location choice framework that incorporates missing land markets—a common problem in many parts of Africa—and allows for congestion in local land. Their framework calculates welfare bounds for new electricity infrastructure as a function of the income and population elasticities of new electricity infrastructure. Estimating these bounds for the South African case, they show that congestion externalities from programme-induced migration substantially reduced local welfare gains (by about 40%).

Spillovers are one explanation for the difference between micro-estimates of the demand for electricity and macro-estimates of its benefits. Credit constraints could be another. Those without access to electricity might not have the money to pay large fixed costs of access or even smaller monthly bills. Recent research suggests that South African households with liquidity constraints may benefit from the use of pre-paid meters (Jack and Smith 2015). These meters have also led to the emergence of mobile platforms to purchase electricity recharges (GNESD 2014). In Thailand, the creation of a new temporary household registration enabled poor urban households to apply for legal connections (Cook et al. 2005). Kenya has experimented with loans enabling households to pay for the costs of new connections (Stima Loans), and studies of access barriers suggest that financial instruments that reduce connection costs may play an important role in broadening access (Lee et al. 2019). In another approach, the Kenyan Power Utility has experimented with creating consumer groups to pool financial resources in order to pay the fixed costs of connections (GNESD 2014).

Access to energy has an intensive margin as well as an extensive margin. Erratic supply is commonplace in developing countries. The poor state of electricity supply has both private and social costs. On the private side, businesses and households suffer from service interruptions and often rely on decentralised generation, using diesel or kerosene, that is significantly more expensive than the grid (Sudarshan 2013). Consumers also choose to make costly compensatory investments in generators, inverters, voltage stabilisers, and the like. When electricity is unreliable or expensive, appliances such as air conditioners become harder to use, with especially severe implications for health and productivity in the hotter developing countries (Burgess et al. 2013, Somanathan et al. 2015). And there is evidence that electricity outages lower manufacturing output at a rate of one to one (Allcott et al. 2014). Across the cities of South Asia and sub-Saharan Africa, the quality of energy services, while generally better than in rural areas, remains highly inequitable and poor in an absolute sense (Eberhard et al. 2008, GNESD 2014, Singh 2014).

As this review makes clear, there are many gaps in our understanding of the relationship between energy access and growth. Some of the key questions where we believe research is most urgently needed are listed below.

**Next steps and research priorities**

- What are the direct gains of energy access to households and firms?
- What are the external returns to energy access? What are the sources of external returns?
- How does the advent of lower-cost renewable energy options change the options governments should target in expanding energy access?
- How does willingness to pay for access depend on scale, reliability, and quality of supply?
- What are the effects of low-quality supply on firm productivity in the long run?

### b. Energy market design

Whereas the discussion around energy access and growth tends to focus on the consumer demand side, access needs to go hand- n hand with efficiency. Too little attention has been given to how energy markets in developing countries function differently. The main reason for this is that in many cases, a true market for energy simply does not exist.

When attempts have been made to improve market functionality, success has been mixed. The standard paradigm for organising the power sector in developing countries pulls directly from first-best economic theories: improve the operational performance of utilities, ensure a reliable supply, and attract private-sector investment through fair market mechanisms. Over the last few decades, however, only about a dozen developing countries have been able to adopt this model successfully (World Bank 2019b). For most developing countries, it represented a straitjacket that clashed with political interests and difficulties in enforcing regulation. When reforms did take place, they were often partial, leading to confused systems in which elements of market activity were mixed with a strong state presence (Joskow 2008). We discuss the political economy of market reforms in the next section.

The networked nature of grid expansion means it benefits from economies of scale—declining average costs—making electricity transmission a natural monopoly. Vertically integrated utilities spanning from generation to transmission to distribution were—and, in many countries, still are—the norm for rolling out access to unelectrified frontiers. Yet as networks expand, inefficient operations, mounting subsidies, difficulties in enforcing payments, and financing constraints begin taking their toll (World Bank 2019b). Few fundamental reforms take place during good times; in reality, problems bubble up until there is a time of crisis and the lid blows off. Once forced to change, the energy sector gets stuck in a hybrid setup where independent power producers on attractive power purchase agreements sell alongside incumbent generators to a single buyer, introducing distortions in the dispatch of power and adding contractual rigidity across the sector.

Market rules and public investments into the sector therefore have direct impacts on how efficiently markets operate. However, rigorous evidence from developing countries on market design is lacking, and what little there is is rarely used in policy design. A cross-country study on utility reforms found that the impacts of privatisation and independent regulators on access and service quality were mixed at best (Estache, Goicoechea, and Trujillo 2009). Corruption leads to adjustments in the quantity and quality of services in line with the behaviour of a profit-maximising monopoly, stanching any potential benefits. Another study, using a panel of developing and transitional economies over two decades, finds that competition—but not privatisation—leads to gains in economic performance (Zhang, Parker, and Kirkpatrick 2008). In Argentina, however, the privatisation of local water companies saw improvements in the quality of service provision, reducing child mortality in surrounding areas (Galiani, Gertler, and Schargrodsky 2005). Overall, the evidence suggests that for privatisation to improve outcomes over the long term, it should be coupled with policies that promote competition and effective regulation (Parker and Kirkpatrick 2005).

Developing countries often struggle to attract enough investment in electricity to match the demand for power. To encourage investment, inefficiencies in the domestic market (e.g., subsidies, non-payment, theft) need to be eliminated or reduced. Energy subsidies in these countries, which mainly benefit the non-poor, are often high, making them unattractive places to invest in electricity generation and distribution (McRae 2014). Removing subsidies is politically difficult and requires a shift from viewing energy as a right to viewing it as a private good, a theme we touch on in the next section (Burgess, Greenstone, Ryan, and Sudharshan 2019).

In a bid to boost private investment, several countries, such as India, have also turned to adopting market-oriented reforms; limited evidence exists thus far on the impacts (Malik et al. 2015). Markets do not operate independently of the state but depend on public investments in infrastructure and regulation to function well. For example, congestion on the transmission grid, which is publicly built, allows firms to exercise market power, raising prices and limiting competition in the energy market (Ryan 2019a). Expanding competition and supply therefore depends on the state of the entire electricity network, upstream to down.

Further research is needed on supply-side market design and how market rules determine the efficiency of energy markets. The increasing penetration of renewable energy also has a bearing on energy market design. Though this topic is important to either discussion, we address it below as part of the discussion of climate change mitigation.

**Next steps and research priorities**

- How does the hybrid construction of energy markets in developing countries, with both state and private actors, affect their efficiency?
- To what extent can the privatisation of different segments of the energy market, such as the distribution of electricity or natural gas, affect market efficiency? How does this depend on the political and regulatory environment?
- How can market rules and public investments in infrastructure integrate energy markets to increase efficiency?
- How do reforms in areas like financial contracting, procurement rules, or market formalisation and centralisation affect the efficiency of energy markets?
- What effect will increasing renewable energy penetration have on reliability, generation costs, and consumer benefits from energy access?
- How do regulatory design and institutions affect energy supply and the incentives of energy supply companies?

### c. Political economy of energy supply

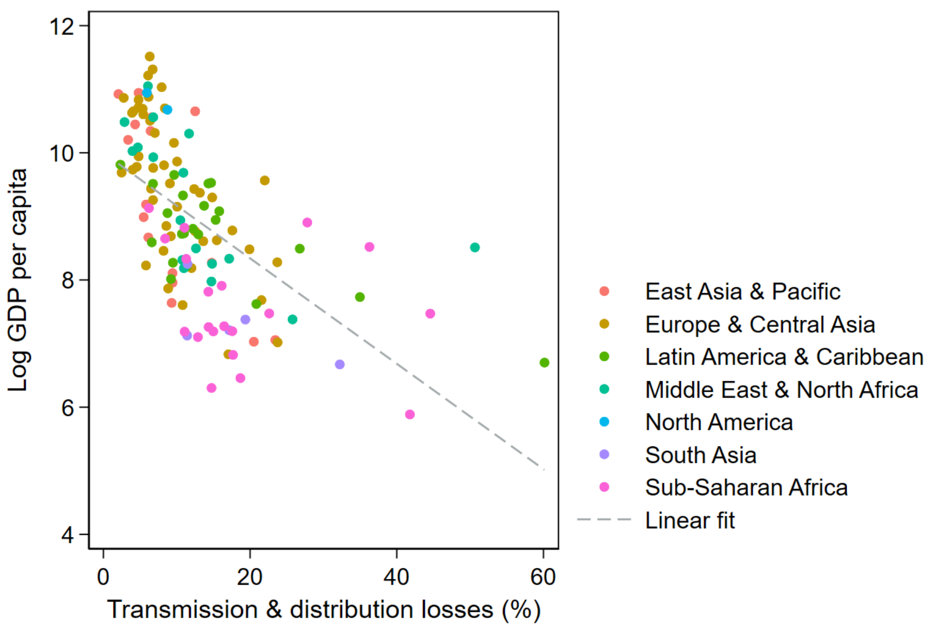


**Figure 3: Transmission and distribution losses (Data: World Bank, 2015)**

The root causes of much of the dysfunction in power sectors across the developing world are political. Even simple problems, like a blown transformer, have deep roots. As discussed in Min (2015), the transformer may have blown because it was overloaded. It was overloaded because farmers drew too much power. They drew too much power because they face no price for doing so. They face no price because their votes have sustained a distorted allocation of subsidised power to rural areas.

The state is inevitably involved in the power sector as an investor, regulator, and supplier because of the scale of electricity networks, the specificity of investment to each country, and the fact that electricity transmission and distribution are monopolies by nature. No country has ever completed electrification without government support (Barnes and Floor 1996). In most developing countries, the power sector is largely state-owned, so the strategic choices made by utilities reflect political concerns as much as economic and technical ones. Power utilities have large employment rolls, issue immense contracting volumes, and can steer valuable electricity services to different communities—all conditions that can exacerbate patronage (World Bank 2019b). It is not uncommon, therefore, political factors to hinder progress toward the declared goals of infrastructure investment and electricity access.

Many countries have looked to market reforms to restructure public companies and open them up to competition from private ones, especially when it comes to power generation, albeit with mixed results. Up to half of the world's countries have pursued at least some reforms around generation: unbundling generation, transmission, and distribution; privatising components; empowering independent regulators; and creating markets to foster competition (Kessides 2012, Brown and Mobarak 2009).

However, many of these efforts have been half hearted, leading to nominal changes in some parts of the sector while further entrenching state-owned utilities and political control in the most politically crucial segments, such as distribution (Murillo 2009, Lal 2006). Even in countries that have pursued reforms, the power sectors remain dominated by what Victor and Heller (2007) call "dual firms" that reflect the organisational and management characteristics of private firms but retain strong political networks and interests. This includes entities like Eskom in South Africa, the National Thermal Power Corporation in India, and Petrobras in Brazil. In contexts where state-backed firms compete with independent power producers, such as Pakistan, public entities often benefit from subsidised inputs or kickbacks, artificially positioning themselves higher on the merit list. Remedying the problems of investment in and access to the power infrastructure in developing countries therefore requires a political economy perspective that pays close attention to how political institutions shape the incentives and strategies of elites, different interest groups, and citizens.

Even with reforms, private companies may be reluctant to invest in a country's power sector. Corruption along all stages of the chain can frustrate or delay investors. If reforms fail, a later government may take over their plans, as occurred with the Dabhol facility near Mumbai (Bettauer 2009). In other cases, governments may renege on contracts and not pay at all. Investors often seek sovereign guarantees to guard against such situations, placing the risk entirely on the government.

