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IGC evidence paper
Energy & Environment

EVIDENCE PAPER
ENERGY / MARCH 2021

DIRECTED BY
LSE
UNIVERSITY OF OXFORD

FUNDED BY
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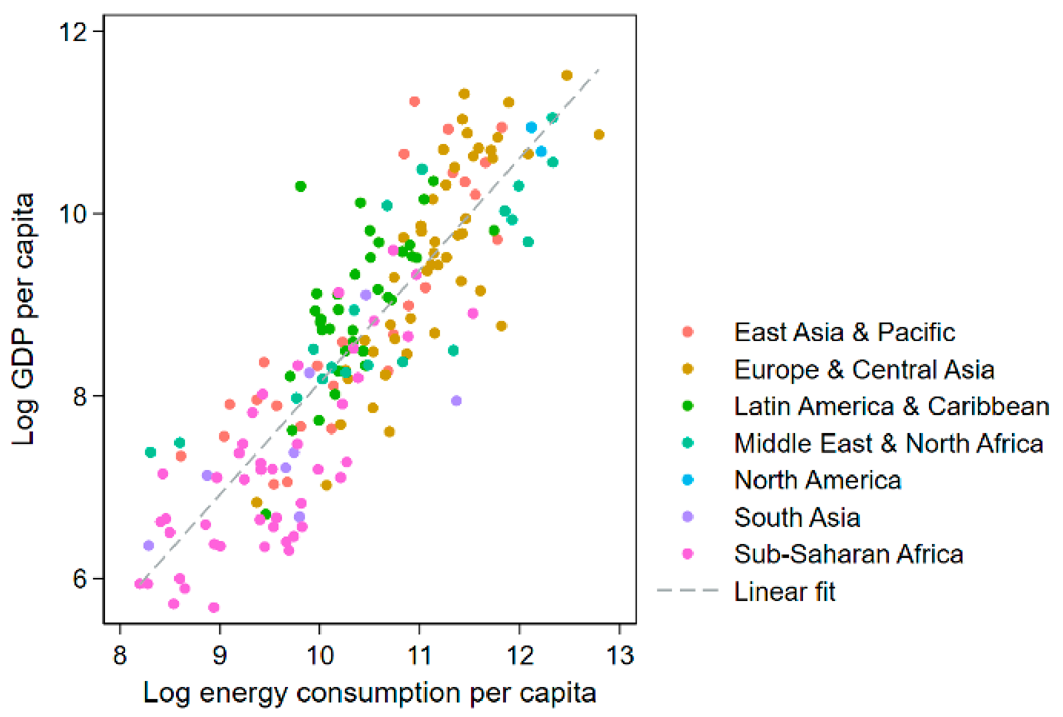
1 Introduction

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 across countries in energy consumption is even wider than in income. 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 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 clean, 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 2012, 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. 2019). **Most of the increase in energy consumption in the coming decades will come from developing countries** (Wolfram et al. 2012). If the majority of that growth comes from fossil fuels, and the International Energy Agency (IEA 2018) projects that under current trends they will supply 74% of primary energy demand in 2040 (down from 81% in 2017), it will create damaging consequences to health, productivity, and ecosystems in those countries and around the world (IPCC 2015).

Most of the increase in energy consumption in the coming decades will come from developing countries.

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 air 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 almost all 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 max-**

imises 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. 2020a). **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.**

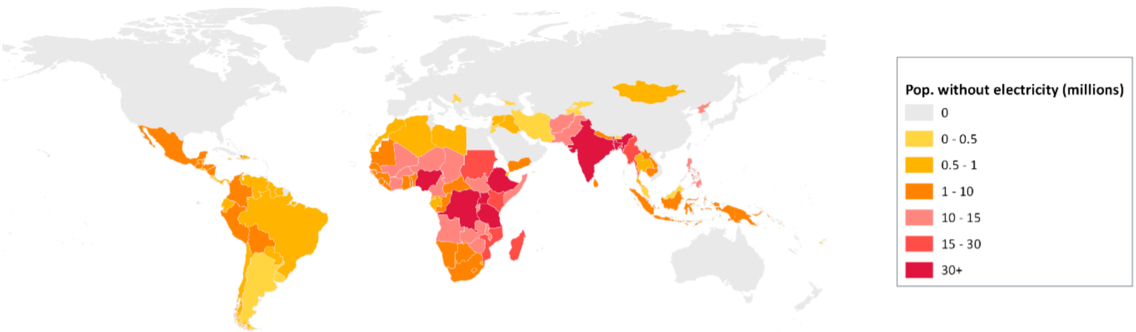
Renewable energy can reduce both local and global externalities from energy use, and is therefore an essential element of any pro-development energy policy.

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, set prices that incorporate the external costs of energy use, 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, clean, and reliable energy

FIGURE 2 **Population, in millions, without electricity**



Data: WDI, 2015

Energy access has many sides. Everyone, even the poorest, uses energy in their daily lives to provide some services, whether for cooking food, staying warm, transporting themselves or their produce, lighting their home, or entertaining themselves and their families. The main difference in developing countries is in the type of energy people use, and how much. In developed countries, the energy services that meet these needs have more or less converged to a set of convenient and relatively low cost technologies, such as electricity and the combustion of natural gas and other fossil fuels, which are used in large quantities to provide a broad set of services. In developing countries, a range of traditional energy technologies are used, each to their own purpose, and the transitions to modern technologies are often protracted.

Cooking and lighting are examples of energy services in which both traditional and modern technologies serve the same needs, side by side, in the same countries or even the same communities. For cooking, 2.8 billion people use solid biomass fuel, such as charcoal, crop residue or cow dung (IEA 2017). As they grow richer and energy supply networks develop, many of these households switch to natural gas or electricity, which are cleaner, for households, and have a lower cost in household labor. This transition is unfolding at different rates in a range of developing countries today. **For lighting, a billion people, mostly in sub-Saharan Africa and South Asia, do not have access to electricity** (Figure 2). The "traditional" technology for these households is most often the kerosene lamp (the kerosene lamp, invented in the 1860s, itself supplanted various candle and lamp technologies (Nordhaus 1996). 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).