The presence of large firms operating on an equal plane with the government creates space for corruption and rent-seeking when institutions are weak. The biggest firms might directly influence the terms of a tender, restricting competition from potential outside entrants. Even when it appears that markets are competitive and well-functioning, allocative inefficiencies exist. Well-connected firms in India, for instance, have been found to underbid in power auctions to win contracts, only to renegotiate for better terms after being awarded the tender (Ryan 2019b). Stronger contract enforcement, therefore, can improve productive efficiency by correctly allocating contracts to lower-cost firms. Understanding how politics and key actors influence the allocation and terms of generation projects should therefore be a main focus of further work.

The scale of energy markets means that an efficient market may require a high degree of cooperation across borders. Consider the interconnection of transmission systems. What successful precedents exist for countries with low levels of development effectively fostering cooperation and investment to increase their power systems' scale and efficiency? Many countries are too small and poor to develop a modern power sector on their own. Many entire countries in sub-Saharan Africa maintain less than one gigawatt of installed generating capacity, the amount provided by a single fossil fuel or nuclear plant in the industrialised world. In Senegal, almost all power comes from small-scale, expensive, and dirty diesel generation due to the historical lack of large industrial customers to anchor more efficient baseload power plants. When the price of oil spiked in 2011, Senegal experienced widespread shortages of fuel, resulting in a disastrous power crisis. The government's inadequate response led to violent protests and the electoral defeat of President Abdoulaye Wade—another instance of energy directly influencing politics in a developing country.

Greater regional integration and shared investment represent one possible way to overcome this problem. Significantly increasing regional integration could save more than $40 billion in capital spending in the African power sector and save African consumers $10 billion per year by 2040 (McKinsey 2015). Similar benefits could be seen if the ASEAN grid in southeast Asia was connected (IEA 2019). The difficulty of regional integration, of course, is that it involves long-term investments and trust between states, something that could be potentially feasible for ASEAN but less so for other groups of states that lack a history of common association. Developing-country governments may be reluctant to commit to one another due to lack of trust, or they may be unwilling to sacrifice control over their own power sector, which has political value. Influential firms may also balk at the thought of opening themselves up to competition from abroad.

The above discussion suggests that political capture is a problem on the supply side of the energy sector; populism may represent an equally important problem on the demand side. Prices are set strategically, at levels that do not cover costs, to court politically favoured groups or secure votes (Brown and Mobarak 2009, Di Bella et al. 2015, Coady et al. 2015). High levels of line losses and billing irregularities are common, and tolerated by political leaders, who may benefit personally or politically by reducing enforcement (Figure 3; Min and Golden 2014). The social norm of considering electricity a right generates losses, supply rationing, and unmet demand (Burgess et al. 2019). Regular power outages or disruptions are masked by technical terms such as "load shedding" when in reality they merely reflect the pervasive mispricing of electricity. Such subsidies have long-term consequences, too, sapping investments that would improve infrastructure quality (McRae 2015).

In some cases, political reforms can help expand access. Min (2015) tracks night-time lights satellite imagery to show that democratic governments in the developing world provide electricity to 10% more of their citizens than those in economically similar non-democratic states. Yet, this expansion may itself be short-sighted: It is driven by the pursuit of electoral majorities by democratic incumbents, who prioritise visible policy outcomes like grid extensions and new village electrification projects even as other critical activities like maintenance and new power generation are deferred. These patterns are especially pronounced in Africa and South Asia. Minimal consideration goes into whether dramatic, "grid everywhere" approaches to electrification are the most suitable strategy for a country's given context. Politicians also routinely increase the supply of electricity—for instance, by reducing load shedding—during crucial elections (Baskaran, Min, and Uppal 2015) to enable higher levels of illegal power usage and help them win more votes (Min and Golden 2014). While this may benefit citizens temporarily, it is clearly economically inefficient — people want power all the time, not only when they go to vote.

A root cause of many of the failures of energy markets seems to be the norm that electricity (and other forms of energy) are considered a right, rather than a private good that must be purchased (Burgess et al. 2019b). When this norm is present, politicians are committed to provide energy at low prices regardless of its external costs. Consumers, in turn, feel justified in not paying for consumption. Public suppliers lose money on every unit supplied and must eventually restrict supply to contain their losses. The result is that many consumers cannot access a reliable electricity supply, even when their willingness to pay exceeds the cost of supplying it. How can we move from this equilibrium where electricity is a right to one where it is treated as private good? This is an area where there is an urgent need for research that identifies evidence-based and politically feasible solutions.

The literature has shown is that energy markets in developing countries are characterised by a high degree of informality and often by heavily subsidised prices. Energy access is mediated by high levels of informality in developing-country cities. In India, Delhi and Ahmedabad have found some success with both regularisation schemes and the creation of small local franchises (USAID 2004). Metering points on slum perimeter walls, coupled with financing assistance, have been used with some success in Manila (USAID 2004). The problems of energy access faced by the urban poor can be exacerbated when utilities are forbidden or discouraged from supplying to unauthorised slums, where households have uncertain land and tenure rights (Scott et al. 2005). When metering is incomplete or erratic, government subsidies for access can lead to perverse incentives for utilities *not* to invest in improving service quality, thus locking households into persistent regimes of low-quality supply (McCrae 2015). In Senegal in the 1990s, urban and rural areas were served by different agencies, leading to peri-urban households falling through the cracks in terms of access and quality (GNESD 2014). From the utility point of view, serving the urban poor can represent significant additional costs due to consumption levels and low revenues because of billing difficulties. When the transaction costs involved in obtaining legal connections are high, energy theft can become commonplace (Scott et al. 2005).

The political space for energy subsidy and tariff reforms is narrow. Taking away or reducing the benefits for a good that everyone uses and that makes up a large part of the budgets of the poor can spark political disaster. Energy subsidies are not as progressive as they are presented to be, often benefitting wealthier urban consumers (Coady, Flamini, and Sears 2015a, 2015b). Urban electricity subsidies can also be hard to target; for instance, South Africa's Free Basic Electricity subsidy programme has struggled to reach some of the poorest households, who may live on untitled land or share electricity connections with authorised residents. Sound experimental evidence on behavioural responses to the removal of energy subsidies is naturally difficult to come by, but such evidence would be valuable to the design of new policies. The prevailing view is that income redistribution should not be carried out through energy policy but instead shifted to more efficient policy instruments like basic incomes or direct transfers (Barnwal 2014). As global energy prices remain low—and in some domains like electricity, they continue to plummet—there is a real opportunity to make changes.

While there has been significant work on designing effective tax systems for developing countries that consider not only the impact of tax rate or base changes but also asymmetries in information and difficulties in compliance (Slemrod and Gillitzer 2014, Slemrod 2016), there is far less on energy pricing.

**Next steps and research priorities**

- How do supply-side politics affect investment, contracting, and the efficiency of energy markets?
- How do demand-side politics affect tariffs, reliability, and the benefits of energy access?
- How does the provision of energy affect social norms about the state?
- How can financial and institutional structures create a favourable investment environment for private suppliers?
- What kinds of institutions are most robust to political interference? How can rent-seeking and elite capture be minimised?
- How does state control over distribution affect efficiency? Given political constraints, how can we develop independent and robust regulatory processes for the allocation of power and determination of tariffs?
- What reforms can successfully move from the “electricity is a right” equilibrium to one where electricity is treated as a private good? What are the welfare consequences of such reforms?
- Can unconditional transfers effectively replace energy subsidies? How can unconditional transfers be targeted to compensate the losers in energy subsidy reform?
- What are the effects of allocating energy contracts, investment, and supply on political rather than economic grounds?

## 3. Global externalities from energy consumption

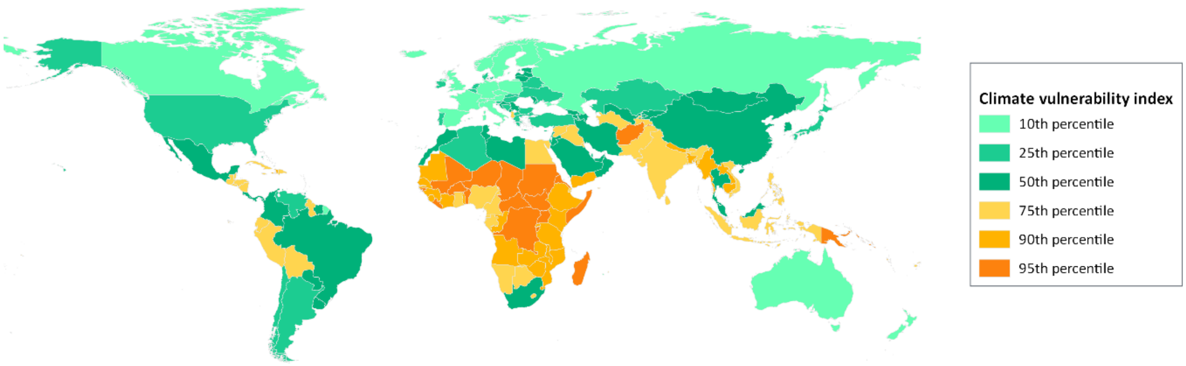


Figure 4: Vulnerability to climate change (Data: ND-GAIN, 2017)

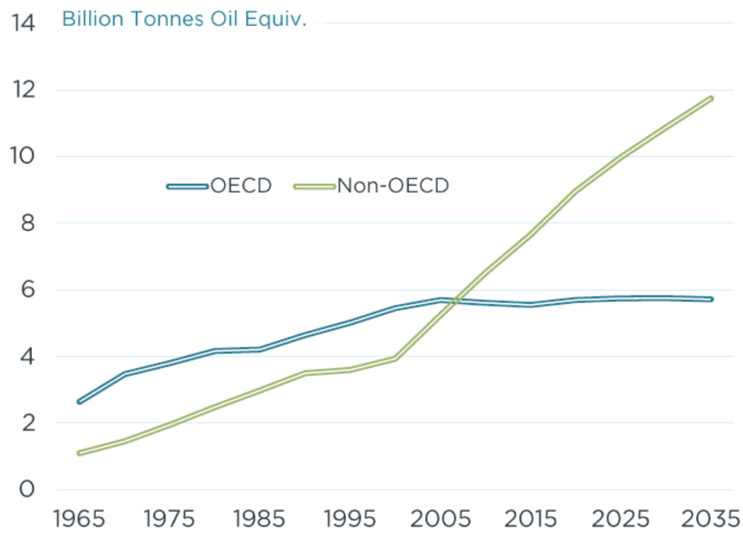


**Figure 5: Global energy demand, 1965-2035, in BTOE (Source: EPIC, BP Statistical Review 2015)**

Energy consumption supplied by fossil fuels over the last century is causing large-scale environmental changes at the global level. These changes will disproportionately harm low income countries and poor, rural populations (Figure 4; IPCC 2014, 2018). The scale of these changes means strategies to promote inclusive growth and eliminate extreme poverty must now incorporate both mitigation and adaptation.

What consequences do the magnitude of the global externalities generated by energy consumption have for energy policy in developing countries? Countries that are growing rapidly today and thus will experience a major increase in their energy use could make an important contribution to climate change mitigation if they build energy systems that are less carbon-intensive than what developed countries have built in the past decades. The rapid acceleration of innovation in renewable technologies and storage – and the associated declines in wholesale electricity prices – has led to optimism that significant progress in mitigation is possible. At the same time, renewable energy growth may have higher costs, in terms of reliability, on power grids that have little dispatchable energy generation.

How can low income countries, where a large fraction of the population works in economic activities that are heavily dependent on the weather, put in place strategies to adapt to these shocks? Low income countries will have no choice but to help their populations adapt to the risks brought by a hotter, more variable, and disaster-prone climate. Poor countries are going to be severely harmed by climate change, with lower agricultural yields and manufacturing productivity and higher rates of premature death (Lobell and Tebaldi 2014, Burke, Hsiang, and Miguel 2015a, Burgess, Deschenes, Donaldson, and Greenstone 2017). Studies of climate damages continue to be important and can be extended in many ways, particularly in providing hyperlocal information on what climate change will look like on the ground.

### a. Mitigation and energy policy

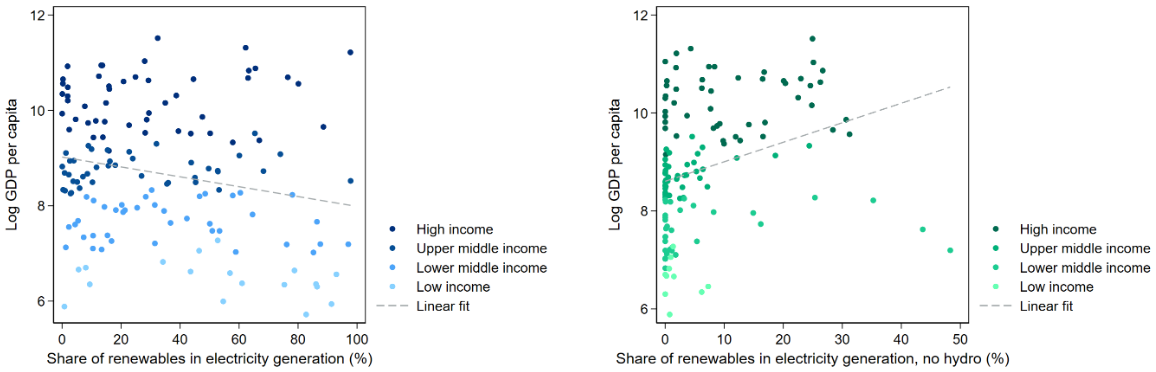


**Figure 6: Share of renewables in generation (with and without hydropower) based on income group (Data: World Bank, 2015)**

Fast-growing developing countries will account for the bulk of the increase of energy consumption in the coming decades. This increased use of energy is essential to support the increases in growth needed to reduce poverty.

However, if countries rely on fossil fuels to meet this increased consumption, it will lead to shorter and sicker lives for their people and increase the likelihood of disruptive climate change for the planet as a whole. To play their part in meeting global climate targets, these countries need to find a cleaner road to energy consumption. Many developing countries such as Brazil or Zambia, have been fortunate enough to benefit from abundant hydropower, creating a clean electricity mix. However, hydropower, like other renewables, can come with a degree of variability (in this case, seasonally), so governments need to look into thermal base loads or other means of storage. The question remains how future demand will be met, especially if hydro capacities—or willingness for large dam construction projects—reach their limits. Strip out hydro and developing countries do, on average, lag behind on installation of renewables—though it must be said that this applies almost as readily to developed countries as well (Figure 6). Switching to a low carbon supply of electricity is one way to mitigate emissions; consuming more efficiently is another. Significant advancements in a large range of energy-consuming activities—from the thermal efficiency of generation plants to improved heating/cooling of structures to ultra-efficient light bulbs—present ample opportunities to get more out of each unit of energy. There is an urgent need to identify the best mechanisms to support these countries in meeting their future energy demands cleanly.

Large-scale renewable energy sources have the potential to support energy demand growth while cutting local and global air pollution. There are several reasons to be optimistic about the growth of renewable energy in the years to come. The cost of large-scale renewables, especially solar, has fallen dramatically in the last decade (IEA 2014). Innovation has flourished. Moreover, in many low income countries, such as in East Africa, petroleum fuels are currently essential sources of power generation. The expense of the existing supply makes renewable generation cost-competitive in a growing number of settings today. The renewable potential in South Asian and sub-Saharan Africa is enormous. For example, sub-Saharan Africa is estimated to have 474 gigawatts of potential hydropower, wind, and geothermal capacity and an immense 11 terawatts of potential solar capacity (McKinsey 2015). Finally, some developing countries—most notably China—have recognised that unfettered use of fossil fuels has large negative health impacts and that regulations that make these fuels more expensive are an important next step.

Despite this favourable environment, increasing renewable supply in developing countries from the current low base will not be a straightforward process.

In the first instance, renewables do not compete on a level playing field with fossil fuels. The absence of taxes or regulatory systems to price the externalities associated with fossil fuels means that such fuels are effectively subsidised since their external cost is not reflected in energy prices. This places renewables at a substantial competitive disadvantage. Indeed, fossil fuels are often subsidised below even their private cost through mandated prices and inconsistent enforcement of payments. This can also affect the expansion of decentralised energy systems as the grid is also typically subsidised.

Additionally, other political, technical and economic obstacles prevent renewables from generating a substantial share of electricity supply in low and middle income countries. Politically, renewable energy generation is placed at a disadvantage when energy prices do not reflect the social costs of pollution, even as innovations like hydraulic fracturing have brought down the private prices of oil and gas. Technically, the integration of intermittent renewables will strain power grids, given the high costs of energy storage and the weak grid management infrastructure in developing countries. With increased renewables, the system requires a more flexible generation mix, abundant transmission capability and more efficient system operation. Developing countries that already have unreliable supply and frequent load-shedding may struggle to manage substantial renewable capacity in the existing grid. Economically, the finance of renewable generation, with its high capital and low marginal costs, will require clear regulatory and policy support.

A key focus for this theme therefore is to understand how energy policy needs to be changed to allow renewables to be an important part of the energy supply in developing countries.

The externalities from increased energy consumption requires a profound shift in energy policy from simply incentivising the adoption of low carbon energies or investments that increase energy-efficiency to now also tackling the challenges of adapting the existing grid to changes in geographical location and the intermittency that comes with an increased use of renewables.

These need to take place both in developed and developing countries. But the political economy of countries with fragile institutions and low state capacity makes these challenges more considerable for low and middle income countries. In the next section, we discuss potential ways to address the problems caused by intermittency, in particular market integration and pricing. We then turn to the financial constraints that developing countries are likely to experience when making the large scale investments necessary to adopt cleaner sources of energy and the effectiveness of potential solutions to reduce them. Finally, we discuss demand-side management and how governments can implement policies that incentivise the use of renewables.

**Next steps and research priorities**

- Can markets (e.g., cap-and-trade) be used to incentivise carbon emissions reductions in developing countries?
- Energy policy in the presence of weak institutions: how should incentive schemes for carbon reductions be designed in an environment with low monitoring and enforcement?

### 1. Intermittency, market integration and pricing

A challenge for many renewables, especially solar and wind, is that their intermittent nature makes them inappropriate as a source of baseload power. Even at relatively low rates of penetration (e.g., as little as 10%), renewables can harm grid stability and reliability (IRENA, 2012). This aspect of renewables is especially problematic in developing countries, which have small power grids, with no backup capacity and weak monitoring and control of transmission and distribution constraints.

There are both economic and technical ways to address this problem of intermittency. We focus on the economic side. Regional integration of electricity markets can increase the value of energy produced from renewable sources (Kambanda, 2013), by mutualising the risk of lower and unexpected supply. For example, the U.S. state of Iowa and Denmark have been able to greatly expand the production of wind power through their participation in regional electricity markets that allow them to sell wind generated electricity to places where the demand is not perfectly correlated with local demand (IWEA, 2015; Mauritzen, 2012). While there has been substantial integration in many developed countries, the situation is very different in many developing countries and regions; for example, just 5% of energy is traded across borders in Africa (APP, 2015).

Increasing the energy market integration and trade in energy across national borders therefore offers significant benefits. Besides opening-up opportunities for renewables, the integration of electricity markets also offers other economic benefits by equalising prices across regions, as well as introducing some potential costs by increasing the opportunities for the exercise of market power (Cicala, 2015). Further evidence on the opportunities, challenges, and potential impacts on renewable electricity generation associated with regional power market integration in sub-Saharan Africa and South Asia is needed.

**Next steps and research priorities**

- What are the most efficient approaches to managing intermittency issues associated with low carbon energy sources in developing country contexts?
- What are the gains from market integration in managing intermittency? How do approaches differ in smaller grids?
- Given that developing countries already employ backup power in response to unreliable grids, are there policy channels to encourage developing countries to use storage technologies that may be of social value by aiding in grid management?
- Can pricing designs, such as real-time pricing, help manage intermittency challenges?

### 2. Financing renewables

Though this has been on the decline, much of the costs of renewables come in the form of up-front capital costs (EREC 2013). When capital markets function poorly, this becomes a real constraint for the uptake of renewables. Credit and capital constraints are particularly important in low income countries, which could act as a significant barrier for mitigation strategies. There is a large basket of candidate renewable-financing mechanisms, including renewable purchase obligations, feed-in tariffs, feed-in price premia, auction procurement, capital subsidies, accelerated depreciation or exemption from import duties. An important area of investigation is which of these, or other, mechanisms can be effective in developing countries. For example, more than 30 states in the United States have implemented renewable portfolio standards that introduce minimum requirements for renewables' share and allow for trading to achieve this flexibly (EIA 2012). In India, low targets and incomplete compliance have made such standards a weak spur to renewable capacity addition—states, which set their own Renewable Purchase Obligations, are reluctant to increase generation costs in any way.

Historically, the most common policy for attracting renewable energy independent power projects in Africa has been feed-in tariffs, which pay the owners of energy systems per unit of electricity produced. However, feed-in tariffs have resulted in fewer projects than anticipated. In contrast, the competitive tenders run in South Africa and Uganda in recent years have had much greater success. South Africa shifted from a feed-in tariff regime in 2011 and since then has run four renewable energy bid rounds, resulting in 92 solar and wind projects totalling 6,237 milliwatts. Prices are now far below the original feed-in tariffs and have fallen 48% for wind and 71% for solar photovoltaics. Wind energy prices are now as low as US$c 4.7/kWh. Uganda's GETFiT competitive tenders, although on a much smaller scale, have also been successful in generating a pipeline of projects at prices cheaper than those obtained from unsolicited or directly negotiated deals. Other developing countries are also leading the way: Brazil's descending price clock auctions have been successful in attracting significant investment at low prices. In India, a recent auction for 1.2 gigawatts of solar capacity delivered bids of US$c 3.6/kWh. There is huge potential to adopt competitive tenders or auctions for grid-connected renewable energy in other developing countries. The challenge is ensuring auction designs fit country contexts and that transaction costs are appropriate to local markets. It remains to be seen to which extent some of the very low prices observed can be delivered in practice, and some countries, such as Peru, are putting auction rules in place to encourage deployment (IRENA 2015).

**Next steps and research priorities**

- What is the magnitude of credit constraints and capital market imperfections in the adoption of renewables and are there efficient solutions for developing countries?
- How can one leverage auction theory and past experiences to enhance the performance of renewable auctions?
- Does addressing inefficiencies in electricity markets (see section 2) reduce capital market constraints?

## 3. Demand-side management and energy efficiency

Renewables do not compete on a level playing field with fossil fuels. The absence of taxes or regulatory systems that either implicitly or explicitly price the externalities from the combustion of fossil fuels means that such fuels are effectively subsidised since their external cost is not reflected in energy prices. This places renewables at a substantial competitive disadvantage. Indeed, fossil fuels are often subsidised below even their private cost through mandated prices and inconsistent enforcement of payments. This can also affect the expansion of decentralised energy systems as the grid is also typically subsidised.

The range of interventions that will create a lower carbon content in the expected increase in energy consumption in developing countries have focused so far on the supply-side and the constraints that may limit the adoption of renewable energy. However, a number of interventions on the demand-side could be considered. One of them is improving energy-efficiency or designing policies that incentivise energy-efficient investments from firms and households.

Energy-efficiency is a large component of many climate change abatement plans, yet efficiency policies have not often been rigorously evaluated, particularly in low and middle incomes countries where the scope for implementing them is the greatest. Low hanging fruit in energy efficiency improvements are likely to be abundant. However, a common concern is that energy efficiency policies do not reduce, but rather increase, energy consumption by lowering the effective price of energy services (Jevons, 1905; Nordhaus, 1996). Differentiating between the private and social returns of efficiency in such programmes will be important in developing countries. For example, when tariffs are below private costs for political reasons, there may be much stronger rationales for utility-led demand-side management and energy-efficiency programmes.