The long energy transition from traditional to modern sources of energy is inseparable from the process of economic development. We summarize the study of this transition under three broad questions.

First, on energy demand: what energy services and technologies do households demand, and what are the returns, both privately to households and businesses and socially to their broader economies, from increasing energy access?

Second, on energy supply: how do market structure and government policy on energy supply affect the efficiency of energy markets?

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

The long energy transition from traditional to modern sources of energy is inseparable from the process of economic development.

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. There is substance to this gap. Historical experience may be a poor guide to creating policy today, since technological change—namely, the advent of low-cost renewable energy—has made many tenets of market design obsolete. **Moreover, some policies that function well in developed-country markets may do poorly in developing-country markets, when state capacity is weaker or market failures are more widespread.**

A Energy demand and the benefits of access

The returns to energy access can be thought of in two parts: the private part and the social part.

The private part of the return to energy access is how much a household or business benefits from energy use. Benefits may take many forms, from better health and productivity to independence and security. For comparability, economists measure these benefits in terms of money. The conceptual leap of measuring benefits in money terms, is that private benefits can often be well-measured by demand, or willingness-to-pay, for energy. However, in the presence of market failures or household "internalities"—benefits not accounted for by household's revealed preference choices— measured demand may be an incomplete or inaccurate measure of private benefits. The first part of our discussion on energy demand considers under what conditions demand is a good measure of the private benefits of access, taking the example of the market for improved biomass cookstoves.

The social part of the return to energy access is the part that accrues to parties other than those using the energy. Part of the reason why energy markets are of such policy interest is that the social part of the returns to energy access is an unusually large part of the gross benefits and costs of energy use, in large part due to environmental externalities, such as air and water pollution. Since environmental externalities are such an important an object of policy, we consider them separately in Sections 3 (global externalities) and 4 (local externalities) below. In this section, we consider the social part of the return to energy use *not due* to environmental externalities. The second part of our discussion on energy demand considers why, aside from environmental harms, energy use may create external benefits or spillovers, focusing on access to electricity and the returns to electrification.

Challenges of measuring private benefits: the cookstove example

Is demand the right all-in measure of the private benefits of energy use? In principle, energy demand, a household's willingness-to-pay for energy services, measures the value that they get from that service in monetary terms. Energy economics has long been concerned that, in practice, demand may not capture all the benefits of using, or of saving, energy. A variety of reasons for why demand is not a complete measure have been proposed, including informational market failures, agency problems and credit constraints, but empirical evidence for many of these mechanisms remains thin. One example of this struggle is the literature on the energy-efficiency gap, a difference between the actual costs of energy use and the perception of those costs by households (Allcott and Greenstone, 2012). Another example, which has great policy importance for developing countries, is the literature on household adoption of cleaner cookstoves.

The literature on improved or "clean" cookstoves illustrates different views on whether demand is a sufficient measure of the benefits of energy access. Households cooking with biomass often use traditional cooking stove technologies, built out of local materials like mud, that are very cheap and easy to maintain but which demand a lot of fuel and generate a lot of air pollution in people's homes. Engineers can easily come up with stoves that consume much less fuel and emit less pollution than traditional versions. A large literature has asked whether household adoption of such stoves is efficient, or for some reason too slow (J-PAL 2020).

Households appear to have very low demand for stoves that are demonstrably better on technical grounds (Mobarak et al. 2012). In part, this is because manufactured stoves that are initially more efficient may be difficult to maintain, relative to traditional stoves, leading to a failure to use and maintain them (Duflo et al. 2016). News of stove failures spreads through social networks, suppressing demand (Miller and Mobarak, 2015). All this sounds like the efficient functioning of a marketplace—stoves that fail on some dimension, such as durability, are weeded out by household adoption decisions.

Nonetheless some, particularly stove advocates, argue that adoption of improved cookstoves may be too low, even if a number of specific stoves have failed. One reason would be internalities, or benefits or costs within households that are not captured by stove demand. Indoor air pollution is a leading example. Biomass cooking, particularly when it takes place indoors, generates high levels of indoor air pollution (Duflo et al. 2016). Households may not know or consider the health effects of such pollution when buying a stove. Further, such an intra-household failure may arise if men decide whether to spend money on an improved stove but women do the cooking.

A second reason why adoption would be too low, even from the household's own point of view, would be credit constraints (sometimes called liquidity constraints). Credit constraints, as a market failure and source of inefficiency, have been extensively studied in development economics, macroeconomics and other fields. Stoves, like other energy-using goods, are durable, and buying a higher-cost stove up-front may bring benefits, in terms of lower pollution or reduced energy cost, spread years into the future. Several studies have given evidence that demand for improved stoves that reduce energy consumption is significantly affected by access to credit (Levine and Cotterman 2012, Bensch et al. 2015, Berkouwer and Dean 2019).

Many other investments in energy access and energy-using durables are potentially affected by credit constraints in developing countries. A study in Kenya found that demand for electricity connections was far below the fixed cost of providing such a connection, whether measured by revealed preference, experimental estimates, or by stated preference estimates (Lee et al. 2019). The authors also note that stated preference demand under a longer payment timetable, like a loan, was much higher than when the connection was to be paid up front. Kenya has experimented with loans for the costs of new connections (Stima Loans) and with creating consumer groups to pool resources to pay fixed costs (Singh et al. 2014). Perhaps surprisingly, for poor populations credit constraints may bind not only for large, fixed investments but even for paying monthly bills. Recent research suggests that South African households with liquidity constraints may benefit from the use of pre-paid meters (Jack and Smith 2019). These meters have also led to the emergence of mobile platforms to purchase electricity recharges (Singh et al. 2014). In Thailand, the creation of a new temporary household registration enabled poor urban households to apply for legal connections (Cook et al. 2005).