Consider cities, which consume about 75% of the world's primary energy (United Nations 2014). At the same time, they are at the heart of any demand-side and energy-efficiency policies as they represent the richest consumers and largest markets. Such policies can not only reduce consumption – in turn aiding mitigation efforts – but also address some of the costs of bad urban energy services. For instance, experimental evidence from installing pre-paid meters in Cape Town, South Africa, found that these new technologies reduced consumption while directly removing the challenges associated with bill payments (Jack et al. 2015). In cities the role of passive building design deserves more attention, especially as Africa and Asia home to some of the fastest growing cities and so a large number of new buildings will have come off the ground. The specific issues around building more compact and more efficient urban areas are discussed in the IGC Cities evidence paper.

Engineering estimates suggest that some investments may have particularly high returns—for instance, efficient air conditioners and cool-roof technology (McNeil et al. 2011, Phadke et al. 2013, Akbari et al. 2011). Yet for many technologies touted for their high returns, actual adoption and use remains low. The wedge between high projected returns and low adoption is commonly referred to as the "energy-efficiency gap". Jaffe and Stavins (1994) and Allcott and Greenstone (2013) survey the field two decades apart; unfortunately, despite the time lapse, the latter survey highlights a lack of credible empirical evidence on the question of why no one is making these investments. If market or information failures prevent investment, then policy intervention could promote both energy efficiency and economic efficiency. Alternatively, it may be that efficiency measures have unobserved costs of adoption or less-than-ideal real-world performance, neither of which would justify policy intervention.

A recent literature has begun to sort out these issues, although primarily in developed countries. For example, recent research in the United States underscores how engineering estimates of energy savings may overestimate real-world performance, a divergence that may explain a good portion of the observed "energy-efficiency gap" (Fowlie, Greenstone, and Wolfram 2018, Allcott and Greenstone 2017). Davis et al. (2014) find lower-than-expected returns to energy efficiency from appliance replacements in Mexico, arising in part due to rebound effects. A randomised-controlled trial of industrial energy audits in Indian manufacturing plants saw that plants responded to increases in energy productivity by using more, not less, energy (Ryan 2018). The literature on consumer and firm responses to energy standards and labels is largely focused on developed countries like the United States (Houde 2014, Houde and Spurlock 2015). Much more research of this type is required in low and middle income countries.

The use of behavioural economics to encourage the adoption of more efficient technologies could be a promising avenue of research here. There is a growing base of evidence on the use of 'nudges' as a means to change consumer energy behaviour, including evidence from India (Allcott and Mullainathan 2010; Sudarshan 2013, 2015). However, there is a growing base of evidence on the use of behavioural "nudges" as a means to change consumer energy behaviour, including evidence from India (Allcott and Mullainathan 2010, Sudarshan 2013, 2015).

**Next steps and research priorities**

- What are the most cost-effective carbon reduction strategies—in terms of using energy more efficiently or generating energy without greenhouse gas emissions?
- Are there informational or other barriers to individuals and firms making energy-efficiency investments in developing countries?
- What are the spillovers of energy-efficiency programmes through technology transfers and leakage?

## b. Adaptation and public goods

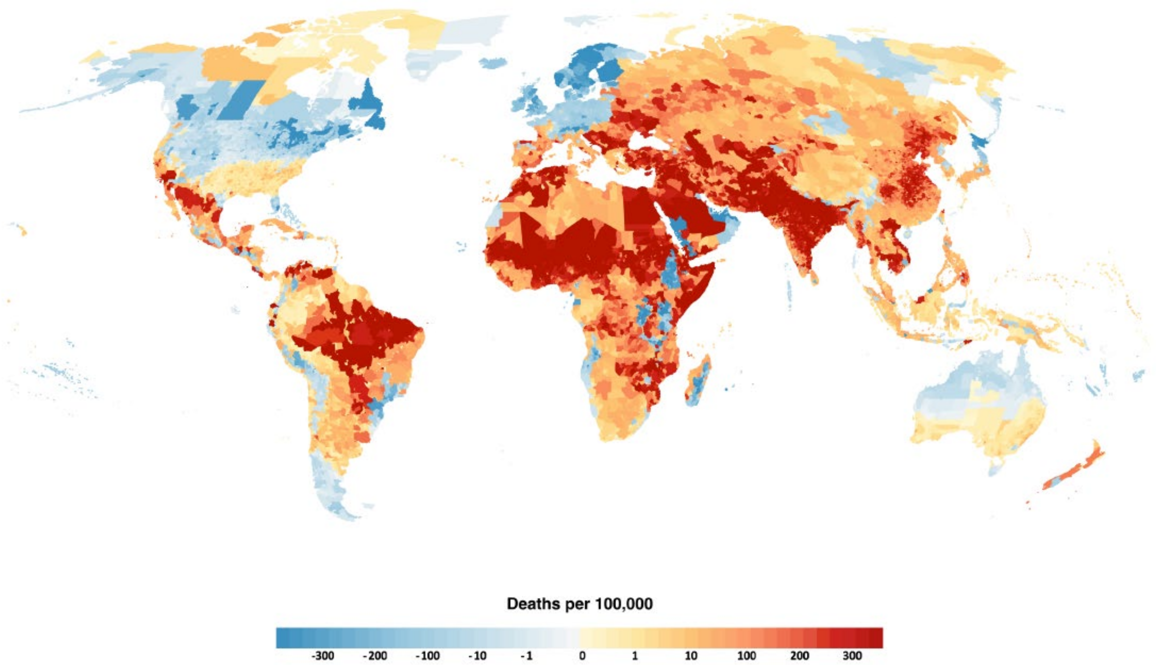


**Figure 7: The (heterogeneous) mortality cost of climate change in 2099 under RCP 8.5 warming (Source: Carleton et al. 2019)**

Households and firms will require assistance in adapting the global externalities generated by increased use of energy across developing countries. Climate change reaches far and wide, touching all aspects of an economy. A warmer world saps the productivity of agriculture and lowers the efficacy of labour (Lobell et al. 2014, Burke et al. 2015a). Hot days and nights inhibit the body's physiological processes, especially among the elderly, leading to premature death (Karl et al. 1993, Sherwood  and Huber 2010). Floods destroy capital and end lives, shooing away economic activity (Kocornik-Mina, McDermott, Michaels, and Rauch 2019). Changes in climate alter the conditions under which social interactions occur, potentially increasing the likelihood of conflict (Burke, Hsiang, and Miguel 2015b). The list continues. There is also research indicating that higher temperatures substantially reduce the growth prospects of developing countries (Dell, Jones, and Olken 2012, Burgess et al. 2017).

Poor countries in particular are going to be severely harmed by climate change, with lower agricultural yields and manufacturing productivity and higher rates of premature death (Lobell & Tebaldi, 2014; Burke, Hsiang & Miguel, 2015a; Burgess, Deschenes, Donaldson & Greenstone, 2017). Studies to predict the potential economic damages from climate change, in particular at the hyperlocal level, will remain an important avenue of research, as they will help inform what type of public services are critically needed in response and where these needs are the strongest.

One of our main focus for this theme will be on how economic policy can help households and adapt to the global externalities generated by increased use of energy across the developing world. In response to these effects, governments will likely need to provide a wider range of public services and run campaigns to induce adaptive behaviour. Income growth which is the central focus of all of IGC's four research themes is a key form of adaptation. Africa and South Asia's success in reducing vulnerability to climate change likely lies in its ability to generate sustained growth and development. There is thus an urgent need to understand how policies that affect trade, structural change and growth can aid adaptation to climate change. Increasingly economic policy will need to be designed with this objective in mind.

Higher incomes offer more possibilities to escape the mortality consequences of climate change through, for instance by allowing people to work in sectors that are less exposed to climatic change or by enabling them to purchase technologies that protect them from the deleterious effects of higher temperature (Barreca et al, 2013; Graff, Zivin, Hsiang & Neidell, 2013). A large-scale study estimating the causal relationships between climate and mortality covering 40% of the global population finds that without adaptation the mortality cost of climate change will be 125 additional deaths per 100,000 by 2100 (Carleton et al. 2019). Modelling mortality responses to temperature as a function of incomes and climate, they find that increased income reduces the mortality cost of climate change by 2100 to 48 deaths per 100,000, down from 125 without any change. Further climate adaptation reduces this to 28 deaths per 100,000. There is an urgent need for more research on how income growth can be encouraged in a form that enables households and firms to protect themselves from the effect of climate change.

Here greater provision of public goods to aid adaptation are likely to play a central role. The implications of climate change should be baked-into decisions on planning and investments made by the state. Consider public investments into infrastructure. Such investments will play a role in supporting the income growth that aids adaptation; at the same time, however, these assets are uniquely exposed to natural disasters, and especially if they are on the coast, to sea-level rise. Coastal areas have long been a boon for commerce but their susceptibility might make infrastructure investments here risky. This is due to the outright damage from disasters but also the long-term re-allocation of economic activity away from these areas. An analysis of Vietnam's infrastructure construction shows clear short-term benefits from coastal road construction, but these benefits vanish and become sub-optimal to roads built further in-land once future sea-level rise is factored in (Balboni, 2019). 72% higher welfare gains could have been achieved if construction deviated from the most inundation-prone areas. Similar considerations will come into play in the design of cities and of the infrastructure systems that support them.

Response at the firm and sectoral levels are also likely to be critical. Spatial reallocation is likely be a key response to climate change, but we understand little about how flows of workers into cities and from agriculture into services and manufacturing can be encouraged in anticipation. As discussed in the IGC Cities Evidence paper, if migration is the result of climate change damage as opposed to the result of a welfare-improving choice, the benefits of proximity that cities give rise to may not be captured. Individual firms also need to adapt to the risks imposed by climate change. Despite evidence that firms are aware of climate change, conscious efforts to adapt appear minimal (Agrawala et al. 2011). Inertia to respond to risks is well-documented among both individuals and firms. Cognitive barriers affect our abilities to judge and act on complex, probabilistic decisions over adaptation (Grothmann & Patt, 2005). Information and other behavioural nudges may therefore help induce optimal decisions into adaptation. In this area public information campaigns and the promotion of climate resilient technologies are likely to play a central role.

Households currently engaged in agriculture merit special attention as they are likely to be most affected by growing climate externalities imposed by growing energy consumption in the developing world. Here transfer schemes and financial and insurance instruments could play a significant role for adaptation. For the hundreds of millions of poor households who depend on agriculture as their main source of livelihood, sharp changes in the weather can be disastrous. Incomes plummet, resulting not only in short-term hardship but also potentially in death. Using detailed weather and mortality data spanning half a century in data, Burgess et al. (2017) find an increase in hot days raises mortality among rural, but not urban, poor. When heat strikes during the growing season, the poor who are engaged in agriculture suffer from reduced productivity and wages, which drives the witnessed increase in mortality. Importantly, the availability of local bank branches – a potentially life-saving source of credit – alleviates these impacts. There is an urgent need to think about how transfer schemes and financial and insurance instruments can be designed to help the most vulnerable households adapt to climate change.

Understanding how new technologies and crop choices can protect farmers is also critical here. Farmers adjust to fluctuations in the weather by moving into non-farm activities or changing the size of cultivation (Banerjee, 2007; Kazianga & Udry, 2006). Fortunate farmers may have access to weather insurance, helping them ride out the vagaries of the climate (Barnett & Mahul, 2007). What matters, however, is whether households are constrained in accessing these adaptative measures. Given the general equilibrium effects present in climate shocks, there is a clear argument for the provision of public goods to aid adaptation. How these should be designed, targeted, and implemented, in particular for the most vulnerable, is an active area for research that we plan to deepen and encourage.

**Next steps and research priorities**

- How can trade, growth and structural change help households and firms in developing countries adapt to the effects of climate change?
- What types of investments in infrastructure and cities make people and firms more resilient to the impacts of climate change?
- What are the necessary public goods to aid adaptation to climate change for households and firms?
- How should insurance markets, financial markets and transfer schemes be designed to help vulnerable households, particularly in agriculture, adapt to the effects of climate change?
- What is the role of information provision about the impacts of climate in inducing socially optimal policies and behaviour to adapt to these effects?
- How can behavioural nudges be used to incentivise optimal decisions in adaptation?

# 4. Local externalities from energy consumption

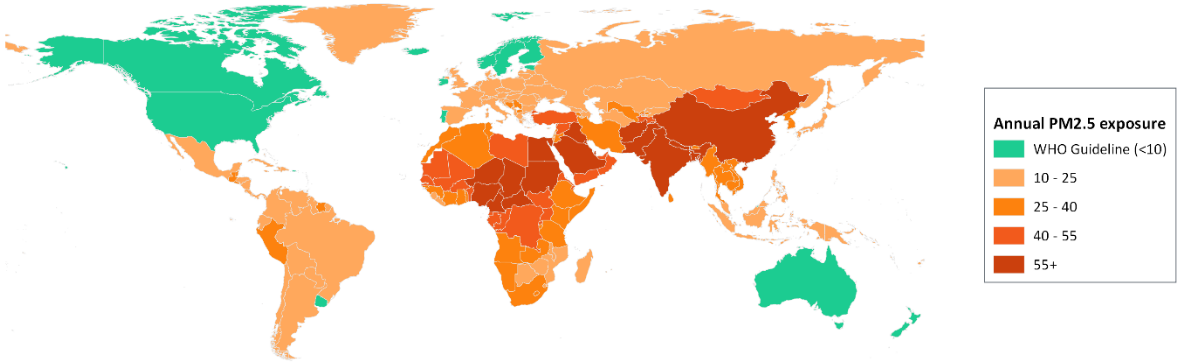


**Figure 8: Annual PM2.5 exposure by country (Data: WDI, 2015)**

Massive expansions in energy access during industrialisation and urbanisation—when people move from bicycles to cars, for example, or from darkness to electricity—have always massively increased pollution. Only a handful of countries in the world have air that is safe to breathe (Figure 8), and today's developing countries have the most acute air-pollution problem ever experienced in world history. Growth in output may mis-measure or overstate welfare gains if growth degrades environmental quality and natural resources. For the billions growing up under a cloud of haze, such long-term exposure is sure to impact health and human capital, imposing unknown costs on the growth potential of a country. Additionally, the air is not the only medium through which people are exposed to pollution: contaminated water, either due to poor waste and sewage treatment or other reasons, can also undermine health and well-being.

As evidence of pollution's deleterious shadow mounts, more thought is being put into mechanisms for improving environmental quality. However, there remains little rigorous work on the efficacy and costs of environmental regulations in developing countries (Greenstone and Hanna 2014 and Duflo et al. 2013 are exceptions). Households value clean air, but we know little about the heterogeneity in valuation across space and income and even less about the costs of different kinds of abatement investments. Information on source of pollution and abatement strategies are severely lacking at local levels. Translating information about the problem into behavioural change is another tall order. Regulators in developing countries do not have good information on the sources of emissions or the costs of abatement via different strategies. The pure technological costs of abatement—like a factory running a machine or the retirement of a polluting vehicle—may be much lower than the social benefits of that abatement, such as the regulatory systems needed to ensure the machine runs or the vehicle is scrapped properly. Even when sound environmental regulations are put into place, they often go unenforced. Progress in reducing externalities from energy use can only be made if enough attention is paid to both the design and implementation of policies.

### a. Consequences of pollution for health and human capital

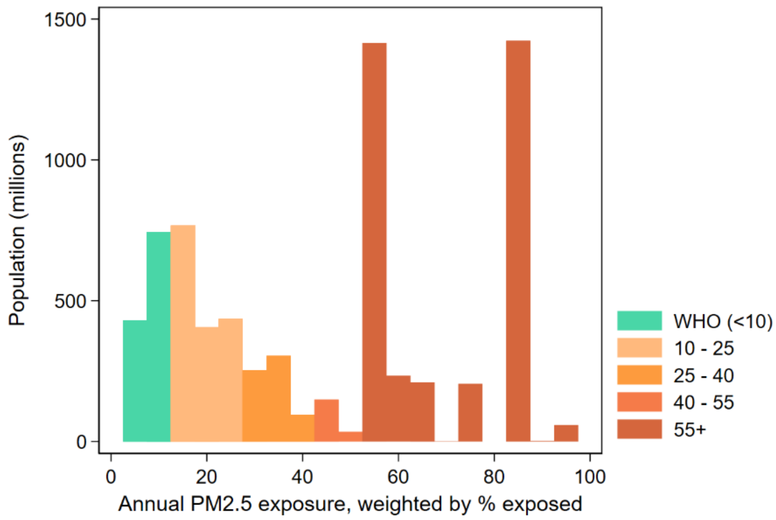


**Figure 9: Population, in millions, of those exposed to certain PM2.5 levels. Bin width of 5 (Data: WDI, 2015)**

| Country | Pollutant | Health impact: magnitude | Methodology | Author (year) |
|---|---|---|---|---|
| Indonesia | PM | Infant mortality: 1.2% | Quasi-experiment | Jayachandran (2008) |
| Mexico | CO and PM | Infant mortality: elasticities of 0.227 (CO) and 0.415 (PM) | IV | Arceo et al. (2012) |
| China | TSP | Life expectancy: 2.5 years | Spatial discontinuity | Chen et al. (2013) |
| China | Water quality | Stomach cancer deaths: 9.7% | Quasi-experiment | Ebenstein (2012) |
| Bangladesh | Feacal coliform | Infant mortality: 27% | Quasi-experiment | Field et al. (2011) |
| Kenya | *E. coli* | Child diarrhoea: 25% | RCT | Kremer et al. (2011) |
| Mexico | SO2 | Labour supply: 0.61 hours/week | Quasi-experiment | Hanna & Oliva (2015) |
| India | Agrochemical | Multiple, child & infant health | Quasi-experiment | Brainerd & Menon (2014) |

**Table 1: Health Impacts of Pollution on Environmental Quality (Source: Greenstone & Jack, 2015)**

As illustrated in Figure 9, there are a fortunate few who are not exposed to harmful levels of air pollution. For the remaining six billion, air pollution is either silently deteriorating their health or overtly draining years off their lives. Particulate matter air pollution cuts global life expectancy short by nearly 2 years (Greenstone and Fan 2018) and may represent the greatest "external" threat to public health in the world. Dirty water also allows for the rampant spread of disease: Diarrhoea kills 2,195 children every day, more than AIDS, malaria, and the measles combined (Liu et al. 2012). The health consequences of foul air are just now beginning to be understood, but the early conclusions have been clear: Pollution damages health and human capital. Not only do exposed humans get sick, their cognitive functions decline (Gibbens 2018). While pollution was rampant at the time of industrialisation in Europe, it is likely that today's developing countries are faced with an even more acute crisis. Identifying the precise and heterogenous impacts of pollution is an essential start for planning how to combat this growing crisis.

Exposure to pollutants such as airborne particulate matter (PM), ozone, and nitrogen dioxide is directly associated with increased mortality and the onset of cardiovascular and respiratory disease (Brunekreef and Holgate 2002). London's great smog event of 1952, triggered by stagnant weather conditions that dramatically increased the concentration of air pollutants, is a perfect case study. Over the course of a few days, several thousand more people died than expected, establishing a direct link between pollution and mortality. Importantly, the death rate remained higher for *months following* the episode (UK Ministry of Health 1954). Damaging effects have been found even at low levels of exposure.

The production of energy through combustion is the leading culprit for man-made particulate pollution (Philip et al. 2014). Large coal-fired power plants spew toxic pollutants into the air. The advent of mechanised transit and the proliferation of backup electricity generation have brought people much closer to the harmful by-products of combustion. Farmers looking to clear their fields of residual crops opt for the cheapest and quickest way: They burn their fields. Pastoralists eyeing more land for their animals choose to cut—or, again, burn—the forests to clear space. Winds carry these carcinogenic clouds into nearby areas and cities, exposing large numbers to pollution. An estimated 12.5% of all deaths in India in 2017 were directly attributable to air pollution, with over half due to exposure to ambient particulate matter (India State-Level Disease Burden Initiative 2019). Poor air quality in India is estimated to have reduced average life expectancies by three years (Greenstone et al. 2015).

The failures of energy distribution described in the first section increase the pollution intensity of energy production and use in developing-country cities. Unreliable electricity spurs the combustion of kerosene, diesel, coal, and fuel oil, which are large sources of urban air pollution (Guttikunda 2013a, 2013b, 2014, 2015). This pollution lowers productivity, makes people sick, shortens their lives (Hanna and Olivia 2015, Zivin 2012, Guttikunda 2013c, Chen et al. 2013, Greenstone et al. 2015), and undermines the economic and health benefits of moving to a city in the first place. Pushed into building up captive power to combat unreliable supply, demand for electricity could be unnaturally suppressed, leading to ineffective policy.

Pollution is also generated in or near the home. Indoor air pollution is the third highest risk factor in the global disease burden (Lim et al. 2013). In developing countries, the burning of charcoal for cooking and heating is a dangerous source of black carbon, a component of PM2.5. After subsidies were granted on coal to be used in boilers for winter heating in Northern China (areas above the Huai River), average life expectancies were reduced by about 3 years (Ebenstein et al. 2017) for the intended beneficiaries of the policy. Long-term exposure has devastating effects: Aggregated up, the 500 million residents of Northern China are expected to lose 2.5 billion years of life expectancy. The social and economic costs of this are staggering. In Bangladesh, an estimated 57 million people were exposed to arsenic-contaminated water in wells, resulting in higher levels of morbidity and negatively affecting schooling attainment, the likelihood of being in a skilled occupation, entrepreneurship levels, and income (Pitt, Rosenzweig, and Hassan 2015). Another study in Bangladesh found that households that switched from deep wells to surface wells contaminated with feacal bacteria saw infant and child mortality increase by 27% (Field, Glennerster, and Hussam 2011).

While there is an extensive body of research linking pollution to adverse outcomes, more work is needed to uncover the causal impact of sustained pollution exposure in developing countries. Data is more readily available in developed contexts, but it is unclear how generalisable findings are to countries like India or China. Much of the literature examines exposure in the short term or at certain points in time (e.g., infancy or in utero) to analyse impacts. A broader quantification of the impacts of pollution exposure of many years is only beginning to be built up (see, e.g., Chen et al. 2018 and Ebenstein et al. 2017).

Finally, the distributional and heterogeneous impacts of pollution are even less understood. Does the burden of pollution exposure fall equally on everyone? This seems unlikely, as individuals can engage in defensive behaviours—the subject of our next section—and because proximity to sources of pollution is correlated with other covariates, such as household wealth. Even within the household there may be heterogeneous impacts: Women and children, often responsible for more household tasks, can be more susceptible to indoor air pollution. A better grasp and quantification of these dynamics is the first step toward designing solutions to combat pollution.

**Next steps and research priorities**

- Measure the productive, cognitive, and life-expectancy effects of pollution in developing countries.
- Measure the effects of long-term exposure to air pollution.
- Assess the distributional and heterogeneous impacts of pollution exposure by gender, socio-economic status, caste, or other categories.