This cookstove example illustrates several reasons why household demand for an energy-using durable may not measure the entire private benefits, or costs, of that durable. We would argue that many energy-using investments have a similar character, since they affect household decision-making in so many and such far reaching ways. For example, consider the channels through which electrification benefits households. 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 changes where households and firms choose to locate (Dinkelman and Schulhofer-Wohl 2015). Electrification may improve both the quantity and quality of schooling, for example by allowing for reading time in the evening, but we are not aware of any present empirical evidence on this point. Electrification may also provide health benefits by inducing households to switch away from unsafe or polluting technologies such as biomass stoves or kerosene lighting (van de Walle et al. 2013; Barron and Torero 2017).

The private and social benefits of electrification

Thus far we have used cookstoves and electrification as examples to show the subtlety of valuing, in a comprehensive way, the private benefits of energy access. The literature on rural electrification in developing countries is also a good case to consider the possible external benefits of energy use, due to spillovers in demand or productivity. Electrification has seen a boom of research in recent years on household valuations for electricity access and the benefits of such access. We will briefly review this work on the nature of rural demand, and then argue that, with the present evidence, there is still plenty of room for uncertainty about the right bundle of electrification policies.

> **Policy-makers in Africa, South Asia and elsewhere are adopting a "whatever it takes" strategy to electrification, investing aggressively in rural areas even where demand is low.**

The private benefit of energy access for the poor has lately been measured by several field experiments on the demand for electricity connections. The demand for grid electricity connections in Kenya is far below the cost, roughly $400, of providing such a connection (Lee et al. 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 et al. 2020b). Households 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. Households also take-up solar electricity as an alternative when the grid is too costly or not available (Burgess et al. 2020a, Aklin et al. 2017, Grimm et al. 2016). If both sources are available, however, households, particularly richer households, have a strong preference for grid electricity to serve higher loads (Burgess et al. 2020b).

Given such estimates of low demand, should the policy recommendation be that electrification be stopped, in areas as poor as rural Kenya or rural Bihar? On this question, policy is arguably way ahead of the base of research evidence, and has answered a resounding "no"—**policy-makers in Africa, South Asia and elsewhere are adopting a "whatever it takes" strategy to electrification, investing aggressively in rural areas even where demand is low.** We see at least three broad mechanisms, from the empirical literature on the benefits of electrification, to justify such an approach, though the evidence in these areas is partial and falls short of a complete account of the value of electrification.

First, most of the existing evidence on the demand for electricity is for rural households. But electricity is used by businesses, farms, schools, hospitals, cell phone towers and for all manner of other uses. The literature on these uses is incomplete, but suggests high demand for electricity from these sectors. **Unreliable electricity supply is viewed by firms as a significant obstacle to doing business** (Straub 2008). Macroeconomic modelling on the general equilibrium effects of power outages across several African countries finds that outages reduce output per worker by 20 percent on average (Fried and Lagakos 2020). Power shortages reduce the average output of Indian manufacturers by five percent, and considerably more so among small firms that lack backup generators (Allcottet al. 2016, 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 et al. 2015). Electricity is conducive to investments in irrigation, boosting agricultural productivity in Brazil (Assuncao et al. 2015). For villages subject to an exogenous income shock around the time of electrification, there is evidence that electrification in India increased non-agricultural employment (Fetter and Usmani 2020). In the Philippines, the cost of electrifying rural communities was recovered within a year, a result driven by large increases in agricultural income (Chakravorty et al. 2016). Electricity distribution networks have high fixed costs. If there are high returns to electrification in some rural sectors, but not necessarily for households themselves, then these high returns may justify rural electrification *en masse*.

Unreliable electricity supply is viewed by firms as a significant obstacle to doing business.

Second, even if private demand were measured for all households, businesses, and other uses, the sum of private demands may be less than the aggregate value of electricity if there are spillovers due to electricity use. A simple example would be that if one household in a village gets a TV, many other people may stop by to watch. A more complex example would be businesses adopting technologies (like a higher capital intensity of manufacturing) that have some returns for the business itself, but also returns to the worker or other businesses, i.e. agglomeration externalities productivity (Greenstone et al. 2010).

Longer-run estimates at a higher level of aggregation show large productivity benefits to electrification over the span of decades (Lipscomb et al. 2013). Historical experience also suggests there may be external returns. In both England's industrial revolution and the United States' Rural Electrification Administration, energy allowed the adoption of technologies that boosted labour productivity, leading to economic growth (Jorgenson 1984, Lucas 2002, Crafts 2004). These historical examples are powerful, but must be interpreted cautiously, since technology adoption and electrification are endogenous to economic growth. Contrary to the above literature, Burlig and Preonas (2016) find that village-level electrification has no medium-term impact on a number of economic outcomes, including employment, asset ownership and education levels. Spillovers are one explanation for the difference between micro-estimates of the demand for electricity and macro-estimates of its benefits. Substantial "external" benefits to village electrification have been found in Vietnam and India (Khandker et al. 2013, van de Walle et al. 2013).

Third, economic efficiency may not be the only or even the main aim of policy-makers for rural electrification. Many governments are intent on universal electrification as a right regardless of its economic benefits, for the dignity of their citizens and as a means of redistribution, so that even poor households can be integrated into a shared, modern way of life.

These examples, of clean cookstoves and rural electrification, show both the importance and empirical difficulty of measuring the demand for energy and the benefits of access. Energy uses touches every aspect of the economy. Because of the breadth of the interactions of energy with the economy, and the number of plausible reasons why demand may be an incomplete measure of the social return to investment in energy is unusually large. 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.

The literature on energy access therefore suggests several areas that are high priorities for future work. These would include reconciling micro-estimates of the demand for electricity with macro-estimates of its return; understanding how market failures or inter-household spillovers affect the relationship between measured demand and the benefits of energy use; and understanding the mechanisms for any external returns of energy use. While we have focused on cooking and electricity use, many of these questions would apply equally well to energy use for heating or for transportation. We summarize some of the main research priorities in the next page.