### b. Guarding against pollution and the willingness to pay for environmental quality

Given that pollution is the greatest external risk to human health, we might expect that both governments and individuals have a high willingness to pay for preventing it. Yet poor environmental quality throughout the developing world could imply that this willingness to pay is low. An experiment generating exogenous variation in the quality of water supply in Kenya found that households were only willing to pay $11 per year for clean water (Kremer et al. 2011). For a long time, policy concerns over matters like pollution were displaced by the conquest of growth. Simply put, the marginal utility of consumption outranked the marginal utility of environmental quality.

This could in part be a function of a historical lack of information on impacts. China was, until recently, the embodiment of the growth-at-all-costs approach: tremendous economic success with disastrous implications for environmental quality and pollution. However, in 2013, China declared war on air pollution, setting aside $270 billion for its National Air Quality Action Plan, with the Beijing city government topping up with an additional $120 billion (Greenstone and Fan 2018). In the three years between 2013 and 2016, China succeeded in reducing particulate pollution exposure by 12% on average, an improvement on par with the progress made in the United States between 1998 and 2016. Few countries, if any, have made such substantial progress in improving air quality in such a short span of time.

Not all countries have the resources, determination, or institutions to wage a war on pollution at the scale China did. Residents who are stuck in highly polluted areas might therefore seek mechanisms to reduce their own exposure or carry on despite the risks. How can—and how do—households or individuals defend themselves against the ruinous effects of pollution? Any protective measure is sure to be costly. How much are individuals willing to pay to defend themselves from local pollution and improve overall environmental quality? Does this willingness extend beyond only the private gains from such behaviour? These are important questions that we need more evidence on in order to determine what optimal environmental regulation should look like.

One methodological challenge has been measuring revealed willingness to pay (WTP). One difficulty for estimation is that market failures (e.g., capital constraints) may cause the measured WTP to differ from its "true" value (Greenstone and Jack 2015). Defensive responses to pollution are likely to be diverse, with a range of costs. Quantifying how much households are willing to pay for their own self-protection requires us to first obtain a better understanding of the choices households make in the face of pollution, such as fertility decisions or adjustments to migration (Greenstone and Jack 2015).

Obtaining exogenous variation has, naturally, proven difficult thus far. Research in China closely tracked the sales of air purifiers and, using quasi-experimental variation from the North vs. South China divide created by the Huai River policy, determined the marginal willingness to pay for clean air (Ito and Zhang forthcoming). The estimated marginal willingness to pay is increasing in incomes, but with substantial heterogeneity. Continuing, Ito and Zhang (forthcoming) examine how widespread media coverage on pollution starting in 2013 affected the willingness to pay. As the issue has been given more serious attention, the willingness to pay for clean air has increased considerably. Applying these results, a cost-benefit analysis showed clear benefits from a heating-system reform programme around the Huai river, with households willing to pay $32.7 per year to eliminate the pollution stemming from this policy.

**Next steps and research priorities**

- Can we measure willingness to pay for environmental quality through household defensive responses to local pollution?
- How do social norms and market failures (e.g., imperfect information, capital constraints) affect willingness to pay for environmental quality through defensive expenditures?
- What causes willingness to pay for environmental quality to change? Do public information campaigns alter willingness to pay?

### c. Enforcing regulation in settings with weak institutions

| Country | Finding | Methodology | Author (year) |
|---|---|---|---|
| Brazil | Decentralisation increases water pollution | Fixed effects | Lipscomb and Mobarak (2011) |
| Mexico | Policy loopholes undermine effectiveness | Temporal discontinuity | Davis (2008) |
| Mexico | Voluntary certification lowers regulatory costs | Structural identification | Foster and Guiterrez (2012) |
| Mexico | Large inframarginal payments lower policy impacts | Fixed effects, regression discontinuity | Davis et al. (2015) |
| Bangladesh | Policy has large unintended consequences | Quasi-experiment | Field et al. (2011) |
| Philippines | Public and private provision are substitutes | Fixed effects, IV | Bennett (2012) |
| India | Public support improves the effectiveness of environmental policies | Fixed effects | Greenstone and Hanna (2014) |

**Table 2: Evidence for High Marginal Costs of Environmental Policies in Developing Countries (Source: Greenstone & Jack, 2015)**

Regulation is necessary to make energy bear its full social cost, guiding consumers and firms to internalise these costs in their behaviours. Poor environmental quality, therefore, might be the product of poorly designed regulation. We have discussed one potential reason for the current poor state of environmental quality: The utility from further consumption exceeds that of an improved environment—beating poverty trumps all else. Another view is that high marginal costs slow improvements in environmental quality. A key factor determining this is the local capacity for policy design and implementation of abatement policies. When institutions are weak, the cost of enforcing regulation can become prohibitive to the point where further investments into abatement are no longer socially efficient. Acquiring information about pollution and compliance with regulations can also be costly. Although advances in technologies and monitoring are greatly reducing the costs of detecting violators, the costs of monitoring and enforcement alone may make investments in new policy unpalatable. Tough environmental regulations on the books are not enough (Greenstone and Hanna 2014).

India is an excellent case study in strong environmental regulations leading to weak outcomes. A command-and-control system regulates industrial pollution, yet a large randomised-controlled trial found generally weak monitoring of air and water pollution and widespread non-compliance (Duflo et al. 2013). A system of mandated third-party pollution audits among industrial firms seemed, at first, to be a reasonable way to ensure compliance. However, firms were free to choose their auditors and paid them directly, allowing them to collude in fudging the numbers: Many firms came in just under the threshold for penalisation. The experiment randomly allocated firms to auditors and made payments through a common pool, breaking the direct links between them. As a result, auditors reported more truthfully, and plants lowered emissions (Duflo et al. 2013). This highlights the importance of political economy in determining the effectiveness of regulations when enforcement is weak.

Imperfect information is an overarching challenge. Regulators in India receive unreliable and infrequent emissions data. Breaking policy incurs a heavy penalty, but information flows to the regulator are weak. While plants are required to purchase costly abatement equipment, the regulator does not have the monitoring capacity to ensure that the equipment is used and that emissions are being reduced. The result is that emissions remain high. To compensate for this weak information, proxies like energy consumption or capital investment can be penalised with measures that are costly (e.g., plant closure) but unpredictable and thus ineffective overall (Duflo et al. 2014).

In the presence of imperfect information, a degree of flexibility may be necessary to allow regulators to collect and use local information. The potential challenge with flexibility is that it comes with discretion, a power which can be abused. A field experiment in Gujarat, India found significant discretion in regulators' decisions about which plants to inspect and what penalties to impose (Duflo et al. 2018). By upping the frequency of inspections and removing the element of discretion, they successfully increased regulatory scrutiny—plants were more routinely visited by inspectors, as required. However, they found that regulators were no more likely to identify the most extreme polluters, and so compliance increased only marginally.

Technology offers a solution to the information problem. Ongoing follow-up work in Gujarat seeks to understand the effect of more reliable information through the installation of Continuous Emissions Monitoring Systems (CEMS) for industrial air pollution. Real-time emissions data not only helps in monitoring; it also acts as the first step toward creating a market for emissions.

Transparency around pollution levels can also allow environmental regulation to have a further reach. Rating industries on pollution emission levels acts as a strong public signal to show which firms are adhering to pollution standards. In Maharashtra, India, the government released information on 20,000 industrial stack samples over several years under the Maharashtra Star Rating Programme. Residents were informed about industry emissions in their area, allowing citizens to call for action and encouraging competition between firms to reduce emissions.

**Next steps and research priorities**

- How can regulations meant to reduce local pollution emissions and improve environmental quality work when monitoring and enforcement are weak?
- Political economy of regulation: Why do governments adopt, or fail to adopt, environmental regulations, and how does this depend on benefits and costs?
- As new technologies reduce the marginal costs of detecting violators to near zero, what are the implications for efficient and politically feasible regulation in developing countries?
- What role does rent seeking or even bribery play in determining local environmental quality, and can such behaviour be reduced?
- Exploring the efficacy of information disclosure, emissions markets, and other advanced regulatory instruments in developing economies.

## 5. Conclusion

Many developing countries today—from Rwanda to Ethiopia to India to the Philippines—are undertaking an enormous and urgent push to bring modern energy to all of their citizens. This effort is justified by the necessity of modern, reliable energy for inclusive economic growth and, increasingly, for participation in an interconnected society. The enormous growth in energy services needed for this higher level of access will result in enormous damage to the local and global environment if powered by fossil fuels. Hence, there is a need for a new pro-development energy policy that achieves modern levels of energy access and service while limiting the growth of environmental damages from energy use.

In this evidence paper, we have argued that the problem is not only—or even mainly—one of technology, but also one of politics and policy. In the short term, the research we cite has shown that the features of energy markets everywhere—complex links between energy consumption and external costs; a large share of public ownership, investment, and regulation; political interference and populism; difficulties in contracting and market design due to natural monopoly and asset specificity—result in a series of market and governance failures in developing countries. Even taking technology as given, there appear to be large possible efficiency gains and welfare gains from policy reforms that cut through these distortions. We do not mean to say that any of these constraints are easily solved, or even that many of them could be wholly removed, but only that at the margin they appear to leave space for beneficial policy reforms.

To repeat a few examples: Could politicians remove energy subsidies if they buy out citizens with targeted unconditional transfers? What feasible policies around transportation and environmental regulation might address the unbearable level of air pollution observed in many developing country cities today? How can public investments lower the costs of adaptation to extreme heat?

In the longer run, technology is changing rapidly, and the technology that countries choose to expand their energy sectors itself depends on the policy environment. Renewable energy is a case in point. Developing countries will adopt renewable energy if it is cost competitive. Whether renewable energy is cost competitive will depend on whether energy prices include social costs, on public investments to physically integrate markets, on institutions to contract and procure energy and establish energy markets, and on international policy toward technology transfer and trade. The next five years—and the next fifty—will be tumultuous for the energy sector and the global environment. Research on the design of energy policies is likely to be of enormous social value, even when it remains some way behind the pace of change on the ground.

## References


Adhvaryu, A., Kala, N., & Nyshadham, A. (2014). Management and shocks to worker productivity: evidence from air pollution exposure in an Indian garment factory. Retrieved from University of Michigan: https://economics.stanford.edu/files/PM_oct14.pd

Adkins, E., Eapen, S., Kaluwile, F., Nair, G., & Modi, V. (2010). Off-grid energy services for the poor: Introducing LED lighting in the Millennium Villages Project in Malawi. *Energy Policy,* 38(2), 1087-1097.

Agrawala, S., Carraro, M., Kingsmill, N., Lanzi, E., Mullan, M., & Prudent-Richard, G. (2011). Private sector engagement in adaptation to climate change: approaches to managing climate risks.

Akbari, H., Xu, T., Taha, H., Wray, C., Sathaye, J., Garg, V., ... & Reddy, K. N. (2011). Using cool roofs to reduce energy use, greenhouse gas emissions, and urban heat-island effects: Findings from an India experiment (Working Paper No. LBNL-4746E). Retrieved from Lawrence Berkeley National Lab (LBNL), Berkeley, CA.

Aklin, M., Bayer, P., Harish, S. P., & Urpelainen, J. (2017). Does basic energy access generate socioeconomic benefits? A field experiment with off-grid solar power in India. *Science Advances*, 3(5), e1602153.

Alam, M. (2013). Coping with blackouts: Power outages and firm choices. Retrieved from Department of Economics, Yale University.

Allcott, H., Collard-Wexler, A., & O'Connell, S. D. (2016). How do electricity shortages affect industry? Evidence from India. *American Economic Review*, *106*(3), 587-624.

Allcott, H., & Mullainathan, S. (2010). Behavior and energy policy. *Science*, *327*(5970), 1204-1205.

Allcott, H., & Rogers, T. (2014). The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. *American Economic Review*, *104*(10), 3003-37.

Allcott, H., & Greenstone, M. (2017). Measuring the welfare effects of residential energy efficiency programmes (Working Paper No. w23386). *National Bureau of Economic Research.*

Apte, J. S., Kirchstetter, T. W., Reich, A. H., Deshpande, S. J., Kaushik, G., Chel, A., ... & Nazaroff, W. W. (2011). Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India. *Atmospheric Environment*, *45*(26), 4470-4480.