BOX 1 Next steps and research priorities

- **What is the demand for energy access and energy use for a range of users, energy sources, and end uses of energy?**
- **How does the advent of lower-cost renewable energy changes household demand for energy services?**
- **What are the direct gains of energy access for households, firms and public facilities?**
- **Do energy demand estimates line up with direct estimates of the gains from energy access? Why or why not?**
- **What are the external returns to energy access? What are the sources of external returns?**
- **What explains the differences in micro and macro estimates of the returns to electrification?**

B Energy supply

Whereas the discussion around energy access and growth tends to focus on the demand side, access needs to go hand in hand with efficiency. **Too little attention has been given to how energy markets in developing countries function differently**. In all countries, the supply side of the energy sector is not an idealized competitive market, but a heavily regulated mix of public and private entities. The reason is that energy supply typically exhibits high fixed costs, and thus increasing returns to scale, and tends to a natural monopoly. The state therefore must be involved in the operation or at least the regulation of these businesses to avoid market power. Examples of supply segments that fit this description include natural gas transmission pipelines and electricity distribution networks. Furthermore, energy prices are often visible to the public and perhaps not coincidentally, become an instrument of redistribution which further complicates their efficient supply.

What is different in developing countries, then? Several features of developing country economies can exacerbate the underlying natural monopoly problem. First, markets may be thin: the generating capacity in most East African countries is small enough that there are increasing returns to scale in generation at the level of the country, which is not true in large developed markets. Thus additional segments of supply, which are not natural monopolies in, say, the United States, are nationalized in developing countries. Second, contracts are less likely to be enforceable. Many investments in energy markets have a high degree of asset specificity. If a company builds a natural gas pipeline or a power plant in Ghana, that asset has a high value to Ghana but zero value serving any other country. Specificity can strain contract enforcement, since governments may be tempted to renege on investments. Ghana recently had a power crisis, during which it had to buy on contract a large amount of power from private generators. These generators produce, at a high cost, on offshore barges, rather than actually investing in the country. This strategy may be seen as a reluctance by private companies to make any completely sunk investment in Ghana's generation sector. If they cannot come to terms with some future government, the barges will be towed away to the next crisis.

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 (Burgess et al. 2020a; World Bank 2019b). **Few fundamental reforms take place during good times; in reality, problems often 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.

Few fundamental reforms take place during good times; in reality, problems often bubble up until there is a time of crisis and the lid blows off.

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, it 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 et al. 2006). 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 et al. 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 et al. 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 disproportionately benefit the non-poor, are often high, making them unattractive places to invest in electricity generation and distribution (McRae 2015).

A lack of investment results inevitably in low reliability and low quality of energy supply. Access to energy has an intensive margin as well as an extensive margin. It is commonplace in developing countries for governments to make a big push on the extensive margin, to get people access to cooking gas or electricity, only to neglect the intensive margin of ensuring a reliable supply. 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. 2017, Somanathan et al. 2015). And there is evidence that electricity outages lower manufacturing output at a rate of one to one (Allcott et al. 2016). 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, Singh et al. 2014).

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.

In a bid to boost private investment, several countries 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. Many developing countries may not have the scale, especially on their own, to build reasonably competitive supply sides. We therefore see high potential returns to regional integration and cooperation in the construction of supply infrastructure. At a glance this cooperation may seem to exacerbate political risk, but it may as well mitigate risk, by binding countries towards a common goal. And even in large advanced economies like the United States, integration of electricity markets can have substantial benefits (Cicala 2020).

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.

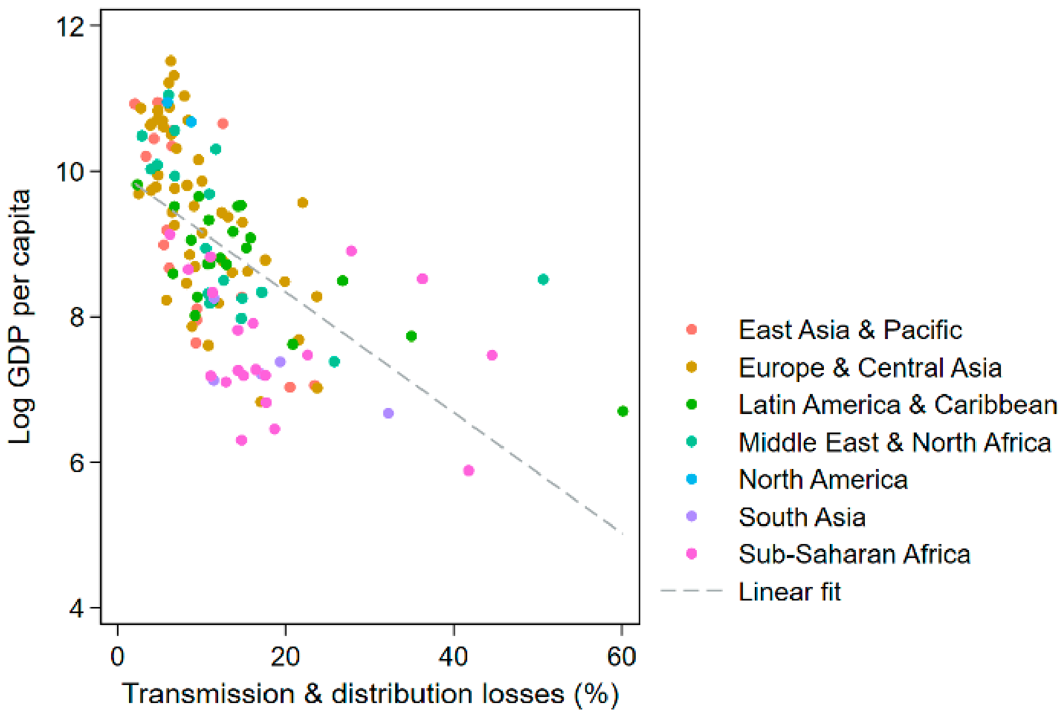
BOX 2 Next steps and research priorities

- **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 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?**
- **How do reforms in areas like financial contracting, procurement rules, or market formalisation and centralisation affect the efficiency of energy markets?**
- **What are the benefits of market integration in the electricity sector, both across regions within a country and across countries?**
- **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 the energy sector

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.

FIGURE 3 **Transmission and distribution losses**



Data: WDI, 2015

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.

Challenges in market reform

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 ex-

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.

ist 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.

Political capture and subsidies

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, Flamini, and Sears 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). Recent work in India using detail billing detail for millions of households and a close-election regression discontinuity design suggests that some of the subsidies might be instead politically targeted (Mahadevan 2021). The social norm of considering electricity a right generates losses, supply rationing, and unmet demand (Burgess et al. 2020a). **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).

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.

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. 2020a). 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 us 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 (McRae 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 (Singh et al. 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). New technologies, such as pre-paid metering systems, have shown promise to alleviate some of these concerns (Jack and Smith 2019).

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 2015; Coady, Parry, Sears, and Shang 2015). 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 2019). 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.

BOX 3 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

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 2015, 2018). The scale of these changes means **strategies to promote inclusive growth and eliminate extreme poverty must now incorporate both mitigation and adaptation strategies.**

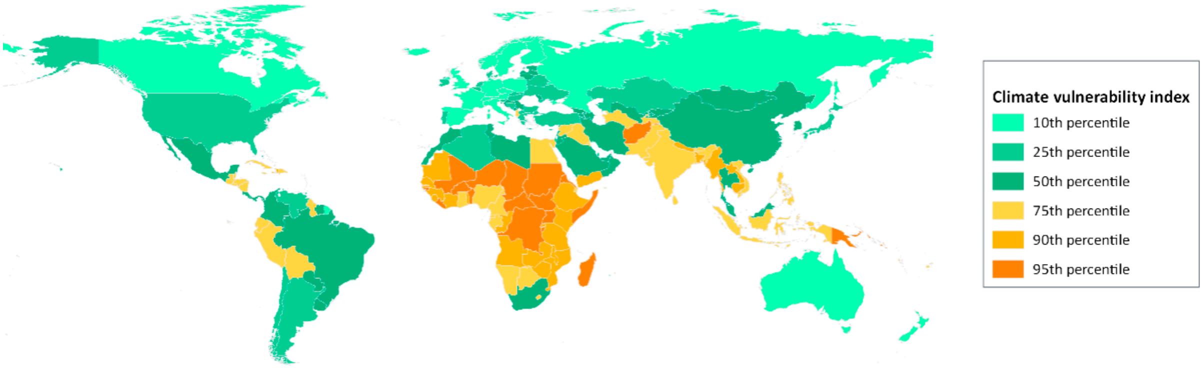
What consequences do the magnitude of the global externalities generated by energy consumption have for energy policy in developing countries? **Countries that are growing rapidly today, and thus will experience a major increase in their energy use** (e.g., Davis and Gertler 2015, Gertler et al. 2016), **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.** For electricity, 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 least in the power sector. At the same time, renewable energy growth may have higher costs, in terms of reliability, on power grids that have little dispatchable energy generation. There is an urgent need to identify the best mechanisms to support these countries in meeting their future energy demands cleanly. 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.

Strategies to promote inclusive growth and eliminate extreme poverty must now incorporate both mitigation and adaptation strategies.

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 adaptation strategies to climate 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.

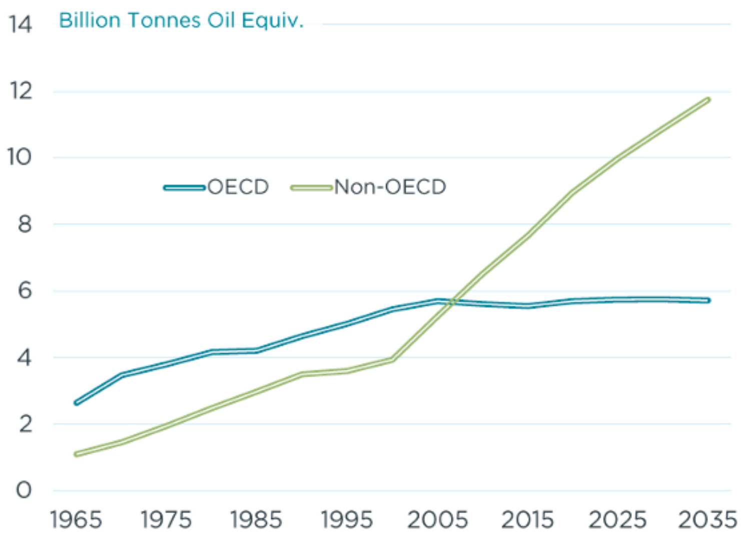
We first review mitigation policies on the supply side, with an emphasis on renewables in a developing context. We then examine mitigation policies on the demand side, with a discussion about how demand management and energy efficiency policies might contribute to mitigating energy demand (and emissions) growth. Finally, we review the evidence so far on the global impacts of climate change and discuss the need for further research in the role of the public sector to enable adaptation.

FIGURE 4 **Vulnerability to climate change**



Data: ND-GAIN 2017

FIGURE 5 **Global energy demand, 1965-2035, in BTOE**

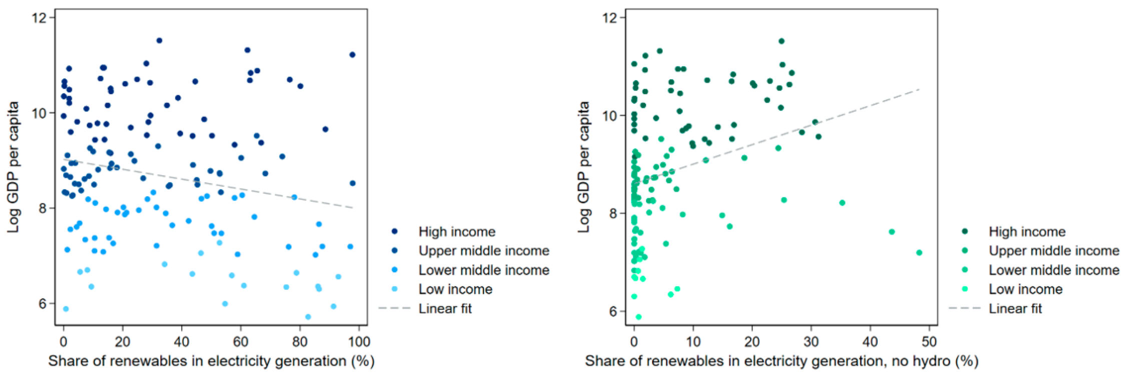


Source: EPIC, BP Statistical Review 2015

A Mitigation with supply-side energy policies

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, often in the form of clean electricity generation, which offers a clearer path to a transition away from the dependency on fossil fuels.