Assunção, J., Lipscomb, M., Mobarak, A. M., & Szerman, D. (2015). Infrastructure development can benefit the environment: electrification, agricultural productivity and deforestation in Brazil. *LACEA 2015 Papers*.

Balboni, C. A. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities (Working Paper). Retrieved from The London School of Economics and Political Science (LSE).

Banerjee, L. (2007). Effect of flood on agricultural wages in Bangladesh: An empirical analysis. *World Development*, *35*(11), 1989-2009.

Barnes, D. F., & Floor, W. M. (1996). Rural energy in developing countries: a challenge for economic development. *Annual Review of Energy and the Environment*, *21*.

Barnett, B. J., & Mahul, O. (2007). Weather index insurance for agriculture and rural areas in lower-income countries. *American Journal of Agricultural Economics*, *89*(5), 1241-1247.

Barron, M., & Torero, M. (2017). Household electrification and indoor air pollution. *Journal of Environmental Economics and Management*, *86*, 81-92.

Baskaran, T., Min, B., & Uppal, Y. (2015). Election cycles and electricity provision: Evidence from a quasi-experiment with Indian special elections. *Journal of Public Economics*, *126*, 64-73.

Beach, B., & Hanlon, W. W. (2017). Coal smoke and mortality in an early industrial economy. *The Economic Journal*, *128*(615), 2652-2675.

Behrens, K., Duranton, G., & Robert-Nicoud, F. (2014). Productive cities: Sorting, selection, and agglomeration. *Journal of Political Economy*, *122*(3), 507-553.

Bettencourt, L. M. (2013). The origins of scaling in cities. *Science*, *340*(6139), 1438-1441.

Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences*, *104*(17), 7301-7306.

Bettencourt, L. M., Lobo, J., & Strumsky, D. (2007). Invention in the city: Increasing returns to patenting as a scaling function of metropolitan size. *Research Policy*, *36*(1), 107-120.

British Petroleum (2013). *BP statistical review of world energy June 2013.* Retrieved from British Petroleum London: http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html

Brown, D. S., & Mobarak, A. M. (2009). The transforming power of democracy: regime type and the distribution of electricity. *American Political Science Review*, *103*(2), 193-213.

Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *The Lancet*, *360*(9341), 1233-1242.

Burgess, R., Deschenes, O., Donaldson, D., & Greenstone, M. (2014). The unequal effects of weather and climate change: Evidence from mortality in India (Working Paper).

Burgess, R., Greenstone, M., Ryan, N., & Sudarshan, A. (2019). Demand for electricity in a poor economy (Working Paper). Retrieved from London School of Economics: http://www.lse.ac.uk/economics/Assets/Documents/personal-pages/robin-burgess/demand-for-electricity-in-a-poor-economy.pdf

Burgess, R., Greenstone, M., Ryan, N., & Sudarshan, A. (2019). Electricity is not a right. *Journal of Economic Perspectives*, forthcoming.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, *527*(7577), 235.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Climate and conflict. *Annual Review of Economics*, *7*(1), 577-617.

Burlig, F., & Preonas, L. (2016). Out of the darkness and into the light? Development effects of rural electrification (Working Paper No. 268). Retrieved from University of California Berkeley: https://ei.haas.berkeley.edu/research/papers/WP268.pdf

Bushnell, J., & Novan, K. (2018). Setting with the Sun: The impacts of renewable energy on wholesale power markets (NBER Working Paper No. w24980). Retrieved from the National Bureau of Economic Research.

Carleton, T., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., ... & Rising, J. (2018). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits (Working Paper No. 2018-51). Retrieved from Becker Friedman Institute.

Castellano, A., Kendall, A., Nikomarov, M., & Swemmer, T. (2015). *Brighter Africa: The growth potential of the sub-Saharan electricity sector.* Retrieved from McKinsey Company.

Chakravorty, U., Emerick, K., & Ravago, M. L. (2016). *Lighting up the last mile: The benefits and costs of extending electricity to the rural poor.* Resources for the Future Discussion Paper, 16-22.

Chen, Y., Ebenstein, A., Greenstone, M., & Li, H. (2013). Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy. *Proceedings of the National Academy of Sciences*, *110*(32), 12936-12941.

Cicala, S. (2017). Imperfect markets versus imperfect regulation in US electricity generation (Working Paper No. w23053). Retrieved from the National Bureau of Economic Research.

Ciccone, A., & Hall, R. (1996). Productivity and the density of economic activity. *American Economic Review 86*(1), 54-70.

Coady, D., Parry, I. W., Sears, L., & Shang, B. (2015). How large are global energy subsidies? (Working Paper No. 15-105). Retrieved from the International Monetary Fund.

Coady, D. P., Flamini, V., & Sears, L. (2015). The unequal benefits of fuel subsidies revisited: Evidence for developing countries. Retrieved from the International Monetary Fund.

Combes, P. P., Duranton, G., Gobillon, L., Puga, D., & Roux, S. (2012). The productivity advantages of large cities: Distinguishing agglomeration from firm selection. *Econometrica*, *80*(6), 2543-2594.

Conway D, Dalin C, Landman WA, Osborn TJ (2017) Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy* 2: 946–953.

Crafts, N. (2004). Productivity growth in the industrial revolution: A new growth accounting perspective. *The Journal of Economic History*, *64*(2), 521-535.

Davis, L. W., Fuchs, A., & Gertler, P. (2014). Cash for coolers: evaluating a large-scale appliance replacement programme in Mexico. *American Economic Journal: Economic Policy*, *6*(4), 207-38.

Davis, L. W., & Kahn, M. E. (2010). International trade in used vehicles: The environmental consequences of NAFTA. *American Economic Journal: Economic Policy*, *2*(4), 58-82.

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, *4*(3), 66-95.

Di Bella, M. G., Norton, M. L., Ntamatungiro, M. J., Ogawa, M. S., Samake, I., & Santoro, M. (2015). Energy subsidies in Latin America and the Caribbean: stocktaking and policy challenges (Working Paper No. 15-30). Retrieved from the International Monetary Fund.

Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. *American Economic Review*, *101*(7), 3078-3108.

Dinkelman, T. & Schulhofer-Wohl, S. (2015). Migration, congestion externalities, and the evaluation of spatial investments. *Journal of Development Economics*, *114*, 189-202.

Duflo, E., Greenstone, M., Pande, R., & Ryan, N. (2013). Truth-telling by third-party auditors and the response of polluting firms: Experimental evidence from India. *The Quarterly Journal of Economics*, *128*(4), 1499-1545.

Dupas, P. (2011). Health behavior in developing countries. *Annual Review of Economics*, *3*(1), 425-449.

Ebenstein, A., Fan, M., Greenstone, M., He, G., & Zhou, M. (2017). New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy. *Proceedings of the National Academy of Sciences*, *114*(39), 10384-10389.

Eberhard, A., Foster, V., Briceño-Garmendia, C., Ouedraogo, F., Camos, D., & Shkaratan, M. (2008). Underpowered: the state of the power sector in Sub-Saharan Africa. Retrieved from World Bank Group: https://www.openknowledge.worldbank.com/handle/10986/7833

Eberhard, A., Kolker, J., & Leigland, J. (2014). South Africa's renewable energy IPP procurement program: Success factors and lessons. Public-Private Infrastructure Advisory Facility, World Bank Group.

EIA (2012). Most states have renewable portfolio standards. Available from: http://www.eia.gov/todayinenergy/detail.cfm?id=4850

Estache, A., Goicoechea, A., & Trujillo, L. (2006). Utilities reforms and corruption in developing countries. Retrieved from The World Bank: http://dx.doi.org/10.1016/j.jup.2008.07.002.

Estache, A., Gomez-Lobo, A., & Leipziger, D. (2001). Utilities privatization and the poor: lessons and evidence from Latin America. *World Development*, *29*(7), 1179-1198.

Fankhauser, S. (2017). Adaptation to climate change. *Annual Review of Resource Economics*, *9*, 209-230.

Field, E., Glennerster, R., & Hussam, R. (2011). Throwing the baby out with the drinking water: Unintended consequences of arsenic mitigation efforts in Bangladesh (Working Paper). Retrieved from Harvard University, Department of Economics.

Fisher-Vanden, K., Mansur, E. T., & Wang, Q. J. (2015). Electricity shortages and firm productivity: evidence from China's industrial firms. *Journal of Development Economics*, *114*, 172-188.

Fowlie, M., Greenstone, M., & Wolfram, C. (2018). Do energy efficiency investments deliver? Evidence from the weatherization assistance program. *The Quarterly Journal of Economics*, *133*(3), 1597-1644.

Galiani, S., Gertler, P., & Schargrodsky, E. (2005). Water for life: The impact of the privatization of water services on child mortality. *Journal of Political Economy*, *113*(1), 83-120.

Gibbens, S. (2018). Air pollution robs us of our smarts and our lungs. Retrieved from National Geographic: https://www.nationalgeographic.com/environment/2018/09/news-airquality-brain-cognitivefunction

Gertler, P., Shelef, O., Wolfram, C., & Fuchs, A. (2013). How pro-poor growth affects the demand for energy (Working Paper No. w19092). Retrieved from the National Bureau of Economic Research: from http://dx.doi.org/10.3386/w19092.

Glaeser, E. (2012). Viewpoint: Triumph of the city. *The Journal of Transport and Land Use*, *5*(2), 1-4.

Goldemberg, J., La Rovere, E. L., Coelho, S. T., Simões, A. F., Peres, S., Guardabassi, P., ... & Manuel, M. (2013). Energy poverty in developing countries' urban poor communities: Assessments and recommendations: Urban and peri-urban energy access III. *Global Network on Energy for Sustainable Development by The Energy and Resources Institute (TERI).*

Goel, R., & Guttikunda, S. K. (2015). Evolution of on-road vehicle exhaust emissions in Delhi. *Atmospheric Environment, 105,* 78-90.

Graff Zivin, J., & Neidell, M. (2012). The impact of pollution on worker productivity. *American Economic Review*, *102*(7), 3652-73.

Greenstone, M., & Hanna, R. (2014). Environmental regulations, air and water pollution, and infant mortality in India. *American Economic Review*, *104*(10), 3038-72.

Greenstone, M., Nilekani, J., Pande, R., Ryan, N., Sudarshan, A., & Sugathan, A. (2015). Lower pollution, longer lives: life expectancy gains if India reduced particulate matter pollution. *Economic and Political Weekly*, *50*(8).

Greenstone, M., & Fan, C. Q. (2018). Introducing the Air Quality Life Index. *AQLI Annual Report.*

Grimm, M., Lenz, L., Peters, J., & Sievert, M. (2019). Demand for off-grid solar electricity: Experimental evidence from Rwanda. *IZA Discussion Paper Series (10427)*.

Grogan, L. (2015). Household electrification, fertility and employment: Evidence from the Colombian censuses. *Journal of Human Capital*, forthcoming.

Grogan, L., & Sadanand, A. (2009). Electrification and the household. *University of Guelph,* *Economics Department.*

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change*, *15*(3), 199-213.

Guttikunda, S. K., & Calori, G. (2013). A GIS based emissions inventory at 1 km× 1 km spatial resolution for air pollution analysis in Delhi, India. *Atmospheric Environment*, *67*, 101-111.

Guttikunda, S. K., & Goel, R. (2013). Health impacts of particulate pollution in a megacity—Delhi, India. *Environmental Development*, *6*, 8-20.

Guttikunda, S. K., Kopakka, R. V., Dasari, P., & Gertler, A. W. (2013). Receptor model-based source apportionment of particulate pollution in Hyderabad, India. *Environmental Monitoring and Assessment*, *185*(7), 5585-5593.