FIGURE 6 **Share of renewables in generation (with and without hydropower) based on income group**



Data: World Bank, 2015

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).

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.

The renewable potential in South Asian and sub-Saharan Africa is enormous.

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 (Davis 2017). 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 more today 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. As the share of renewables increases, it will also require policy that ensures that the costs of intermittency imposed by renewables are covered.

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 require 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. 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.

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.

Regional integration of electricity markets can increase the value of energy produced from renewable sources.

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 2020). 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.

Additionally, one could consider pricing schemes, such as real-time pricing, as an avenue to facilitate the integration of renewable power. Evidence in developed countries suggest that consumers are willing to adjust their consumption when given notice, although to a limited extent (e.g., Jessoe and Rapson 2014). Given the more elastic nature of electricity consumption in developing countries, and the fact that new technologies are making consumers more aware of prices (Jack and Smith 2019), it is possible that **effective pricing coupled with good information designs could facilitate the integration of renewables and minimize the costs of intermittency**. This might be particularly true in a context in which households are already used to having electricity not available at all times.

Financing renewables

Though this has been on the decline, much of the costs of renewables come in the form of up-front capital costs (EIA 2020). 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).

BOX 4 Next steps and research priorities

- **How can developing countries best manage the intermittency issues associated with low carbon energy sources?**
- **Do the gains from market integration help in managing intermittency? How does this differ for smaller grids? Does market integration facilitate the exercise of market power and to what degree does such behaviour offset the benefits of integration?**
- **What policies are effective in encouraging the adoption of storage technologies that aid grid management?**
- **Can pricing designs, such as real-time pricing, help manage intermittency challenges?**
- **How large is the role of credit constraints and capital market imperfections in slowing the adoption of renewables? How can these constraints be overcome?**
- **How can the performance of renewable auctions be enhanced through auction theory and past experiences?**
- **What are the most effective financial instruments for increasing low-carbon energy supply?**

B Mitigation with demand-side energy policies

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. However, efficiency policies have not often been rigorously evaluated, particularly in low and middle incomes countries where the scope for implementing them may be greatest.

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, as the incentives to reduce consumption on the part of households might be limited. Note that the issue of limited incentives for energy efficiency is also true for countries with fossil fuel subsidies (Davis 2017). As another rational for public intervention, recent work in the Kyrgyz Republic suggests that the social returns to energy efficiency can also include benefits in the form of increased reliability (Carranza and Meeks 2019), which consumers might not internalize. Recent 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 and Smith 2019).

Such policies can not only reduce consumption – in turn aiding mitigation efforts – but also address some of the costs of poor urban energy services. Cities, which consume about 75% of the world's primary energy (United Nations 2014), are at the heart of any demand-side and energy-efficiency policies as they represent the richest consumers and largest markets. In cities, the role of passive building design deserves more investigation, 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. Recent work in Mexico suggests that energy-efficient housing might not always have the intended energy savings (Davis et al 2019), and therefore careful planning given the existing evidence should help improve the outcomes of such programs. Note that the specific issues around building more compact and more efficient urban areas are further discussed in the IGC Cities evidence paper.

Evidence on the returns to energy efficiency

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 (2012) 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. In a developing context, significant credit constraints can also prevent consumers from availing themselves of profitable investment opportunities. If credit constraints are binding, informational campaigns alone might not solve the problem. Limited warranties or quality could also shorten the expected life of an appliance and limit the net present value of more energy efficient goods, making them less desirable investments.

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 and also due to potential monitoring issues with the replacement of appliances that were not functioning. 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).

If market or information failures prevent investment, then policy intervention could promote both energy efficiency and economic efficiency.

The literature on consumer and firm responses to energy standards and labels is largely focused on developed countries like the United States (Houde 2018, Houde and Spurlock 2015). Countries such as India and China have had both voluntary and/or mandatory certification programs for a wide range energy-intensive appliances and products for over twenty years, with labelling similar to that used in European countries and the EnergyStar program in the US. Much more research is required to understand the impact of these policies 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).

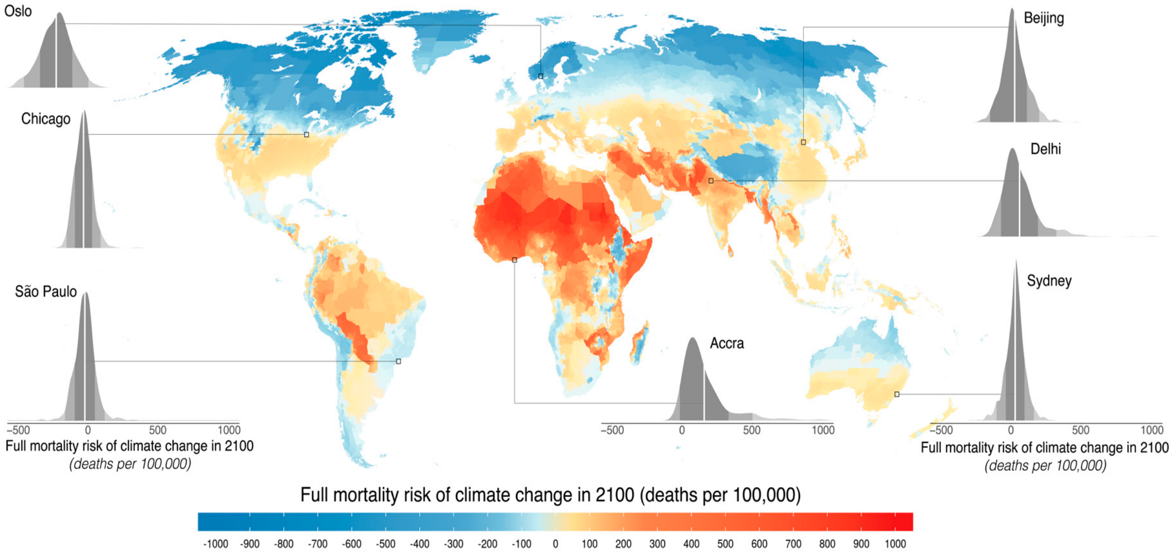
BOX 5 Next steps and research priorities

- **What are the private and social rates of return to energy efficiency investments and policies in low and middle-income countries?**
- **How do energy efficiency strategies compare in terms of greenhouse gas reductions on a cost per ton abated to supply-side interventions? How does the comparison differ in developing countries?**
- **Are there informational or other barriers to individuals and firms making energy-efficiency investments in developing countries?**
- **Is there a larger "energy efficiency gap" in developing countries? What roles are played by existing distortions such as low electricity prices, credit constraints, and limited warranties? If so, what policy tools are available to remove these barriers to making efficient energy efficiency investments?**

C Adaptation and public goods

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 and Tebaldi 2014, Burke et al. 2015a, Baker et al. 2020). 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, Carleton et al. 2020). 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 certainly also includes fundamental changes in the use of energy (Rode et al. 2020) and continues on. There is also emerging research suggesting that higher temperatures substantially reduce the growth prospects of developing countries (Dell, Jones, and Olken 2012, Burgess et al. 2017).

FIGURE 7 **The (heterogeneous) mortality cost of climate change in 2099 under RCP 8.5 warming**



Source: Carleton et al. 2020

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 and Tebaldi 2014; Burke, Hsiang and Miguel 2015a; Burgess, Deschenes, Donaldson and 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 and private forms of defensive expenditures are critically needed in response and where these needs are the strongest. One of our main focuses for this theme will be on how economic policy can help households and governments adapt to the global externalities generated by increased use of energy across the developing world. **The benefits and costs of adaptation in response to climate change is an emerging area of research where more work is a high priority.** The frontier of understanding perhaps comes from a recent paper that examines the full mortality costs of climate change, accounting for adaptation costs and benefits. It makes the point that income growth will naturally provide some protection against climate change but that examination of societies today also reveals that there are adaptation opportunities in response to differences in temperatures. Specifically, it finds that without any income growth or adaptation in response to temperature changes that the mortality cost of climate

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.

change be approximately 125 per 100,000. However, income growth and adaptation (inclusive of its costs) are projected to be enormously beneficial; specifically, they are projected to reduce the projected impact by almost 80% to 28 additional deaths per 100,000 (Carleton et al. 2020), with income growth accounting for the majority of the decline. The precise roles of income and climate-induced adaptation will vary from sector to sector but they must be kept as north stars in any climate strategy.

This finding underscores the urgency of identifying research and policy options to facilitate growth which is the centrepiece of the IGC's mission. Pointedly, 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.

There is thus an urgent need to understand how policies that affect trade, structural change and growth can aid adaptation to climate change.

With respect to adaptation, there are two main areas where research is necessary. First, governments and individuals lack the information about what climate change's impacts will be where they live. So, a key first step is producing hyper-local estimates of climate's impacts, ideally down to the community level. Figure 7 provides local estimates around the planet for mortality risk but, of course, there will be risks in a wide range of other sectors, including labour productivity, exposure to inundation and damages from sea level rise and storms, agricultural productivity, and on. For this information to lead to public and private changes in workplaces, construction of structures and/or sea walls, land use, etc., it needs to be available at the community level with information on the time scale that these changes will arrive. A focus on extending the climate impacts literature to provide information at the local level is critical because information on the global average impact is not helpful to people or governments in any individual community or jurisdiction. A related issue is that there is an important need for research on how to effectively communicate projected climate impacts so that they are influential with local governments and communities and overcome potential cognitive biases and other barriers to information acquisition.

Second, there is an immense opportunity to uncover socially beneficial private and public adaptations to climate change. Existing research has documented that the benefits of people working 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 such as air conditioners (Barreca et al 2016; Graff Zivin, Hsiang and Neidell 2018).

In the case of government, there is a need for how to best consider the implications of climate change when making policy and investment decisions.

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.

Private responses 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 of future changes. 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.

Burgess et al. (2017) is instructive and is an example of the type of research that can help. It documents that 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. For instance, financing can support private investments into more resilient crops or crop varieties that better resist changes in climate. 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.

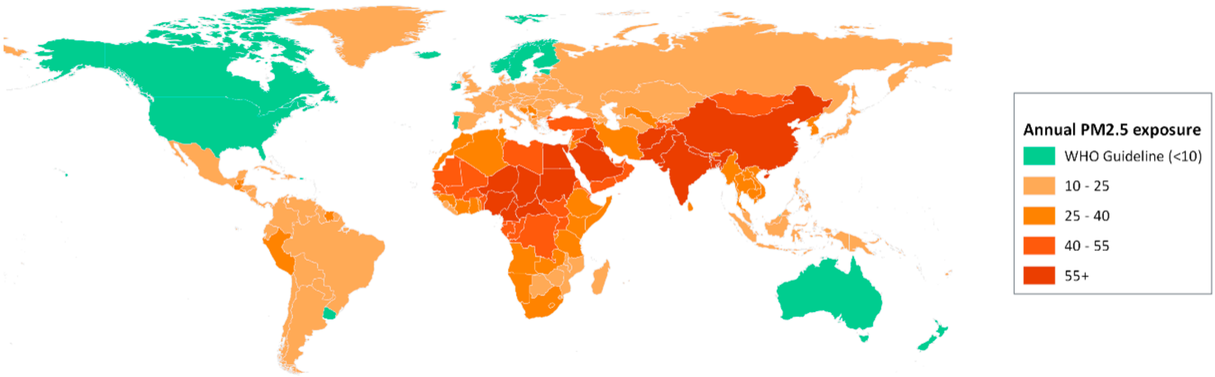
Understanding how new technologies and crop choices can protect farmers is also critical here. Farmers adjust to fluctuations in the weather by moving into non-farm activities or changing the size of cultivation (Banerjee 2007; Kazianga & Udry 2006). Fortunate farmers may have access to weather insurance, helping them ride out the vagaries of the climate (Barnett & Mahul 2007). What matters, however, is whether households are constrained in accessing these adaptive 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. Similarly, agricultural extension efforts can help with land use decisions, including crops switching.