Hanna, R., & Oliva, P. (2015). The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. *Journal of Public Economics*, *122*, 68-79.

Houde, S. (2018). How consumers respond to product certification and the value of energy information. *The RAND Journal of Economics*, *49*(2), 453-477.

Houde, S., & Spurlock, C. A. (2015). Do energy efficiency standards improve quality? Evidence from a revealed preference approach.

Houde, S., Todd, A., Sudarshan, A., Flora, J. A., & Armel, K. C. (2013). Real-time feedback and electricity consumption: A field experiment assessing the potential for savings and persistence. *The Energy Journal*, 87-102.

IEA. (2014). Renewable energy medium-term market report. IEA (2014). Available from: https://www.iea.org/Textbase/npsum/MTrenew2014sum.pdf

IEA. (2019). Establishing multilateral power trade in ASEAN.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). Climate change 2014: Synthesis report. *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 151.

Guilyardi, E., Lescarmontier, L., Matthews, R., Point, S. P., Rumjaun, A. B., Schlüpmann, J., & Wilgenbus, D. (2018). *IPCC special report: Global warming of 1.5°C.*

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J., ... & Sabde, Y. (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet Planetary Health*, *3*(1), e26-e39.

IRENA. (2012). Prospects for the African power sector.

IRENA & CEM. (2015). Renewable energy auctions: A guide to design.

IRENA. (2018). Renewable power generation costs in 2018.

Ito, K., & Zhang, S. (2016). Willingness to pay for clean air: Evidence from air purifier markets in China. *Journal of Political Economy*, forthcoming.

Jacobson, M. Z. (2012). *Air pollution and global warming: history, science, and solutions*. Cambridge University Press.

Jevons, W. S. (1905). *The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines* (p. 374). New York: Augustus M. Kelley.

Jorgenson, D. W. (1984). The role of energy in productivity growth. *The Energy Journal*, *5*(3), 11-26.

Joskow, P. L. (2008). Lessons learned from the electricity market liberalization. *Energy Journal*, 29(2): 9 –42.

Joskow, P. L. (2011). Comparing the costs of intermittent and dispatchable electricity generating technologies. *American Economic Review*, *101*(3), 238-41.

Kambanda, C. (2013). Power trade in Africa and the role of power pools. Retrieved from the African Development Bank: http://www.afdb.org/en/blogs/integrating-africa/post/power-trade-in-africa-and-the-role-of-power-pools012101/

Karl, T. R., Jones, P. D., Knight, R. W., Kukla, G., Plummer, N., Razuvayev, V., ... & Peterson, T. C. (1993). A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. *Bulletin of the American Meteorological Society*, *74*(6), 1007-1024.

Kazianga, H., & Udry, C. (2006). Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso. *Journal of Development Economics*, *79*(2), 413-446.

Lee, K., Brewer, E., Christiano, C., Meyo, F., Miguel, E., Podolsky, M., ... & Wolfram, C. (2016). Electrification for “under grid” households in rural Kenya. *Development Engineering*, *1*, 26-35.

Kessides, I. N. (2012). The impacts of electricity sector reforms in developing countries. *The Electricity Journal*, *25*(6), 79-88.

Khandker, S., Barnes, D., & Samad, H. (2013). Welfare impacts of rural electrification: A panel data analysis in Vietnam”, *Economic Development and Cultural Change, 61*(3).

Kocornik-Mina, A., McDermott, T., Michaels, G., & Rauch, F. (2019). Flooded cities. *American Economic Journal: Applied Economics*.

Lal, S. (2006). Can good economics ever be good politics? A case study of India’s power sector (Working Paper No. 83). Retrieved from the World Bank Group.

Lee, K., Miguel, E., & Wolfram, C. (2019). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, forthcoming.

Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics*, *5*(2), 200-231.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., ... & Aryee, M. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2224-2260.

Liu, L., Johnson, H. L., Cousens, S., Perin, J., Scott, S., Lawn, J. E., ... & Mathers, C. (2012). Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. *The Lancet*, *379*(9832), 2151-2161.

Lobell, D. B., & Tebaldi, C. (2014). Getting caught with our plants down: the risks of a global crop yield slowdown from climate trends in the next two decades. *Environmental Research Letters*, *9*(7), 074003.

Lofgren, H. (2013). *Closing rural-urban MDG gaps in low-income countries: A general equilibrium perspective*. Retrieved from the World Bank Group.

Lucas, R. (2002). *The Industrial Revolution: Past and Future.* Harvard University Press, Cambridge.

Malik, K., Cropper, M., Limonov, A., & Singh, A. (2015). The impact of electricity sector restructuring on coal-fired power plants in India. *The Energy Journal*, 287-312.

Mauritzen, J. (2012). Dead battery? Wind power, the spot market, and hydro power interaction in the Nordic electricity market. *Mimeograph.*

McKinsey and Co. (2015). Brighter Africa: The growth potential of the sub-Saharan electricity sector. Available from: http://www.mckinsey.com/~/media/mckinsey/dotcom/insights/energy%20resources%20materials/powering%20africa/brighter_africa_the_growth_potential_of_the_sub-saharan_electricity_sector.ashx

McNeil, M.A, Ke,  J., Rue de Can, S., Letschert, V., & McMaho, J. (2011). *Business case for energy efficiency in support of climate change mitigation, economic and societal benefits in India.* (Technical Report No. LBNL-5344E.) Lawrence Berkeley National Laboratory.

McRae, S. (2015). Infrastructure quality and the subsidy trap. *American Economic Review 105*(1):35–66. http://dx.doi.org/10.1257/aer.20110572

Min, B. (2015). *Power and the vote: Elections and electricity in the developing world.* New York: Cambridge University Press.

Min, B., & Golde, M. (2014). Electoral cycles in electricity losses in India. *Energy Policy 65*: 619–625.

Murillo, M.V., (2009). *Political competition, partisanship, and policy making in Latin American public utilities.* New York: Cambridge University Press.

Nordhaus, W. (1996). Do real-output and real-wage measures capture reality? The history of lighting suggests not. *The economics of new goods.* Chicago: University of Chicago Press, 27-70.

Ozturk, I. (2010). A literature survey of the energy-growth nexus. *Energy Policy*, 38(1), 340–349.

Pan, Z., & Zhang, F. (2002). Urban productivity in China. *Urban Studies 39*(12):2267–2281. Retrieved from: http://dx.doi.org/10.1080/0042098022000033863

Parker, D., & Kirkpatrick, C. (2005). Privatisation in developing countries: A review of the evidence and the policy lessons. *Journal of Development Studies 41*(4):513– 541. Retrieved from: http://dx.doi.org/10.1080/00220380500092499

Phadke, A., Abhyankar, N., & Shah, N. (2013). *Avoiding 100 new power plants by increasing efficiency of room air conditioners in India: Opportunities and challenges.* Retrieved from Lawrence Berkeley National Laboratory.

Philip, S., Martin, R.V., van Donkelaar, A., Lo, J.W., Wang, Y., Chen, D., & Macdonald, D.J. (2014). Global chemical composition of ambient fine particulate matter for exposure assessment. *Environmental Science & Technology*, *48*(22), 13060-13068.

Pitt, M., Rosenzweig, M., & Hassan, N. (2015). Identifying the cost of a public health success: Arsenic well water contamination and productivity in Bangladesh (NBER Working Paper No. 21741). Retrieved from the National Bureau of Economic Research.

Rud, J.P. (2012). Electricity provision and industrial development: Evidence from India. *Journal of Development Economics, 97*, 352-367.

Ryan, N. (2018). Energy productivity and energy demand: Experimental evidence from Indian manufacturing plants (NBER Working Paper No. 24619). Retrieved from the National Bureau of Economic Research.

Ryan, N. (2019a). The competitive effects of transmission infrastructure in the Indian electricity market (Working Paper).

Ryan, N. (2019b). Contract enforcement and productive efficiency: Evidence from the bidding and renegotiation of power procurement contracts in India (Working Paper).

Scott, N., McKemey, K., & Batchelor, S. (2005). *Energy in low-income urban communities* (Technical Report Contract Number R8146). Department for International Development.

Shaw, D., & Perera, N. (2014). *Factors at country level influencing choice in utilisation of energy resource potential.* Evidence on Demand.

Sherwood, S., & Huber, M. (2010). An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Science*, *107*(21), 9552-9555.

Singh, Gopal K., & Mohammad Siahpush (2014). Widening rural-urban disparities in life expectancy, United States 1969-2009. *American Journal of Preventive Medicine 46*(2):e19–e29. Retrieved from: http://dx.doi.org/10.1016/j.amepre.2013.10.017

Singh, R. et al. (2014). “Energy access realities in urban poor communities of developing countries: assessments and recommendations”. *GNESD-UNEP.*

Slemrod, J., & Gillitzer, C. (2014). *Tax Systems.* Cambridge: MIT Press.

Slemrod, J. (2016). Tax compliance and enforcement: New research and its policy implications (Working Paper No. 1302). Retrieved from the Ross School of Business.

Somanathan, E. et al. (2015). The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing (Centre for Development Economics Working Paper No. 244). Retrieved from Delhi School of Economics.

Sudarshan, A. (2013). The behavioural effects of monetary contracts: *Using peer comparisons and financial incentives to reduce electricity demand in urban Indian households.* Stanford Institute for Theoretical Economics: Psychology and Economics Summer Workshop (Sep 23-25).

Sveikauskas, L. (1975). The productivity of cities. *The Quarterly Journal of Economics 89(*3):393-413. Retrieved from: http://dx.doi.org/10.2307/1885259

Straub, S. (2008). Infrastructure and development: A critical appraisal of the macro level literature (Working Paper No. 4590). Retrieved from the World Bank.

UK Ministry of Health. (1954). Mortality and morbidity during the London fog of December 1952. Reports on Public Health and Medical Subjects No 95. Retrieved from the Highline Medical Services Organisation, London.

United Nations. (2009). *Scaling up renewable energy in Africa: 12th ordinary session of heads of state and governments of the African Union*. Addis Ababa, Ethiopia. Retrieved from: http://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Renewable_Energy/Publications/Scaling%20Up%20web.pdf

United Nations. (2014). *World urbanization prospects: The 2014 revision.* Retrieved from the United Nations: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

USAID. (2004). *Innovative approaches to slum electrification.* United States Agency for International Development.

U.S. Department of Energy. (2012). Energy savings performance contracts (ESPCs). Available from: http://energy.gov/sites/prod/files/2013/10/f3/espc_intro.pdf

Van de Walle, D., Ravallion, M., Mendiratta, V., & Koolwal, G. (2013). *Long-term impacts of household electrification in rural India*. Retrieved from The World Bank.

Victor, D. G., & Heller, T. C. (Eds.). (2007). *The political economy of power sector reform: the experiences of five major developing countries*. Cambridge University Press.

Wolfram, C., Shelef, O., & Gertler, P. (2012). How will energy demand develop in the developing world? *Journal of Economic Perspectives*, *26*(1), 119-38.

World Bank. (2019). *Beyond the gap: How countries can afford the infrastructure they need while protecting the planet*.

World Bank. (2019b). Rethinking Power Sector Reform in the Developing World.

World Bank. (2019c). Fact Sheet: Energy Storage Partnership.

World Health Organization. (2016). Ambient air pollution: A global assessment of exposure and burden of disease.

Zamuda, C.D., Bilello, D., Conzelmann, G., Mecray, E., Satsangi, A. Tidwell, V., Walker, B. (2018) Energy Supply, Delivery, and Demand. *In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 174–201

Zhang, Y. F., Parker, D., & Kirkpatrick, C. (2008). Electricity sector reform in developing countries: an econometric assessment of the effects of privatization, competition and regulation. *Journal of Regulatory Economics, 33*(2), 159-178.

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