BOX 5 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 governments effectively deliver the local information on climate impacts necessary to help the public and private sectors effectively adapt?**
- **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, congestion and other external costs. Only a handful of countries in the world have air that is safe to breathe, by the standards of the World Health Organization (Figure 8), **and today's developing countries have the most acute air-pollution problem ever experienced in world history.** Growth in output may mismeasure 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. However, our focus will be on the pollution associated with energy consumption.

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,

Today's developing countries have the most acute air-pollution problem ever experienced in world history.

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.

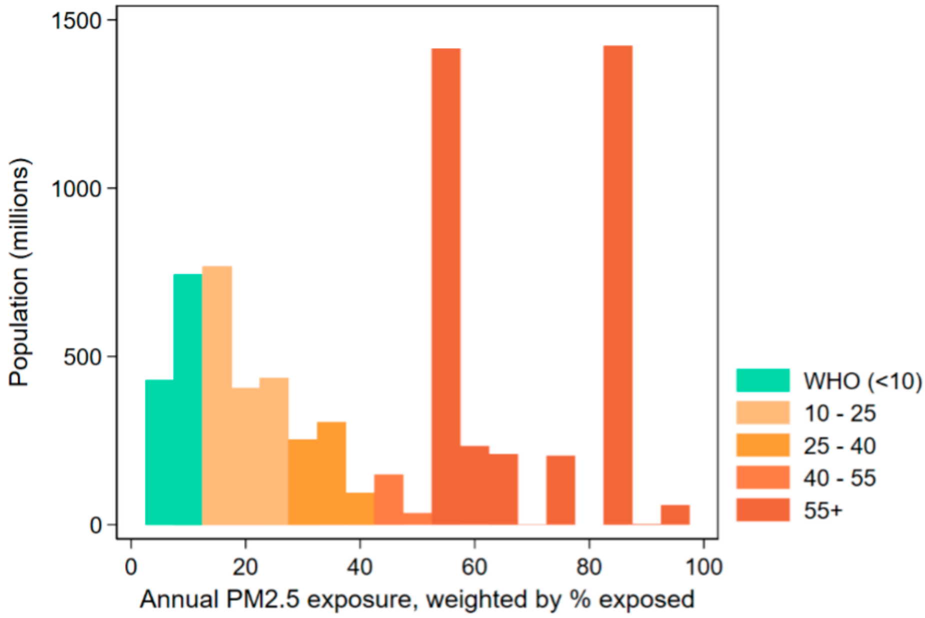
A Consequences of local externalities from energy consumption for health and productivity

TABLE 1 **Health Impacts of Pollution on Environmental Quality**

Country	Pollutant	Health impact: magnitude	Methodology	Author (Year)
Indonesia	PM	Infant mortality: 1.2%	Quasi-experiment	Jayachandran (2009)
Mexico	CO and PM	Infant mortality: elasticities of 0.33 (CO) and 0.40 (PM)	IV	Arceo et al. (2016)
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)

Source: Greenstone & Jack, 2015

FIGURE 9 **Population, in millions, of those exposed to certain PM2.5 levels. Bin width of 5**



Data: WDI, 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. From the mid-19th to mid-20th centuries, acute pollution exposure accounted for at least one out of every 200 deaths in London (Hanlon 2019).

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 (Balakrishnan et al. 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 (Goel and Guttikunda 2015, Guttikunda and Calori 2013, Guttikunda et al. 2013). This pollution lowers productivity, makes people sick, shortens their lives (Hanna and Oliva 2015, Graff Zivin and Neidell 2012, Guttikunda and Goel 2013, 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. 2012). 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 faecal 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., Zhang et al. 2018 and Ebenstein et al. 2017).

An especially intriguing and emerging area of research examines the impacts of air pollution exposure on cognitive development and cognition. Recent work in the US and China suggests that early life exposure can affect long-run cognitive development and cognition (Isen, Rossin-Slater, and Walker 2017, Bishop, Ketcham, and Kuminoff 2019, Ebenstein and Greenstone 2020). Evidence on this from developing countries could greatly increase the known costs of air pollution associated with energy consumption. Finally, the distributional and heterogeneous impacts of pollution across a wide range of outcomes are even less understood. There is an active need for research in this area.

Pollution is not the only local externality that is caused by energy use. Energy use in the transportation sector, for example the growth in the use of private vehicles, causes massive externalities due to congestion. Many developing country cities, from Lagos to Karachi, are notoriously gridlocked. An experiment in India, at a partial equilibrium level, found that a hypothetical congestion pricing regime would nonetheless have little benefit, since commuters value traveling at peak times very highly (Kreindler 2020). Is congestion pricing feasible, given nearly complete smartphone adoption in many cities, and what would be its benefits on a large scale? What is the right policy mix for transportation in developing country cities? We leave questions of urban economics to the IGC Cities theme. However, there is often not a clean demarcation between these topics, since public investments, infrastructure and policy with respect to urban growth feed back upon energy demand and the externalities due to energy use.

BOX 6 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, water pollution and other externalities from energy use.**
- **Assess the distributional and heterogeneous impacts of pollution exposure by gender, socio-economic status, caste, or other categories.**
- **Measure congestion externalities and their effect on energy demand, as well as the reverse relationship from energy demand growth to congestion.**

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. Ito and Zhang (forthcoming) also 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.

BOX 7 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

TABLE 2 **Evidence for High Marginal Costs of Environmental Policies in Developing Countries**

Country	Finding	Methodology	Author (Year)
Brazil	Decentralisation increases water pollution	Fixed effects	Lipscomb and Mobarak (2016)
Mexico	Policy loopholes undermine effectiveness	Temporal discontinuity	Davis (2008)
Mexico	Voluntary certification lowers regulatory costs	Structural identification	Foster and Guiterrez (2013)
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)

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. 2018).

Transparency around pollution levels can also allow environmental regulation to have a further reach.

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.

BOX 8 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.

The next five years—and the next fifty—will be tumultuous for the energy sector and the global environment.

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.

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